Lecture Notes in Networks and Systems 996

Mykola Nechyporuk
Volodymir Pavlikov
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Integrated Computer Technologies in Mechanical Engineering - 2023

Synergetic Engineering, Volume 2

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Lecture Notes in Networks and Systems 996

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Preface

The International Scientific and Technical Conference "Integrated Computer Technologies in Mechanical Engineering"—Synergetic Engineering (ICTM) was established by the National Aerospace University "Kharkiv Aviation Institute."

The Conference ICTM'2023 was held in Kharkiv, Ukraine, during December 2023. During this conference, technical exchanges between the research communities were carried out in the forms of keynote speeches, panel discussions, as well as special sessions. In addition, participants were treated to a series of receptions, which forged collaborations among fellow researchers. ICTM'2023 received 202 papers submissions from different countries.

All of these offer us plenty of valuable information and would be of great benefit to the experience exchange among scientists in modeling and simulation. The organizers of ICTM'2023 made great efforts to ensure the success of this conference. We hereby would like to thank all the members of ICTM'2023 Advisory Committee for their guidance and advice, the members of program committee and organizing committee, and the referees for their effort in reviewing and soliciting the papers, and all authors for their contribution to the formation of a common intellectual environment for solving relevant scientific problems. Also, we are grateful to Springer-Janusz Kacprzyk and Thomas Ditzinger as the editor responsible for the series "Lecture Notes in Networks and Systems" for their great support in publishing these selected papers.

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Project Management and Business Informatics

Methodology for Assessing the Processes of the Occupational Safety Management System Using Functional Dependencies

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Abstract. The existing functional dependencies between the measured values of quality indicators and their assessment on the dimensionless scale that were used to assess qualimetry objects of various nature have been analyzed. It has been shown that, as a rule, non-linear dependencies should be used for the objective assessment of qualimetry objects. The main task of the researcher is to choose the type of nonlinear dependence, this requires additional scientific research. The tool for choosing one or another non-linear dependence is the understanding of the physical essence of the qualimetry object, that is, the understanding of the regularities of the relationship between the measured value of qualimetry indicators and their assessment. For this, it is important to use methods of expert assessments, because, as a rule, such regularities are unknown. The functional dependence that is used to obtain assessments of indicators of the state of occupational safety in production is stepwise and includes a shape parameter. When the shape parameter changes, the curvature of the dependence changes, thereby changing the assessment on the dimensionless scale. This feature of the applied dependence makes it possible to develop a universal technique, that is, by changing the shape parameter, this dependence can be applied to various indicators of labor safety in any production. As an example, the article examines the machine-building industry and assesses the most dangerous factors. A step-by-step technique for determining a complex indicator of occupational safety in production has been developed, and its effectiveness and universality have been shown by an example of measured numerical values of dangerous factors.

Keywords: Functional Dependence · Management System · Multi-criteria Assessment · Object of Qualimetry · Complex Indicator · Occupational Safety

1 Introduction

An important factor in the sustainable economic development of the organization is ensuring the quality, safety and competitiveness of products. The implementation of management systems based on the requirements of international standards such as ISO 9001,

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ISO 45001, ISO 14001 and others contributes to improving the enterprise's performances [1–3].

One of the vectors of the sustainable development strategy is the safety of human life and health that is impossible without an effective system of occupational health and safety management. Occupational safety management involves the development of a system of measures aimed at obtaining objective information about the object of management that allows making management decisions on the improvement of its condition from the point of view of safety. To achieve effective management, more sophisticated and economical methods of collecting and processing information are needed.

It is known that in the process of work, a person is affected by the factors of the production environment and the work process that may affect health. For proper forecasting and minimization of harmful and dangerous factors, their assessment is required, and such assessments should have quantitative values.

The methodology of quantitative assessment is regulated by the subject of science - qualimetry. In qualimetry, there are a number of scientific directions of research concerning all objects regardless of their nature - these are tasks related to multi-criteria assessment. One of these directions is the problem of bringing various quality indicators of objects to a single dimensionless scale. The second direction is the unification of quality indicators into a single (comprehensive) assessment of the object of qualimetry. Let us consider the system of harmful and dangerous factors as the object of qualimetry.

2 Literature Review

Over the past decades, multi-criteria assessment has become a necessary tool for making complex decisions, as it promotes the active participation of stakeholders in the joint decision-making process and allows taking into account a wide range of criteria that may be both measurable and non-measurable. This approach combines quantitative and qualitative aspects that allows taking into account various aspects of the problem and the importance of each of them when making a decision. In addition, multi-criteria assessment helps to achieve consensus and increases the level of trust between participants in the decision-making process [4–8].

In qualimetry, mathematical dependence is an integral part of many processes of assessment and comparison of various indicators [9–13]. For example, the article [14] discusses the problems of quantitative assessment and ranking of economic development in countries using indicators and indices. To assess the quality of investments, mathematical relationships between the actual values of investments and their assessments on the dimensionless scale are used.

The scientific work [15] examines the psychological effects of the COVID-19 pandemic on various professional groups and uses qualitative methods to quantify the psychological stress experienced by these groups and identifies seven main signs of stress. In work [16], mathematical dependencies are used to compare the economic development of the European Union countries, and in work [17], they are used to study the economic indicators of the countries' development.

The authors [18] used various functional dependencies between the measured indicators of dangerous factors and their evaluation on a dimensionless scale to assess the indicators of occupational health and safety processes. In the study [19], to obtain estimates of process quality indicators, it is proposed to apply the error function, which provides requirements for quality indicators, allows to effectively obtaining estimates on a dimensionless scale, which makes it possible to obtain and increase the amount of statistical information.

Thus, techniques that apply mathematical dependencies are an effective tool for assessing, comparing and solving complex problems in various fields. They have a more accurate application of the values of various indicators and ensure objectivity and scientific accuracy in the conducted studies [20–25].

3 Research Methods

The analysed assessment methods are used to assess product quality and its influence on various processes of the quality management system; therefore, we believe that the literature review has confirmed the relevance of research aimed at the development of methods for assessing the state of occupational safety. It is proposed to apply a type of dependencies that will allow assessing the state of occupational safety in production:

$$F(x) = \frac{1}{1 + nm^{-kq_i}}, \tag{1}$$

where the coefficients n and m are found as follows:

$$m = m_1^{\frac{1}{(q_{\min} - q_{\max})k}}, \tag{2}$$

where

$$m_1 = \frac{(1 - q_{\max})q_{\min}}{(1 - q_{\min})q_{\max}}. \tag{3}$$

$q_{\min}$ and $q_{\max}$ are the minimum permissible and maximum permissible value of the indicator of the harmful factor.

Thus, after normalization, the coefficient n is found as follows:

$$n = \frac{(1 - q_{\min})}{q_{\min}} m^{kq_{\min}}. \tag{4}$$

The k parameter influences the steepness of the function along the OX axis. By changing k, it is possible to control the curvature of the function (1) and thus obtain different assessments with the same results of measurements of the harmful factor indicator.

Figure 1 shows a series of three dependencies (1), where the coefficient k varies from 1.2 to 0.8 in steps of 0.2 from left to right. On the OX axis, the scale corresponds to the scale of measurement units and can be changed for each individual indicator of the harmful factor. The extreme left value on this scale (0) corresponds to $Q_{\min}$ – the minimum permissible value of the indicator of the harmful factor. The extreme right value

on this scale (1) corresponds to Q_{max} – the maximum permissible value of the indicator of the harmful factor. They correspond to the respective values of each individual indicator of the harmful factor. Therefore, if working conditions have n indicators of harmful factors, then it is necessary to determine the coefficients n and m for each of them according to Formulas (4) and (2), respectively. Regardless of the units of measurement and the digits of the value of the indicator of the harmful factor on the OX axis, the type and form of the dependence will not change. A change in the shape parameter k will lead to a change in shape.

It can be seen from Fig. 1 that with an indicator of 0.5 measured in units of measurement, its assessment on the dimensionless scale varies from 0.88 at k = 1.2 to 0.3 at k = 0.8. Therefore, having one valid value of the indicator of the harmful factor, we can obtain a range of values of its assessments on the dimensionless scale. In this way, one can choose one of the degree indicators in function (1) and change the assessment of the valid indicator of the harmful factor on the dimensionless scale.

The choice of a particular parameter k is made by a group of experts - experienced professionals who have knowledge of the degree of impact of a particular harmful factor on the health of employees. For example, if, according to experts, any harmful factor has a minor negative impact on human health, the parameter $k = 1.2$ can be used. In this case, the assessment of the harmful factor on the dimensionless scale will be significantly high relative to the others. If experts assess the impact of a harmful factor on human health as significant, it is proposed to use the parameter $k = 0.8$. In this case, the assessment of the harmful factor on the dimensionless scale will be significantly lower than the others. The choice of this or that parameter k allows the manager to adjust the goals for occupational safety in the workplace.

It is known from the theory of qualimetry that quality is a set of characteristics of an object that relate to its ability to meet the established needs of the consumer in accordance with its purpose. Therefore, when choosing the parameter k, either a group of experts or a consumer can be used. In this case, the consumer is also an expert. If the consumer is an expert, then subjectivity is levelled out when choosing the parameter k, otherwise the group of experts applies the theory of expert judgement. With the right choice of the expert evaluation method and its application, subjectivity is minimised.

Since the assessments of single indicators of harmful factors have the same measurement scale (0–1), it is possible to find a comprehensive indicator of the state of occupational safety by applying one of the average values (arithmetic, geometric, harmonic) that make it possible to combine individual assessments. In this case, the comprehensive indicator of the occupational safety state is calculated according to the formula:

$$Q = \frac{1}{n} \sum_{i=1}^{n} F_i. \tag{5}$$

where n is the number of unit indicators of the harmful factor; F_i is the value of the i-th unit indicator of the harmful factor on the dimensionless scale.

We offer a step-by-step technique for determining the comprehensive indicator of the occupational safety state:

Step 1. To determine the list of harmful and dangerous factors in production.

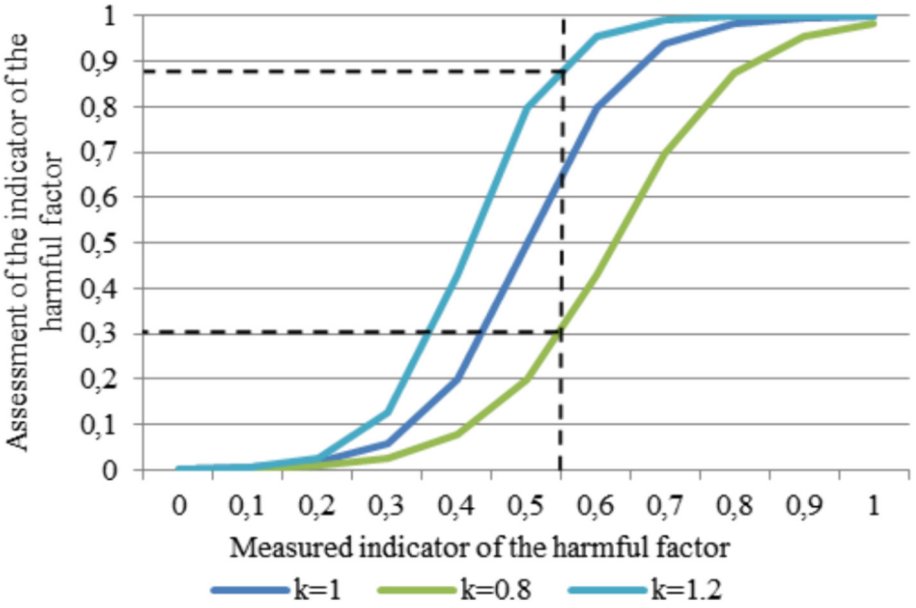


Fig. 1. Series of dependencies (1) at k = 1.2–0.8 with a step of 0.2 from left to right.

Step 2. To determine the maximum permissible, minimum permissible and optimal (best) values for each harmful and dangerous factor according to regulatory documents.

Step 3. To measure these harmful factors and enter the results in a specially prepared table.

Step 4. To determine the assessment of the indicator of the harmful factor on the dimensionless scale according to Formula (1). To do so, it is necessary to use Formulas (2–4) and assign the shape parameter *k*. The form parameter is assigned by a group of experts.

Step 5. To determine the generalized index of occupational safety in accordance with Formula (5) taking into account all individual indicators.

4 Application of the Methodology for Determining a Comprehensive Indicator of Occupational Safety

In order to check the efficiency of the methodology for assessing the occupational safety state, a study was conducted at a machine-building enterprise. To conduct the assessment, hazards at the turner's workplace were considered. During work, employees of machine-building enterprises may be affected by such harmful production factors as: noise, monotony of work processes, injury by moving parts of production equipment, insufficient lighting of the work area, electric shock, etc. It was determined that the main harmful production factors at the workplace of turner are: air temperature, relative air humidity, air movement speed, noise and lighting.

The values of harmful production factors were measured and recorded at workplaces and in the work area for three weeks. The FLIR EM54 combined device was used to measure air temperature, relative air humidity, and air movement speed. The noise level was measured with the GM1351 digital sound level meter. Illumination was measured with the DE-3350/DE-3351 digital lux meter. The optimal norms of harmful factors are determined at the enterprise in accordance with current regulatory documents.

The obtained experimental values of the above indicators of harmful factors and results of mathematical transformations are shown in Table 1.

Table 1. Results of implementing the technique for assessment of occupational safety conditions at the workplace of turner.

No.	Indicators of harmful factors	q_{min}	q_{max}	q_{opt}	q_i	k	F
1	Air temperature, °C	18	27	23	23	1.2	0.99
2	Relative humidity, %	30	75	55	65	1	0.84
3	Air speed, m/s	0.2	0.4	0.3	0.25	1	0.8
4	Noise, dBa	60	80	70	77	0.8	0.64
5	Lighting, lx	300	750	750	650	1.2	0.96

Graphical representations of dependencies for the assessment of harmful factors at the workplace are presented in Fig. 2.

Figure 2 shows the dependencies (1) for different parameters of the form k. To obtain estimates of the indicators of harmful factors on the dimensionless scale OY, where the dimensional scale OX has the corresponding dimension of the measured indicator of harmful factors (air temperature, °C; relative humidity, %; air velocity, m/s; noise, dBA; lighting, lux).

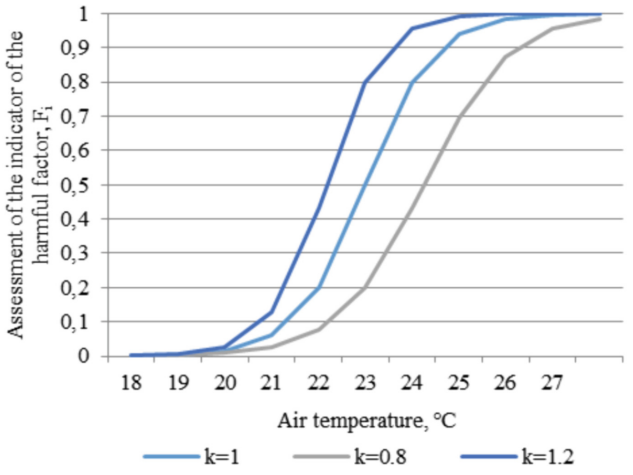
According to the proposed methodology, it is necessary to measure harmful factors using established methods and determine the standard values. A group of experts, depending on the importance of the harmful factor indicator (hazard and impact on the worker), determines the parameters of the form k for each of the harmful factor indicators and enters them into Table 1. According to Formula 1, the assessment of a single indicator of a harmful factor on a dimensionless scale is determined and entered into Table 1.

A complex indicator determined by one of the formulae of average values. In this case, the arithmetic mean value is used.

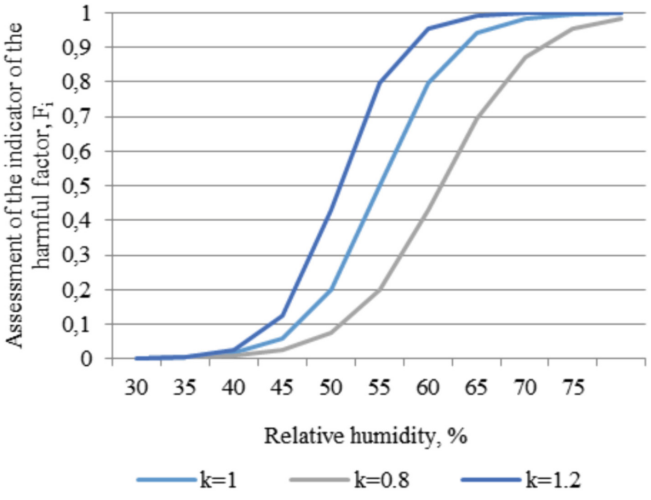
$$Q = \frac{0.99 + 0.84 + 0.8 + 0.64 + 0.96}{5} = 0.85$$

Therefore, with the help of functional dependence and experts, it is possible to obtain the comprehensive indicator of occupational safety at the enterprise. The developed technique is universal, and it can be applied to assess the occupational safety state in productions of various branches of the national economy.

The proposed methodology has been validated for assessing working conditions at a machine-building enterprise. However, it can be equally used and effective for any sector of the economy.

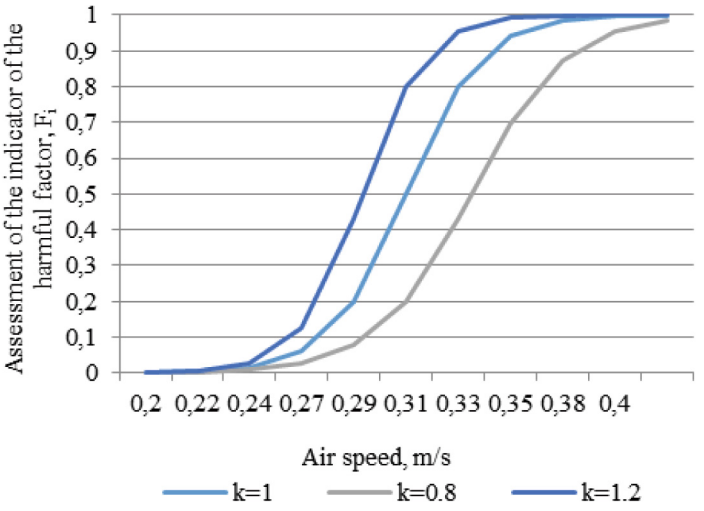


a)

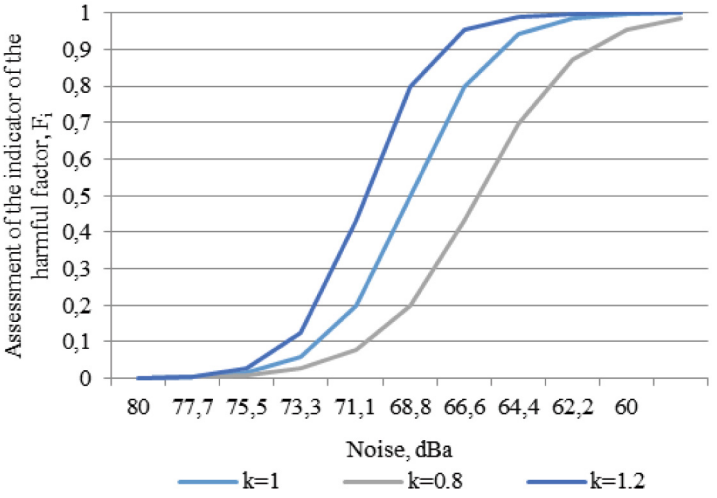


b)

Fig. 2. Graphical representation of dependencies for assessing indicators of harmful factors: a) air temperature; b) relative air humidity; c) air speed; d) noise; f) lighting.

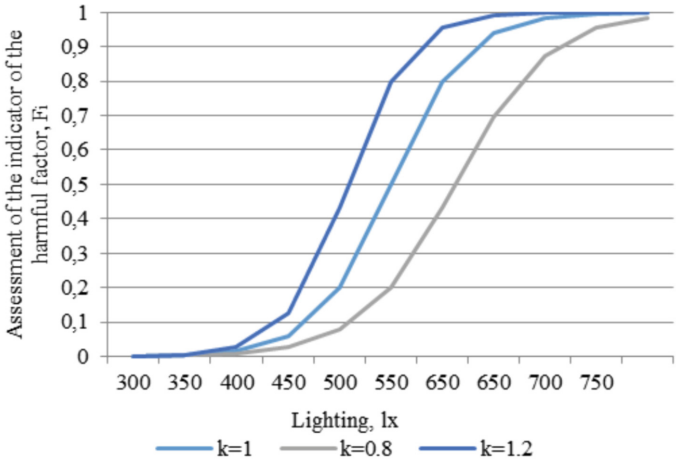


c)



d)

Fig. 2. (*continued*)



f)

Fig. 2. (*continued*)

5 Conclusions

Qualimetric tools are used to assess the state of occupational safety, as they allow to obtain a quantitative assessment of harmful ones. It has been determined that the system of harmful factors as an object of quality measurement has a number of features that should be taken into account when solving the task of quantitative assessment of occupational safety at production facilities.

Thus, the application of functional dependence between individual indicators of harmful factors and their values on the dimensionless scale provides a quantitative assessment of the state of occupational safety in production. With the help of the proposed technique, it is possible to make management decisions that lead to the minimization of the deviation of the actual values of harmful factors from the optimal ones.

A mathematical dependency consists of sequential arithmetic operations, but with Microsoft Excel, the decision maker enters the minimum, maximum and actual (measured) values and gets the result. This allows you to automate the calculation process. The simplicity of the dependence (1) makes it suitable for use in industrial applications.

The proposed mathematical dependence can become a practical tool for assessing the state of occupational safety, and can also be implemented in regulatory documents at the level of an organization or enterprise in order to implement the assessment procedure of the occupational health and safety management system.

References

1. ISO 9001:2015. Quality management systems – Requirements. https://www.iso.org/ru/standard/62085.html. Accessed 08 June 2023
2. ISO 45001:2018. Occupational health and safety management systems - Requirements with guidance for use. https://www.iso.org/standard/63787.html. Accessed 06 Aug 2023
3. ISO 14001:2015. Environmental management systems - Requirements with guidance for use. https://www.iso.org/ru/standard/60857.html. Accessed 08 June 2023
4. Koulinas, G.K., Demesouka, O.E., Marhavilas, P.K., Orfanos, N.I., Koulouriotis, D.E.: Multicriteria health and safety risk assessments in highway construction projects. Sustainability **15**, 9241 (2023)
5. Krenicky, T., Rajabzadeh, M., Khosravi, A., Zaloga, V., Zaborowski, T.: Hybrid multi-criteria decision making model for customer knowledge management in software industry. MM Sci. J. **2022**, 6033–6039 (2022)
6. Gul, M.: A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions. Human Ecol. Risk Assessm. Int. J. **24**(1), 1–38 (2018)
7. Vavrek, R., Adamisin, P., Kotulic, R.: Multi-criteria evaluation of municipalities in slovakia - case study in selected districts. Polish J. Manag. Stud. **16**(2), 290–301 (2017)
8. Keshavarz-Ghorabaee, M., Amiri, M., Zavadskas, E.K., Turskis, Z., Antuchevičienė, J.: MCDM approaches for evaluating urban and public transportation systems: a short review of recent studies. Transport **37**(6), 411–425 (2022)
9. Krenicky, T., Rajabzadeh, M., Khosravi, A., Zaloga, V. Zaborowski, T.: Hybrid multi-criteria decision making model for customer knowledge management in software industry. MM Sci. J. **2022**, 6033–6039 (2022)
10. Vagaská, A., Gombár, M.: Mathematical optimization and application of nonlinear programming (Open Access). Stud. Fuzziness Soft Comput. **404**, 461–486 (2021)
11. Hashemkhani Zolfanir, S., Maknoon, E., Zavadskas, K.: Multiple Nash equilibriums and evaluation of strategies. New application of MCDM methods. J. Bus. Econ. Manag. **16**, 290–305 (2015)
12. Lourenço, M., Lima, T.M., Gaspar, P.D., Santos, F.C.: Assessment and improvement opportunities for occupational health and safety in the portuguese food processing industry. Occupational and environmental safety and health. Stud. Syst. Decis. Control **202**, 731–738 (2019)
13. Beinoraitė, Š., Drejeris, R.: Population entrepreneurship measurement model. Bus.: Theory Pract. **15**, 199–209 (2014)
14. Trishch, R., Sichinava, A., Bartoš, V., Stasiukynas, A., Schieg, M.: Comparative assessment of economic development in the countries of the European Union. J. Bus. Econ. Manag. **24**(1), 20–36 (2023)
15. Ginevičius, R., Trishch, R., Bilan, Y., Lis, M., Pencik, J.: Assessment of the economic efficiency of energy development in the industrial sector of the European Union area countries. Energies **15**(9), 3322 (2022)
16. Ginevičius, R., Trišč, R., Remeikienė, R., Zielińska, A., Strikaitė-Latušinskaja, G.: Evaluation of the condition of social processes based on qualimetric methods: the COVID-19 case. J. Int. Stud. **15**(1), 230–249 (2022)
17. Ginevicius, R., Trishch, R., Remeikiene, R., Gaspareniene, L.: Complex evaluation of the negative variations in the development of lithuanian municipalities | Kompleksinis lietuvos savivaldybių plėtros neigiamų pokyčių vertinimasıo. Transform. Bus. Econ. **20**(2), 635–653 (2021)

18. Cherniak, O., Trishch, R., Kim, N., Ratajczak, S.: Quantitative assessment of working conditions in the workplace. Eng. Manag. Prod. Services **12**(2), 99–106 (2020)
19. Sorocolat, N., Fatieieva, L.: Quality assessment of the occupational safety management system processes according to the requirements of the ISO 45001:2018 international standard. Engineering **29**, 89–96 (2022)
20. Shushura, O.M., et al.: Simulation of information security risks of availability of project documents based on fuzzy logic | Symulacja zagrożeń bezpieczeństwa informacji w zakresie dostępności dokumentów projektowych w oparciu o logikę rozmytą. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Srodowiska **12**(3), 64–68 (2022)
21. Zaloga, V., Dyadyura, K., Rybalka, I., Pandova, I.: Implementation of integrated management system in order to enhance equipment efficiency. Manag. Syst. Prod. Eng. **27**(4), 221–226 (2019)
22. Askari, A., et al.: Workplace risk factors assessment in North-Azadegan oil field based on Harmful Agents Risk Priority Index (HARPI). Iran. J. Public Health **52**(10), 2157–2168 (2023)
23. Alamerew, Y.A., Kambanou, M.L., Sakao, T., Brissaud, D.: A multi-criteria evaluation method of product-level circularity strategies. Sustainability **12**, 5129 (2020)
24. Gorbenko, N.A., Katrich, O.A.: Evaluation of the processes of the quality management system of enterprises for compliance with the requirements of international standards of the series ISO 9000. In: Bulletin of the National Technical University "KhPI": Collection of Scientific Papers. Series: Mechanical-Technological Systems and Complexes, vol. 40, no. 1083, pp. 20–25 (2014)
25. Zolfani, S., Maknoon, R., Zavadskas, E.: Multiple Nash Equilibriums and evaluation of strategies. New application of MCDM methods. J. Bus. Econ. Manag. **16**, 290–306 (2015)

Cognitive Component of Development of the Innovative Diffusion of the Socio-Economic Systems

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Abstract. The concept of the innovative diffusion is associated with the dissemination of innovations through the system of information, social and economic connections between the elements of the socio-economic system. The chapter is devoted to the cognitive component of the development of the innovative diffusion of such systems. The aim of the work is to study the issues of cognitive representation of the development of the innovative diffusion of the socio-economic systems and to design the theoretical base of the use of cognitive technologies for the making the relevant managerial decisions. The factor of cognitiveness, as the ability to perceive and process data to turn them into knowledge, will ensure stimulating the development of innovative sectors of the economy. The peculiarity of the cognitive approach is the possibility of qualitative modeling of complex weakly structured situations that are not subject to severe mathematical analysis. The attention is paid to examples of using the structural-analytical method of pattern recognition to predict the innovative development of the business entity. The authors demonstrated an original cognitive model, which allows to investigate problems that arise in the conditions of developing the innovative diffusion of economic systems. The relevant software complex has been created by the authors.

Keywords: Socio-economic System · Innovative Diffusion · Cognitive Modeling · Decision Trees · Patterns Recognition

1 Introduction

The creation and development of the innovative environment of the socio-economic systems is aimed at obtaining an economic effect. This process is carried out by updating traditional, technically obsolete and environmentally hazardous industries and is based on fundamental scientific knowledge and research. Within the framework of the innovative development concept, the phenomenon of the innovative diffusion, which is

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associated with the dissemination of a wide range of innovations through the system of information, social and economic ties between all elements of the socio-economic system occupies the central place.

Investigation of the functional capabilities of existing forms of organizational innovative structures in the socio-economic systems allows us to conclude that in this system the function of innovation distribution control is implemented insufficiently fully. This fact is largely restraining the innovation activity of business entities. In the presence of a weak demand for innovation from organizations, there is a need for management of distribution of innovations, taking into account the relationship between the processes of their perception and commercialization. This contributes to the occurrence of systemic effects that arise during the innovative diffusion.

Scientific work is devoted to the cognitive component of the innovative diffusion of the socio-economic systems. The cognitive approach will directly simulate the relationship between factors (elements) of complex systems, and the values of indicators are considered secondary. This is determined by the originality and practical importance of elaboration.

The aim of the work is to study the issues of cognitive representation of the development of the innovative diffusion of the socio-economic systems and to design the theoretical base of the use of cognitive technologies for the making the relevant managerial decisions.

2 Cognitive Presentation of Development the Innovative Diffusion of the Socio-Economic Systems

The motivation for the innovative diffusion of socio-economic systems is the driving force and prerequisite for a qualitative technological breakthrough in the development of the national economy. A meaningful assessment of this process is of particular importance in the context of modern challenges of globalization and leads to the growth of the openness of the economy of Ukraine.

To date, there are no perfect mechanisms and tools for such motivation, which makes it impossible to fully and integrally realize the internal market potential and significantly reduces the socio-economic efficiency of transformations on the way to building a market economy capable of withstanding the changing conditions of the external environment.

In works [1–4] the socio-economic system is considered as a coherent set of interconnected and interacting social and economic institutions (subjects) and relations on the distribution and consumption of material and intangible resources, production, distribution, exchange and consumption of goods and services.

For the cognitive representation of the development of the innovative diffusion of the socio-economic systems, the chain of notations will been installed: the development of the socio-economic system, the innovative diffusion, cognitive approach to modeling of development the innovative diffusion of the socio-economic system.

The socio-economic system is inevitably localized in the economic time and space, as well as alternative variants in relation to them. It has certain historical, geographical, ethnic, spiritual, political and economic borders. Thus, the socio-economic system, which

can be understood by civil society, business entity (enterprise), integrated business structure, has two main trends in existence: functioning and development. Exactly the acquisition of a new quality about the progressive modifications of the socio-economic system, as well as adaptation to the new environmental conditions is implemented through development. Conscious changes in the components of the socio-economic system are the results of the emergence and development of economic innovations.

The essence of the economic category "innovation" is defined in [5]. This is combination into a comprehensive definition of its essential characteristics as a process, as a result, as a change and as a system. The meaning of the term "innovation" depends on the specific purpose of the research, measurement or analysis of the object. New products, indicators of new activity, payment systems are economic innovations.

It is necessary to indicate another feature of the development of the socio-economic system, which relates to complex nonlinear systems. In [4–6] the general theory of evolution of systems and the idea of the possible bifurcation nature of their behavior is given. This situation leads to the appearance of diffuse properties, when the behavior of the system is evaluated by sets of basic economic parameters and the regularity of interconnection between them.

In the socio-economic systems, the objects of diffusion may be information, pattern (model) of behavior, norms, innovations. As defined by E. M. Rogers [7], diffusion is a process during which the innovation over time due to certain channels extends among members of the social system. Such diffusion is named innovative. Its research was carried out by foreign and domestic scientists, namely H. Karlsson, V. Ruttan, R. Byers, J. Emrick, J. Pope, D. Kondratieva, H.M. Chamota and others.

As for the above, the complex the socio-economic system includes a set of elements that are in ambiguous and contradictory interaction. The innovative diffusion is a special type of communications, because a new idea is laid down in the transmitted message. Novelty involves the presence of the uncertainty.

The uncertainty is characterized by a number of alternatives in relation to a certain event with a relative probability. Thus, in the problem of the innovative diffusion, a factor of the uncertainty plays a special role. This factor should be taken into account when choosing instrumental research methods. Therefore, when studying the regularity of the development of the innovative diffusion of the socio-economic system, it is advisable to use systems analysis methods.

Methods of system analysis allow directly to simulate the relationship between factors (elements) of complex systems, and the values of indicators are considered secondary. There is their main advantage that increases due to the need to take into account the factor of the fundamental uncertainty.

One of the most powerful methods of system analysis is a cognitive approach.

The peculiarity of the cognitive approach is the possibility of qualitative modeling of complex weakly structured situations that are not subject to strict formal mathematical analysis. Cognitive modeling is a cyclic process and contains several interrelated stages (see Table 1).

The Table 1 is created by the authors on the basis [8–10].

Table 1. Stages of cognitive modeling of the development of the innovative diffusion of the socio-economic systems.

Name of the stage	Characteristics of the stage
Cognitive Structuring	At this stage, a cognitive structuring of information about the situation of the innovative diffusion and external processes affecting its development is carried out. The result of cognitive structuring contains a plurality of basic factors of the state of the system and the external environment, as well as causal relationships between them At the same stage, a subset of target factors, control factors and factors of the external environment, as well as initial values or trends of basic factors are established on the plural factors of the situation. Factors that characterize the objectives of the innovative diffusion can be taken as target
Structural Analysis of the Cognitive Model	In the study of the development of the innovative diffusion it is necessary to know the structural properties of the process, that is, the peculiarities of causal relationships between basic factors. These properties include: – consistency of the objectives of the innovative diffusion. The essence of this issue is that the desired change in one target factors did not lead to undesirable changes in others; – consistency between targets and control factors of the process of the innovative diffusion. The situation management is such a change in control factors, which would lead to the desired changes in target factors, that is, towards the planned dynamics
Scenario Modeling of the Development of the Situation	Scenario modeling is carried out in order to find the most effective management of the innovative diffusion. The impulse change of the current value of the control factor (factors) is transmitted to other factors and considered as control

(*continued*)

Table 1. (*continued*)

Name of the stage	Characteristics of the stage
Evaluation and Interpretation of Modeling Results	Scenarios of controlled development of the innovative diffusion are evaluated by experts on the following indicators: – the degree of achievement of the objectives of the innovative diffusion; – volume and value of resources needed to achieve the objectives of the innovative diffusion; – efficiency of the accepted scenario of the innovative diffusion development, etc.
Monitoring of the Situation	This is a check and application of knowledge about possible trends in the development of the innovative diffusion of the socio-economic systems

The process of the innovative diffusion development is effective when the following is achieved through:

– providing effective employment of labor resources and the creation of additional jobs by education and expansion of new high-tech productions;
– updating of traditional, technically obsolete and environmentally hazardous production, development of the scientific and technical potential of the country;
– expanding of progressive, safe technologies from scientific centers, where innovations are emerging, to ecologically disadvantaged areas;
– increasing the efficiency of economic activity of business entities due to the adoption of innovations.

Factors and signs of the efficiency of the innovative diffusion process are:

– wide range of forms of interaction (interfunctional, inter-branch, interagency, etc.);
– integration of the ability of creative thinking with practical economic judgments, which is achieved by the inclusion in research groups of specialists with production and business experience;
– the speed of creation and high quality of innovative product which is provided by distribution of new information about processes, solutions, alternatives among interested persons of innovative developments;
– formation of an innovative niche in the national economy [11]. This sector is created as a result of economic activity and is characterized by the needs and demands of innovators, stable market capacity for enterprises of innovative economic niche, decrease in competition as a result of innovations.

The most important property of the innovative diffusion of the socio-economic systems is a speed that is impossible without evaluating the efficiency of this process and managing it.

In real innovative processes, the rate of diffusion of innovations depends on various factors, namely: the method of transmission of information, decision-making form, properties of the social system, properties of the innovation.

Cognitive components of the directions of development of the innovative diffusion of the socio-economic systems are presented in Table 2.

Table 2. Cognitive components of the directions of development of the innovative diffusion of the socio-economic systems.

Direction	Characteristics of the innovative diffusion development	Cognitive component
Improvement of ways to transfer information	A new idea or new product is taken by a market and dissipates in it. The innovative diffusion is most promoting the individual needs of each participant in society. Diffusion over the Internet and marketing of innovations accelerate the introduction of innovations	Study of problems and detection of factors of the innovative diffusion process
Extensive use of modern information technologies and computerized systems	This direction ensures the creation of national information resources, accelerates the automation of all spheres of production, industries and management	Evaluation of interrelationships between factors of the innovative diffusion process
Strengthening the value of the main production capacity of society, namely man as a manufacturer of highly intellectual and highly effective labor	The modern economy needs to use a new concept of training. It is based on supporting the development of creative potential of employees, providing continuous training to improve skills and cooperation with higher education institutions. An employee of an important element of the industrial economy becomes the most important factor in the information economy. This characteristic reflects the essence of institutional changes in the socio-economic system	Formation of knowledge on the trends of development and means of impacts on situations of the innovative diffusion process Building cognitive models

(*continued*)

Table 2. (*continued*)

Direction	Characteristics of the innovative diffusion development	Cognitive component
Establishing a system of commercial implementation of the results of innovative activity	The basis for commercialization of innovative products is the action of forming of special integrated structures that perform the following functions: – participation in creating objects of intellectual property rights (venture funds, intelligent towns, etc.); – implementation of expert evaluation of commercial attractiveness of objects of intellectual property rights; – research of market conjuncture and providing effective marketing and financial support for innovative products	Scenario modeling of development and solving problems of the innovative diffusion process Application of knowledge about possible trends in the innovative diffusion development
Stimulating an innovative strategy	World experience shows that the combination of intelligence, production and business is an indicator of innovative changes in the national economy	Interpretation and discussion of each factor of the innovation diffusion process in relation to the impact on the development of the socio-economic system

The national strategy for the development of science, technology and innovations is characterized by a combination of scientific excellence, the creation of key technologies to support the competitiveness of economies and to solve social challenges.

According to the State Statistics Service of Ukraine, in 2019, 782 industrial enterprises of Ukraine carried out innovative activities. In 2020, there were 442 such enterprises.

The shares of the number of industrial enterprises that introduced innovations (production and/or technological processes) in the total number of industrial enterprises amounted to: 13.8% in 2019 and 14.9% in 2020.

By types of economic activity, the most innovatively active were the enterprises for the production of machines and equipment, for the production of food products and for the production of basic pharmaceutical products and pharmaceutical preparations.

In 2020, in order to implement innovations in Ukraine, 177 enterprises acquired new technologies, 55 of them acquired technologies abroad. In 2020, industrial enterprises

purchased 885 new technologies, of which 112 were outside Ukraine. Compared to 2018, in 2020 the number of purchased Ukrainian technologies increased, while the number of technologies which purchased outside of Ukraine decreased.

In the conditions of martial law, Ukrainian enterprises continued their innovative activities.

According to the global innovation index, Ukraine ranked 56th in 2016, 50th in 2017, 43rd in 2018, 47th in 2019, 45th in 2020, 49th in 2021 and 57th place in 2022.

In 2022, innovative results exceeded innovative resources due to Ukraine's high ratings according to the following indicators:

- obtaining rights to intellectual property objects, namely: utility models, trademarks, industrial designs;
- creating of information and communication technologies (ICT), namely: the growth of spending on computer and software, the development of mobile applications and the export of ICT services.

Weaknesses are institutions and infrastructure. Ukraine was not able to improve its position in the ranking due to increased funding for research and development, growth of innovations in the field of health care, stimulation of innovative activities of small and medium-sized businesses in the conditions of martial law [12, p. 11].

In the global economy, it is increasingly emphasized on the central role of knowledge, in particular research and other activities of the countries. This contributes to the development of science, introduction of innovation and economic growth of any country. The use of scientific research potential is an important marker for the current and future national competitiveness and public improvement prospects.

Thus, literary sources and the own investigation indicate that the problem of the innovative diffusion of the socio-economic systems acquires special relevance. Serious difficulties in its decision arise on difficult formalized stages. The cognitive approach opens up new opportunities for issues. Cognitive technologies allow to perform high-quality modeling of situations of development of the innovative diffusion of the socio-economic systems. Such modeling is based on the knowledge of the subject area.

3 Methodology of Confession the Cognitive Innovative Development of the Socio-Economic Systems

The peculiarity of the diffusion direction of innovative development of the socio-economic systems is theoretical comprehension of conditions, forms and methods for obtaining new knowledge.

In modern economic conditions, the status and behavior of individuals depends on their own knowledge, skills, abilities and entrepreneurial activity in the decisive extent. The creative individuals became the progress mover. The new ideas and new decisions are generated by them and provide an increase in the level and quality of life of the total population. The development of the economy is carried out in the process of actions of human masses that comprehend the situation and make profitable decisions of their point of view. In this case, there is incomplete information, limited knowledge and horizons, ambiguity of consequences.

The interconnection between the thinking of the participants and the situation in which they participate can be divided into two functional dependencies: the efforts of participants in understanding the situation is a cognitive or passive function, and the impact of their conditions on the situation in the real world is an influence or active function. This interaction was called reflexivity by the authors of [13, 14].

Reflexivity is the ability to reflection. By reflection is meant a comprehensive conscious psychological process, which is based on understanding and analysis of the individual of its actions, as well as the formation of their own ideas, values and stereotypes under the influence of external and internal factors. Reflexivity is a person's property or ability to direct own activity on itself.

Reflection combines communicative, cognitive and regulatory processes. Basic cognitive processes are a component level of organization of reflexive processes.

An individual acquires new knowledge and adopts new solutions with the help of cognitive processes. Cognitiveness is the ability to perceive and process data to turn them into knowledge. Moreover, cognitiveness can be understood in a broad sense.

Innovative development of the socio-economic systems is a complex process. It carries out functions of industrial and technological support, information, financial, economic and personnel provision, normative and legal regulation of innovations and their commercialization.

Based on the analysis of literary sources [10–15] the following principles of innovative development of the socio-economic systems can be distinguished:

- systems principle. Elements of the system of innovative development should be combined properties that provide a systemic effect from their interaction;
- principle of functional decomposition. Functional subsystems must perform more simple actions than the output functions of this system;
- principle of adaptability. The system of innovation development should be quite flexible and customary in accordance with environmental changes;
- principle of economic efficiency. The economic efficiency of the system is based on criteria for economic efficiency of business entities;
- principle of utility. The utility is considered as an objective comparison of ideas and alternate solutions, as an evaluation of their quality in conditions of uncertainty and multicriteria.

Based on the above, the factor of cognitiveness of innovative development of the socio-economic systems in modern market conditions should provide:

- diversification of production;
- stimulation of the development of innovative sectors of the economy (increase of the share of research and innovative projects and working, increase of expenses for innovations in the total volume of costs by economic entities);
- integrity of understanding the logic of market processes development;
- the need for active and passive adaptation of processes to create innovative products to market trends;
- realization of the marketing function of the socio-economic systems.

These requirements for the cognitive factor of the innovative development of the socio-economic systems are implemented with the active participation of basic cognitive and integrated information processes based on the meta-properties of the individual. Perceiving and processing data to turn them into knowledge are cognitive processes. Setting the objectives, decision-making, economic and mathematical modeling, forecasting, planning, applying of cognitive technologies and control are related to integrated information processes.

The subject of further consideration is cognitive technologies. Their essence was determined by A. Nordmann [16], J. Hushf [17], G. G. Malinetsky [18], L. S. Sikora [19], Jo. Ja. Khromiak [20], Yu. M. Slyusarchuk [20], L. L. Tsymbal [20] et al.

Famous mathematician G. G. Malinetsky gives such a definition of cognitive technologies. They are ways and algorithms for achieving the objectives of subjects that are based on data on the processes of cognition, learning, communication, information processing by man and animals, as well as on the idea of neurobiology, the theory of self-organization, information technologies, mathematical modeling of the elements of consciousness and a number of other scientific areas in the field of fundamental science. Achievements of cognitive technologies are related to the awareness of the key role of self-organization in learning processes, decision-making and pattern recognition.

The authors of [20] emphasize that cognitive technologies relate to methods and algorithms for achieving various objectives by people, firms and political organizations through the tools of the world cognition, communication and information processing. The basis of cognitive technologies is cognitive science, which studies a person's perception of the world, his thinking and gaining experience.

Thus, cognitive technology is defined as information technology that describes the main mental human processes. Cognitive technology is one of sections of the theory of artificial intelligence and involves technologies for acquiring knowledge.

The expediency of using cognitive technologies for innovative development of the socio-economic systems is as follows:

- generalizing the past experience and use the method of evaluation of modern and forecasting of the future state of the investigated object;
- replacing system analytical search and processing of information with an approach based on experience;
- decreasing in the activity of cognitive processes due to an increase in the efficiency of innovative development of the investigated object.

The modern market regarding the cognitiveness of innovative development of the socio-economic systems offers cognitive technologies shown in Table 3. The Table 3 is created by the authors on the basis [21–27].

The authors give an example of using cluster analysis in the innovative sphere.

The use of a cluster approach is one of the most effective mechanisms of structural development of the economy. The most accepted over recent years and an effective organizational form of competitive business development in the innovative sphere is the association of subjects of innovative activity into regional innovative clusters, namely: industrial companies, research centers, scientific institutions, public administration bodies, etc. Clusters of this type are formed on the basis of the territorial concentration of networks of specialized suppliers, manufacturers and consumers, interconnected by a

technological chain. This innovative cluster contributes to the dynamic socio-economic development of the territory in which it is located.

Agent technologies are assigned for the creation and research of the scenarios of innovative development of the socio-economic systems with imitation of complex dynamic processes. Agent-oriented models have a number of advantages. These models can:

– eliminate a one-sided understanding of the essence of innovative processes, the interaction of agents taking part in the innovative diffusion of the socio-economic systems;

Table 3. Characteristics of cognitive technologies in relation to the innovative development of socio-economic systems

Cognitive technology	The essence of the cognitive approach to the research of innovative development
Statistical Analysis of Data	The specificity of the statistical processing of the results of innovative development lies in the fact that the analyzed database is characterized by a large number of various types indicators, their high variability and the complexity of correlations between the data sample elements. There are several objectives of the research, namely: identifying the main factors for motivation of innovative activity of the personnel, analysis of the completeness and intensity of the use of resources for the innovative development of an economic entity, evaluating the effectiveness of expenses recovery The coefficient method, correlation, dispersion, factor, regression and organizational analysis can be used in the study most often
Intellectual Analysis of Data	An integrated analysis of an innovative object is carried out taking into account a systematic approach. The system approach provides a dynamic review of a multiplicity of factors that affect the managerial decision for innovative developments, considers them in a mutual relationship with external and internal trends in the development of an innovative environment Examples of tasks for intellectual analysis of data are: 1. This is an qualitative analysis of an innovative object, such as an analysis of problems, search and justify strategies for achieving the target 2. This is a cognitive analysis of the situation (identification or classification), such as the formulation of the task and purpose of the study; analysis of statistical and qualitative information; allocation of the main characteristic features of the research process; determination of conditions and restrictions; formation of ways to realize the economic interests of the innovation object 3. This is making management decisions about innovative development, such as recognizing production situations Examples of methods of intellectual analysis of data are fuzzy logic, cluster analysis, logistic regression, pattern recognition

(*continued*)

Table 3. (*continued*)

Cognitive technology	The essence of the cognitive approach to the research of innovative development
Imitation Modeling on System Dynamics	The key paradigm of such cognitive technology is to provide an iterative process of developing and analyzing a model for a better understanding of the most significant properties of the problem Causal interconnections between elements of the system of innovative development are taken into account. Particular attention is paid to the feedback between them. There are the main advantages of imitation modeling on system dynamics: – study of complex weakly formalized situations, in which the use of analytical methods is impossible; – modeling the behavior of the system in previously unknown situations. Imitation serves for preliminary verification of new management strategies before conducting an experiment on a real object; – modeling of situations whose observation is complicated by a large duration of their development or control of the situation by accelerating or slowdown in phenomena during imitation Examples of imitation modeling for the innovation sphere are: – the technology of multi-agent systems allows to explore the state of the economic system based on the information about actions of individual elements (agents); study of the behavior of the agent and its connections with other system participants in dynamics; qualitative response of the system to environmental changes; visual illustrating the economic process. The disadvantages of agent modeling are limiting the parameters of the model and a complex determination of the range of agent actions; – genetic algorithm is a heuristic search algorithm used to solve optimization and modeling tasks by sequential selection, combination and variation of the desired parameters. This mechanism resembles biological evolution. An example is precedent-based modeling. A precedent is a description of a problem or situation in conjunction with a detailed statement of actions. Traditionally, precedent includes a description of a problem, a solution to that problem and the result of applying a solution

– allow scenarial imitation calculations in a variety of economic conditions and choose rational ways to solve existing problems;
– provide a user-friendly interface for modifying certain parts of the model, visualization of experiments and scenario analysis;
– do not use complex mathematical abstractions, assuming direct design of dependencies and properties of economic reality into an artificial society of agents.

Thus, in general, the concept of cognitive methodology includes the following elements:

1. Cognitive modeling is the key point of cognitive analysis used to study the external environment and the development of ways and methods of functioning of the socio-economic systems. The external environment is characterized by weakly structuring and instability. It should be noted that the term «instability» means the impossibility or complexity of providing the development of the system, and weakly structuring is the impossibility or complexity of its formalizing.
2. The main applied task of cognitive analysis is to optimize management.
3. Data on the object of management (or decision-making object) have a polytypic character, they are measured in quantitative and qualitative scales. Information is not always reliable and incomplete.
4. Criteria for the quality of decision-making are given implicitly, informative (most valuable) features are unknown.
5. Rules for accepting identification and forecast decisions are unknown.
6. The main requirements for computer systems of cognitive modeling are openness to any possible changes in a multiplicity of factors, the availability of their causal relationships, obtaining qualitative forecasts of development of the economic process (that is, solving the direct task «what will be if…»), clarification of recommendations for managing the economic process (that is, solving the task «what is required to…»).

The possibility of using the theory of pattern recognition is considered in this research.

4 Modeling of Development of the Innovative Diffusion of the Socio-Economic Systems with Application of Cognitive Technologies

Synthesis of the development of the innovative diffusion of the socio-economic system leads to the development of a mathematical model of managing the complex object. This model should provide a generation of such a set of managed factors, the actual influence of which on the management object in the next management cycle with a maximum possible probability will transfer it to a predetermined target state.

Regarding the innovative diffusion of the socio-economic systems, the performed research allows to solve the following tasks:

1. Modeling of innovative development of the socio-economic system.
2. Systematization of organizational innovative structures that create innovations in various criteria and classification features. For example, for the region, such classification features are economic growth, development of new industries, the rise of small and medium-sized businesses, stimulation and commercialization of scientific researches, integration of science, education, production, region administration and consumers, intensification of innovative activity of the regional socio-economic system, etc.
3. Classification indicators processing of organizational and functional activities of innovative centers depending on the stage of innovative development.
4. Identification of an informative features set of development of innovative diffusion of various socio-economic systems.
5. Expert evaluation of the competitiveness of innovative development centers.

6. Classification indicators processing of human factors and behavioral business management instruments.

In work [1] it is determined the concept of economic state of the socio-economic system as a complex economic phenomenon which depends on the specified researcher set of indicators and methods of evaluation of this of this state.

In this case, the management system model must take into account:

– the current state of the object of management and the trajectory, on which it moved into this state;
– the impact of existing and predictable uncontrolled environmental factors on the behavior of the management object;
– the previous experience of real influence of control factors on the behavior of the object of management.

There are the restrictions of such a model. A change in the object of management may occur due to the complexity of the innovative process flowing in the management object and under the influence of external or internal uncontrolled factors (perturbations).

From tasks in this chapter, it will be specified the setting of the first task, namely modeling of innovative development of the socio-economic system. The enterprise is considered as a socio-economic system. The basic factors of innovative development of the economic entity are:

– the competitiveness of the innovative product;
– the productivity of the enterprise;
– the business conditions;
– the market demand;
– the price of an innovative product;
– the market share;
– the quality control;
– the competitors advertising.

The main factors are established, namely:

– the target factors, such as the market share, the price of an innovative product;
– the control factors, such as the competitiveness of the innovative product, the quality control, the productivity of the enterprise;
– the factors of the environment, such as the business conditions, the competitors advertising, the market demand.

These factors are implemented by indicators of innovation development of the enterprise, that is, by indicators of the state of the economic system and the external environmental. An identification factor may be associated with the target factor or characterize the state of the enterprise, namely, satisfactory, critical or unsatisfactory state. The proposed modeling will help predict new values of these indicators to increase the effectiveness of the economic entity activity.

Thus, the main problem in creating a system of management of a complex socio-economic object is to develop a mathematical model that provides a setup on the specifics of the management object through the use of a posteriori information about it and the

environment, as well as at the expense of additional information coming. Already in the process of operating systems.

The works by I. Ansoff [1], K. I. Tarasova [28], T. S. Klebanova [29], V.S. Simankov [30], G. V. Gorelova [31], I. B. Sirodga [32] and others are devoted to the investigation in this area.

The author in the work [33] shows that in general, the management system model solves two global tasks:

1. Identification of the current state of the control object.
2. Making decisions about management impacts.

It is proposed to consider the parameters of the object of management as an external manifestation of its state.

For example, the parameters can be divided into four groups that characterize:

– previous history of the object of management and the external environment;
– a description of the actual state of the object and the external environment;
– the human-independent factors;
– the human-dependent factors (managerial effects on the object of management).

The model of a complex object of management contains a generalized factual information about what managerial actions previously in practice transferred a complex object of management in a certain state and with such previous history into a given target state. Based on this information a decision to choose managerial impacts is made.

Cognitive and process approaches involve the use of knowledge acquired in some activities or in solving practical problems, and cognitive strategies assimilated by a decision-maker in the decision-making process. Different types of cognitive strategies are classified depending on the structure of human knowledge and the information structure of decisions. People use the additive difference model, the elimination-by-aspects model, as well as intuitive and analytical strategies. In order to exclude cognitive strategies in the decision-making process, it have been developed the process tracking procedures which included synchronous verbal protocols and information search measurement.

Solutions support systems provide the identification of the management purpose, the creation of a general analytical structure and the construction of «values trees». An important task in designing the decision support system is to develop decision making models and information support of decisions.

Formalization of decision-making procedures taking into account the above approaches is proposed to be based on utility theory.

Decision-making is a choice of one of the set of the acceptable variants. Let $\{G\}$ is a set of alternatives, and g is a certain alternative belonging to this set, that is, $g \in G$. Then it is considered that for all g it can be given a function $f(g)$, which is called the utility function. This function has the following property: if the alternative g_1 is preferable to g_2 (denoted by: $g_1 \succ g_2$), then $f(g_1) > f(g_2)$. Thus, the search for the alternative of the decision with the highest value of the utility is carried out. An approach with minimization of the opposite evaluation, for example, a negative value of utility is possible.

To solve management tasks in the described conditions, there is cognitive modeling in a broad sense, namely: it is necessary to reflect the problems and trends of the innovative

development of the system in the form of a model, then to investigate possible scenarios for overcoming crisis situations and find technologies for solving such management tasks. The use of cognitive models increases the level of justification for managerial decisions making in a difficult time-changing situation, deprives the expert of «intuitive wandering», saves time on understanding and interpreting the events taking place in the system.

In order to realize the cognitive technology for managerial decisions making in the economic system it is proposed to use a structural-analytical model of pattern recognition [33, 34].

Recognition is an information process implemented by some information converter, for example, an intelligent information channel or a recognition system. Information about the features of the proposed objects enters the system. It is the input of the system. The output displays information about the classes (generalized patterns) assigned to the objects.

When creating and operating the pattern recognition system, a number of tasks are solved:

1. The task of formalization of the subject area. In essence, this is a coding task. The information converter compiles a list of generalized classes, which include specific implementations of objects, and a list of features that these objects may have.
2. The task of forming a learning sample. The learning sample is a database that contains descriptions of specific implementation of objects in the language of features and information about the affiliation of these objects to certain recognition classes.
3. The task of learning a recognition system. The learning sample is used to form patterns of recognition classes based on the generalization of information about the features of the learning sample objects belonging to this class and other classes.
4. The task of reducing the dimension of the features space. After learning it becomes possible to determine value on solving the recognition task for each feature. After that, the least valuable features can be excluded from the system of features.
5. The recognition task. For a new object a recognizable sample without information about the affiliation of the object to a class is formed. The result of recognition is a class of a new object.
6. The task of quality control of recognition. A control sample is formed. The actual average probability of class recognition error and the probability of error in assigning a recognized object to a certain class are determined.
7. The adaptation task. If unsatisfactory recognition quality has been established, descriptions of incorrectly recognized objects can be copied from the recognized sample to the learning sample, supplemented with adequate classification information and used to reformulate the decision rules. As a result, the recognition system adapts and begins to adequately classify these objects.
8. The reverse task of recognition. For a certain recognition class, the system sets the features that are most characteristic of the objects of this class.
9. The cluster analysis task. The degree of similarity and difference of objects (classes, features) is quantitatively measured. The objects are divided into clusters. This information is used for classification.

10. The cognitive analysis task. Information about the similarities and differences of classes or features is of interest to the researcher in itself, and not using it for classification. To decide this task by methods of the theory of pattern recognition, the proposed cognitive approach is considered in a narrow sense. The results of cognitive analysis are cognitive diagrams, vector functional graphs, parametric vector functional graphs and their modifications.

The possibilities of a cognitive approach to the analysis of economic data and the making of managerial decisions are manifested in models of pattern recognition through such definitions:

- the perception is the representation of a pattern of object management in the form of a set of features. The significance of features characterizes the state of the object management;
- the assignment of formal names is the representation of a pattern of a particular object in the form of belonging to some grades of certain semantic scales;
- the generalization (synthesis, induction) is the formation of patterns in the examples of specific objects;
- the analysis of generalized patterns (deduction) is the detection of general and special characteristics for each pattern;
- the analysis of features is the detection of general and special characteristics in the semantic content of each feature;
- the abstraction is determination of the feature value for patterns differentiating, controlled and correct removal of the least valuable features while preservating of all essential information;
- the classification of patterns is the definition of similarities and differences in patterns; combining similar patterns to clusters;
- the classification of features is the definition of similarities and differences of features; associations similar in the value of features to clusters;
- the meaningful comparison of patterns is the definition of features on which two patterns are different;
- the meaningful comparison of features is the determination of elements on which two features are different;
- the pattern recognition (identification) is the comparison of the pattern of a particular object with all generalized patterns.

The author in the work [35] has given a characteristic of intensive and extraneous recognition methods.

The model of the economic system development as a set of models for the object description has been formulated to create the methodology of the cognitive modeling of economic systems based on the pattern recognition theory:

$$M = \{M_O, M_E, M_U\}, \tag{1}$$

Where M_O – model of the economic system (object model); M_E – model of the external environment; M_U – model of managerial system.

The metamodel idea is borrowed in [36].

The model of innovative development of economic system by reacting to external and internal changes, is:

$$M_O(X, Z(X), U, P) \rightarrow \max \min(X, Z, (X), U, P), \tag{2}$$

where X – parameters and controlling factors of the economic system (object) state; $Z(X)$ – uncertain and uncontrolled factors; U – managerial parameter; P – resources vector.

The model of the external environment has uncertain and uncontrolled factors $ME = ME\ (Z)$.

The model of the managerial system, taking into account the interaction of the economic system (object of management) and the external environment, can be represented:

$$M_U = \{M_{OE}, M_D, M_{MO}, M_{ME}, M_U, A, M_S\}, \tag{3}$$

where M_{OE} – a model of interaction of an object and the environment; M_D – system behavior model; M_{MO} and M_{ME} – models of measuring the state of the system and the environment; A – a rule for choosing the processes of changing the object; M_S – «supervisor» model (cognitive engineer, expert, researcher).

The complex aspects of the functioning of the economic system considered in model (3) in accordance with the theory of pattern recognition can be taken into account in the information base and the knowledge base. The information base will contain data on the interaction of the object and the environment, the system behavior and the results of measuring the state of the system and the environment. The information base of knowledge will include knowledge of the «supervisor» and the rules for choosing the processes of changing the object state.

Then the model of the management system is based on the requirements of pattern recognition and is defined as follows:

$$M_U = \{D, K, C\}, \tag{4}$$

where D – information database; K – information base of knowledge about targeted management decisions; C – interpretation of managerial decisions for the current information set about the economic state of the object of management.

The proposed research mechanism of phenomena and processes in the economic system in order to predict possible ways of its development or management of situations and adaptation to them will help to reduce the risk of the human factor.

I. B. Sirodga [32] has proposed the structural-analytical model of pattern recognition:

$$\{X_n, Y, F, B, L, W\}, \tag{5}$$

where X_n – the space of features; Y – the set of elements of the recognizable classes alphabet; $F: X_n \rightarrow F(X)$ – the closure ratio X_n, which postulates the data structure and the defining element of the classification rule structure in the form of the attribute-predicate; $B: F \rightarrow \{0,1\}$ – the reflection on the Boolean algebra, characterizes the logical structure of the pattern; $L: <F, B> \rightarrow Y$ – the classification rule; W – the cost of the recognition system.

The peculiarity of the structural-analytical method of pattern recognition is the introduction of special relations F and B and the use of a special class of classification rules L based on the operator of R-formalization.

Forecasting the probability of transition of an enterprise to another state is based on the meaning of a probable classification error.

The utility should be considered as an objective comparison of the effects of solutions between themselves, and therefore, as a measure of evaluation the qualities of decisions in conditions of uncertainty and multicriteria. Such utility definition is appropriate for the creation of rational, not optimal, management system for the economic object.

Then, there are such varieties of utility of the structural-analytical model of pattern recognition:

1. The feature utility. This type of utility is determined by its property to divide all classes into two groups with the smallest classification error. The values of criteria that determine the dividing ability of the features are considered a quantitative measure of utility. They rank features for building a decisive rule (a classification rule).
2. The decisive rule utility. The decisive rule is a sequence of features for determining the state of the economic object. The value of the set of features that provides the differentiating ability of the classification rule or its selectivity, determines the decisive rule utility. The fact that such a rule is not supplemented when solving the adaptation task, testifies to its greater utility.
3. The cost of the recognition system. This approach minimizes the negative value of utility. Quantitative value is determined by the probability of classification error. The obtained classification rules are stored in the database and can be ranked.

The cognitive modeling of the economic systems based on the theory of pattern recognition includes the following stages:

1. The qualitative analysis of the state of the economic system (production situations):
   - the analysis of problems that need to be solved in the study situation;
   - the search and the substantiation of strategies for achieving the purpose in stable situations or time-changing situations, taking into account restrictions on the possibility of their implementation;
   - the computer systematization of modeling results.
2. The cognitive analysis of the situation (identification of the problem):
   - the formulation of the problem and the research purpose;
   - the collection, the systematization and the analysis of statistical and quality information on the problem;
   - the allocation of the main features of the investigated process and their connections;
   - the determination of conditions and restrictions;
   - the allocation of basic subjects associated with the situation;
   - the formation of ways to realize the economic interests of the subjects.
3. Making management decisions:
   - the introduction of information on the state of the economic system (situation) as the factor values, the storage of them in the information base;

- processing of economic data (the classification data processing, replenishment of the classification rules base, identification of a new state of the economic system);
- the representation of the results of modeling in graphical and table form (numerical and linguistic values of factors);
- the support of analytical activity of the expert (expert analysis of the classification rules, replenishment of the classification rules in the process of additional learning);
- the evaluation of the situation and making of managerial decisions;
- providing intellectual support for the development of a strategy to achieve the purpose with recommendations on the choice of managerial decisions.

The scheme shown in Fig. 1 is developed on the basis of Table 1 and the definitions of the structural-analytical method of pattern recognition [37].

The scheme shows that the process of managerial decision support making on innovative development consists of the few stages. At the first stage of the cognitive structuring of knowledge about the research object, it is proposed to apply progressive methods of strategic analysis such as PEST and SWOT analysis. The preliminary analysis of the economic system indicators is carried out with the use of such methods as correlation and cluster analysis. The next stage includes the construction of a cognitive model, such as the formalization of knowledge using the structural-analytical method of pattern recognition, which involves establishing and substantiating the interrelations between factors, further interpreting the results and identifying trends in the innovative development of the object. After that, strategies for managing the situation around the economic system based on scenario modeling are developed, providing the choice of management strategies based on information profiles of the research object. The monitoring the situation allows verification and application of knowledge about possible trends of innovation development.

The results of cognitive modelling for decision making are presented in order to manage the innovative states of the air transport enterprise of Ukraine [37].

The «object-feature» matrix according to the financial and economic activity of the enterprise for twelve years has been derived in a table form. The values of twenty-nine indicators (features) have been determined. At the primary data processing stage, a correlation and cluster analysis have been performed to determine the set of fourteen informative technical and economic indicators that characterize the enterprise economic states.

Classification data processing has been done with the following quantitative and qualitative indicators, such as the passenger traffic, the cargo traffic, the passengers trust level, the profitability of services, the profitability of sales, the staff profitability, the fixed-asset turnover ratio, the staff turnover rate, the inventory the turnover ratio, the payable turnover ratio, the receivables turnover ratio, the coverage ratio, the innovative development own-fund ratio.

Reliability estimation of the forecast of the enterprise transition to another economic state is based on the value of the probabilistic classification error. In this example, the classification error is zero.

Known economic states to which the enterprise may belong are as following: good state (indicated by 1), satisfactory state (indicated by 2) and critical state (indicated by

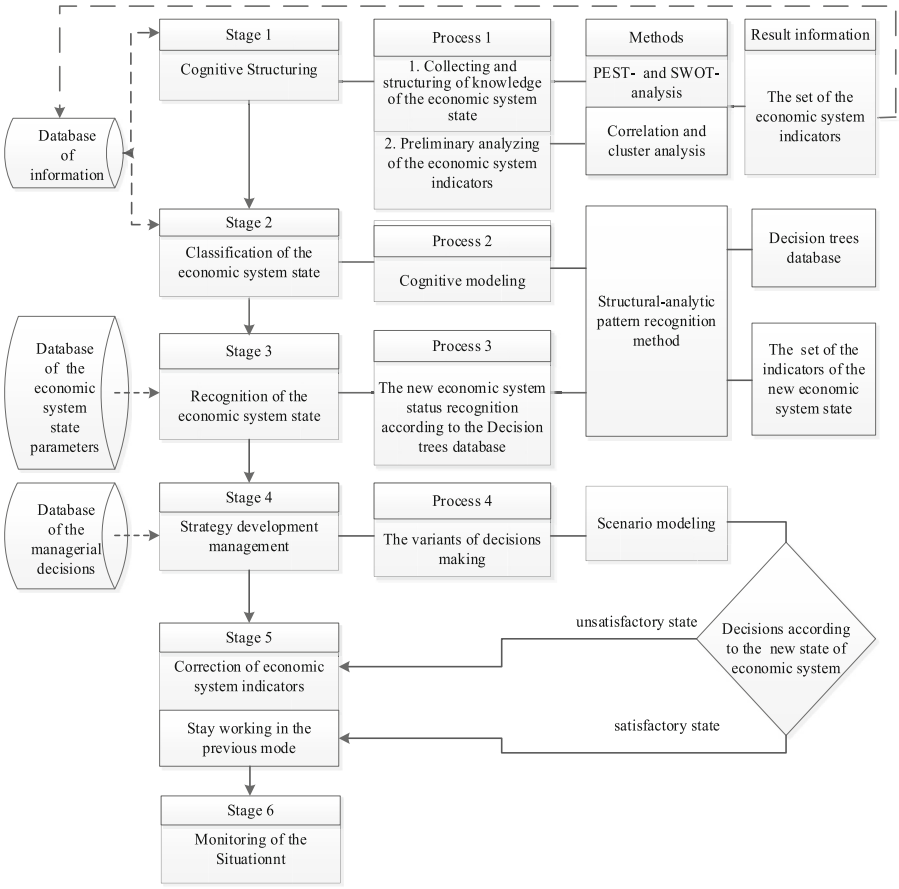

Fig. 1. Scheme of cognitive approach in the managerial decision support making systems on innovative development.

3). According to the results of the research, «good state» is characteristic for four years of air transport company activity, «satisfactory state» – for six years, «critical state» – for two years of twelve. The task of determining the informative indicators describing the states of enterprises with the zero-error classification has been set.

The authors have developed a software complex used for classification data processing. The program provides the modes for extracting feature, states and implementations (table rows). Seven experiments with the different features area have been completed. Mathematical models of enterprise states classification have been presented in a structural form (decision trees).

The decision tree (or classification rule) is a binary hierarchical structure, where the nodes have terminal separating functions (inequalities or equality), and there are the numbers of enterprise states (classes) at the vertices. The left branch of the tree is identified with the true statement about the class separation and the right is identified with the false statement.

Terminal separating functions describe the local regularities of the structural pattern in the researching subject area. It is possible to build several classification rules for one learning data sampling, which have different structural complexity.

The learning of the pattern recognition for automated analysis of experimental data processing has to be provided with four tasks: 1) obtaining an informative set of features with a given value of structural completeness assessment; 2) the output of the informative features set of the learning data sampling; 3) determination of the basic terminal separating functions, which are included in all classification functions sets to construct the decision tree; 4) construction of the decision tree.

Three rational decision models have been chosen to analyze the economic data in order to achieve the reliable result of the classification of the future enterprise state and to take into account the most quantity of features.

The structures of three decision trees are shown in Fig. 2.

For example, the classification rules or classification functions of the enterprise state according to the second decision tree are defined as follows:

1. For the critical state of the enterprise (indicated by the number 3) there are two alternatives:
   - the passengers trust level is not equal to 3, the staff turnover rate is not less than 0.184 and the inventory turnover ratio is less than 41.6;
   - the passengers trust level is 3, the cargo traffic is more than 1.7 and the staff turnover rate is less than 0.184.
2. For the satisfactory state (number 2) there are two alternatives:
   - the passengers trust level is not 3 and the inventory turnover ratio is not less than 41.6;
   - the passengers trust level is 3, the cargo traffic is less than 1.7.
3. For the good state (number 1) there are two alternatives:
   - the passengers trust level not equal to 3, the staff turnover rate is less than 0.184 and the inventory turnover ratio is less than 41.6;
   - the passengers trust level is 3, the cargo traffic is at least 1.7 and the staff turnover rate is not less than 0.184.

Based on the obtained results it can be performed the identification the enterprise states according to the data of the new reporting period. The decision about the state of the enterprise is based on the most identical results of classification for each of the three decision trees. In the case of determining the enterprise state as «satisfactory» or «critical» and the reasons for their occurrence, it is suggested to manage the values of the informative features. Forecasting of the probability of the enterprise transition to another state is based on the value of a probable classification error.

The author in the work [37–39] considers a structural-analytical model of pattern recognition as an effective means to describe the structure of the complex economic systems in the space of various features, as well as to obtain managerial decisions. Classification rules are placed in the knowledge base for theoretical experiments and practical application in solving real tasks.

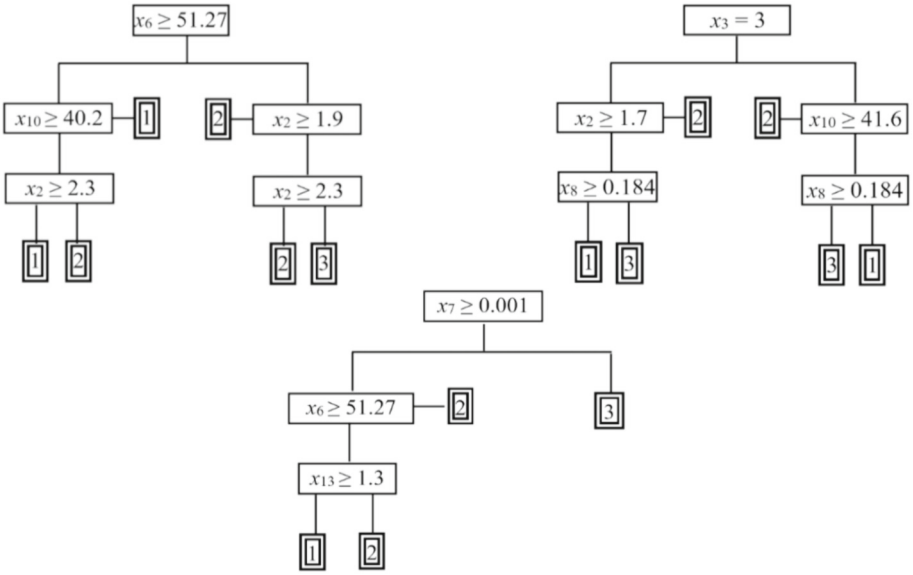

Fig. 2. Schematic representation of metabolism in leveling the rejection of diffusion of innovations.

Thus, the proposed methodological approach to the making of managerial decisions on innovative development in the transport industry allows to achieve more effective management of innovative activities of enterprises in constantly changing operating conditions.

In general, the concept of modeling of the development of the innovative diffusion of the socio-economic system with the use of cognitive technologies allows to realize internal and external reserves and the ability of predicting the results of this process, to create the national information resources, to accelerate automation of production and management and to implement innovations of different functional purposes to the practice.

5 Conclusions

The cognitive component of the innovative diffusion of the socio-economic systems contributes to a more detailed study of problems and identifying factors of the innovative diffusion, evaluation of interconnections between selected factors by modeling of the development scenarios and interpretation of results.

An analysis of the national strategy for the development of science, technology and innovation, which is characterized by a combination of scientific excellence, key technologies to support the competitiveness of economies and address societal challenges is performed.

The problems of theoretical and practical nature are solved in the framework of the research.

The peculiarity of the diffusion direction of innovative development of the socio-economic systems is theoretical comprehension of conditions, forms and methods for obtaining new knowledge. The definitions of reflexivity, reflection and cognitiveness, which ensure the relationship between thinking of participants and the situation of the process of the innovative diffusion, are given. The factors of ensuring the innovative development of socio-economic systems due to the factor of cognitiveness are revealed. The characteristics of cognitive technologies regarding the innovative development of the socio-economic systems are given. Attention is paid to examples of the cluster formation to stimulate innovative development of socio-economic systems, the agent approach to manage the process of innovations distributing in the socio-economic systems and the structural-analytical model of pattern recognition to predict the innovative development of the economic entity.

Cognitive simulation is considered as an instrument of intellectual support for decision-making in the economic systems of transport industry in relation to innovative development. The cognitive modeling will allow not only to investigate problems that arise in unstable, weakly structured environments (the economic systems), but also to take into account the change in the external environment and the object of management, to systematize and verify the representation of an expert on the object of management and its external environment, to predict the values of the factors of the economic system in objectively formed environmental conditions, to develop optimal management strategies in dynamic changed conditions.

Cognitive modeling of innovative states of the transport enterprise on the basis of the structural-analytical method of pattern recognition is made. The obtained results can be used as indicators of selected strategies for economically stable and flexible economic management and coordination of current and prospective innovation activities of the enterprise. The reliability of the results is confirmed by publications. A number of promising tasks that can be solved by the proposed methodology are highlighted.

Modeling of the development of the innovative diffusion of the socio-economic systems with the use of cognitive technologies will allow:

1. To conduct a cognitive structuring of information about the situation in the process of the innovative diffusion of the socio-economic system.
2. To identify the causal relationships between the basic factors of the development of the innovative diffusion.
3. To search for the most effective management of the innovative diffusion.
4. To evaluate and interpret the results of modeling innovative development of the socio-economic systems.

Then the motivation of the innovative diffusion of the socio-economic systems will become a precondition for a qualitative technological breakthrough of developing an economic entity.

The research results are used in the educational process for the implementation of competencies in the ability to abstract thinking, analysis and synthesis, as well as independent acquisition of new knowledge, application of scientific, analytical, methodological tools to substantiate the development strategy of economic entities and related managerial decisions.

References

1. Ansoff, H.: Strategic Management. Wiley, New York (1979)
2. Glaz, V., et al.: Development of systematic methods for managing socio-economic systems. Int. J. Innov. Technol. Explor. Eng. **9**(1), 468–472 (2019)
3. Landa, J.: The coevolution of markets, entrepreneurship, laws, and institutions in China's economy in transition: a new institutional economics perspective. In: Economic Success of Chinese Merchants in Southeast Asia, pp. 215–247. Springer, Heidelberg (2016). https://doi.org/10.1007/978-3-642-54019-6
4. Shamota, G.M.: Diffusion of innovations in Ukraine at the present stage. Probl. Prospects Develop. Banking Syst. Ukraine **31**, 288–296 (2011). (in Ukrainian)
5. Zhavoronkov, V., Zhavoronkova, G.: Development of innovation – technological infrastructure in the region: theoretical – methodological aspect. SMEU **1**(2), 77–87 (2019). https://doi.org/10.23939/smeu2019.02.077. (in Ukrainian)
6. Mazaraki, A., Drozdova, Y., Bay, S.: Theoretical and methodological principles for assessment the readiness of socio-economic systems for changes. Baltic J. Econ. Stud. **6**(1), 80–86 (2020). https://doi.org/10.30525/2256-0742/2020-6-1-80-86
7. Rogers, E.: Diffusion of Innovations, 5th edn. Free Press, New York (2003)
8. Walliser, B.: Cognitive Economics. Springer, Heidelberg (2008)
9. Leon, M., et al.: Fuzzy cognitive maps for modeling complex systems. In: Sidorov, G., Aguirre, A., García, C. (eds.). 9th Mexican International Conference on Artificial Intelligence, MICAI 2010, LNCS, vol. 6437 LNAI, Is. PART 1, pp. 166–174, Springer, Heidelberg (2010). https://doi.org/10.1007/978-3-642-16761-4_15
10. Karaev, R.A., et al.: Cognitive analysis and management of innovative projects of enterprises. Inf. Manag. Syst. **4**, 63–68 (2010). (in Russian)
11. Nikishin, E.V.: Aspects of the theory of diffusion of innovations and logistics of AIC of Ukraine. Econ. Anal. **28**(2), 49–56 (2018). (in Ukrainian)
12. Pisarenko, T.V., et al.: Scientific and scientific-technical activity in Ukraine in 2022: scientific-analytical report. UkrINTEI, Kyiv (2023). (in Russian)
13. Udemans F.: On the Nature of Socio-Economic Systems: the Science, the Practice, the Reflexivity. https://www.researchgate.net/publication/366029592_ON_THE_NATURE_OF_SOCIO-ECONOMIC_SYSTEMS_THE_SCIENCE_THE_PRACTICE_THE_REFLEXIVITY, last accessed 20/11/2023
14. Abdikeev, N.M., et al.: Cognitive economy in the era of innovation. http://rus.neicon.ru:8080/xmlui/bitstream/handle/123456789/7332/33_%10148:552.pdf?sequence=1. Accessed 25 Apr 2021. (in Russian)
15. Zimovin, O.I., Zaika, E.V.: Reflexivity and reflection: the relationship of concepts. Bull. GS Skovoroda Kharkiv Natl. Univ. Psychol. **47**, 65–71 (2014). (in Ukrainian)
16. Nordmann, A.: Ignorance at the Heart of Science? Incredible Narratives on Brain–Machine Interfaces. TU Darmstadt. https://www.uni-bielefeld.de/ZIF/FG/2006Application/PDF/Nordmann_essay.pdf. Accessed 30 Sept 2023
17. Khushf, G., et al.: The Use of Emergent Technologies for Enhancing Human Performance: Are We Prepared to Address The Ethical and Policy Issue. Public Policy & Practice. https://www.academia.edu/592339/. Accessed 23 Nov 2023
18. Malinetsky, G.G.: Culture, humanitarian knowledge and self-organization theory. Observ. Cult. **18**(4), 340–351 (2021). https://doi.org/10.25281/2072-3156-2021-18-4-340-351. (in Russian)
19. Sikora, L.: Cognitive models and logic of operational management in hierarchical integrated systems in risk conditions. TSSD EBTETS, Lviv (2009). (in Ukrainian)

20. Khromyak, J.Y., et al.: Cognitive technologies and their features in management and marketing. Management and Entrepreneurship in Ukraine: stages of formation and problems of development **767**, 75–82 (2013). (in Ukrainian)
21. Dragan, T.M., Druzhinina, E.A.: Coefficient method of analysis of innovative development of the enterprise. Int. Collect. Sci. Works **2**(17), 84–90 (2010). (in Russian)
22. Filipkovska, L.O., Matvienko, O.O.: Conceptual principles of cognitive modeling of enterprise adaptability. In: Ponomarenko, V.S., Klebanova. T.S. (eds.). Applied aspects of modeling of socio-economic systems: monograph, pp. 281–298. Tkachuk AV, Berdyansk (2015). (in Ukrainian)
23. Macal, C., North, M.: Introductory tutorial: agent-based modeling and simulation. In: Winter Simulation Conference, Washington D.C., pp. 362–376 (2013). https://informs-sim.org/wsc13papers/includes/files/031.pdf. Accessed 23 Nov 2023
24. Masloboev, A.V.: Simulation modeling of development of innovative processes on the basis of a method of system dynamics and agent technologies. Qual. Innov. Educ. **3**, 34–42 (2009). (in Russian)
25. Guzhva, V.M.: Adaptive management of enterprises on the basis of precedents: agent-oriented approach. Probl. Econ. **2**, 175–180 (2013). (in Ukrainian)
26. Porter, M.: On Competition. Harvard Business Press (2008)
27. Knyazevych, A.A., Britchenko, I.G.: Cluster approach to creating an innovative infrastructure of the country. Sci. Bull. Mukachevo State Univ. Econ. **2**(1), 24–29 (2015). (in Ukrainian)
28. Tarasova, K.I.: Evolution of information systems in the economy. Business Inform **4**, 289–295 (2020). https://doi.org/10.32983/2222-4459-2020-4-289-295. (in Ukrainian)
29. Kizim, N.A., Klebanova, T.S. (eds.): Adaptive Models in Decision-Making Systems. Inzhek Publishing House, Kharkiv (2007). (in Russian)
30. Simankov, V.S., Lutsenko, E.V., Laptev, V.N.: System analysis in adaptive control. Institute of Technologist and Economy, Krasnodar (2001). (in Russian)
31. Gorelova, G.V.: On cognitive modeling of complex systems, research tools. Tech. Sci. Notices SFU **6**(131), 236–240 (2012). (in Russian)
32. Sirodga, I.B.: Structural-analytical method of machine pattern recognition with different types of features. In: Stoyan, Yu.G., Protsenko, V.S., Manko, G.P. (eds.) Theory of R-functions and current problems of applied mathematics, pp. 212–244. Science Duma, Kiev (1986). (in Russian)
33. Filipkovska, L.O.: Cognitive approach to economic data processing and managerial decision making in an industrial enterprise. In: Kedyukhov O.V. (ed.) Theory and practice of economic development theory and practice of managing the economic development of the enterprise, vol. 2, pp. 242–250. SHEI "DonNTU", Donetsk (2013). (in Ukrainian)
34. Filipkovskaya, L.A.: Investigation of the structural-analytical model of pattern recognition in control and diagnostic tasks. Bionics Prob. **53**, 51–53 (2000). (in Russian)
35. Filipkovskaya, L.A., Skachkov, A.N.: Application of pattern recognition methods in expert economic systems. Issues of design and manufacture of aircraft structures. Spec. Issue "New Technol. Mech. Eng." **3**(63), 215–219 (2010). (in Russian)
36. Ginis1, L., Gorelova, G., Kolodenkova, A.: Cognitive and simulation modeling of socioeconomic systems. In: IV International Research Conference "Information Technologies in Science, Management, Social Sphere and Medicine", pp. 50–54, Atlantis Press, Dordrecht (2017)
37. Filipkovska, L., Matviienko, O.: Managerial decision support making in economic systems based on cognitive modeling. Int. J. Eng. Technol. **7**(4.3), 588–592 (2018). https://doi.org/10.14419/ijet.v7i4.3.19962

38. Filipkovska, L.O., Matvienko, O.O., Nikitenko, S.V.: Formation of primary knowledge about the state of the air transport enterprise to diagnose its economic security. Bus. Inform **5**(448), 165–172 (2015). https://www.business-inform.net/export_pdf/business-inform-2015-5_0-pages-165_172.pdf. (in Ukrainian)
39. Filipkovska, L.O. Toolset of intellectual analysis of economic status of enterprise with application of pattern recognition. In: Proceedings of The Eighth World Congress «Aviation in the XXI-st Century» «Safety in Aviation And Space Technologies», pp. 84–86. National Aviation University, Kyiv (2018). http://conference.nau.edu.ua/index.php/Congress/Congress2018/paper/viewFile/5591/4050

The Effectiveness of the Work of International Organizations: The Current State and Prospects for Evaluating Their Work

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Abstract. The article is devoted to the study of the problems of determining the effectiveness of the activities of international organizations, the criteria of the effectiveness of the work of these organizations. The question of the role and importance of international organizations in the modern world is considered, the main international intergovernmental organizations that ensure the maintenance of peace and security in the world are analyzed. The activity of the UN as the main institution, which is assigned the task of maintaining peace and security in the world by its Charter, is studied in detail. The authors emphasized the role of the UN in resolving conflicts in the world, identified the main problems of this organization's work, as well as the availability of legally established means in the event of a threat to peace and security. Attention is paid to the problems of the effectiveness of the UN in the conditions of a full-scale war in Ukraine. It was emphasized that the main obstacle to the full-fledged activity of the UN today is the presence of aggressor states in its composition and the veto mechanism, which blocks the mechanism of introducing legally prescribed measures to apply the provisions of the UN General Assembly Resolutions. The issue of determining efficiency as a basic feature of the activity of international organizations is analyzed. The level of trust of Ukrainians in international institutions in the conditions of a full-scale war, as well as the main wars waged by the Russian Federation during the last 30 years, was studied. Ways to increase the efficiency of international organizations are proposed, in particular, through periodic verification (auditing) of the activities of international organizations for their effectiveness and the creation of transparent mechanisms for combating the unproductive work of international organizations.

Keywords: International organization · effectiveness · legitimacy · accountability · functionalism · transparency · participation · democracy in IOs

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1 Introduction

Today, in the conditions of a change in the world order, after a series of wars of aggression on the part of the Russian Federation, in the conditions of many unresolved global problems, the question arises: what place in the world do international organizations occupy? Are they effective enough as intended when they were created?

The question of the work of international institutions to solve all the problems brought about by the war is of primary importance. Of course, after all the horrors of the Second World War, the states developed a mechanism to ensure peace and security in the world. To support international peace and security, a number of international organizations have been created both at the international and European level.

Today's realities clearly indicate the obvious: most international institutions have not achieved their statutory goals or have partially achieved them. That is why we are now talking about analyzing the effectiveness of the work of international organizations in order to resolve the issue of the potential possibility of their transformation or recognizing their work as ineffective and ending the existence of individual international institutions.

2 Literature Review

Certain aspects of defining the essence of international organizations, as well as certain issues of the problem of ensuring the effective work of international intergovernmental organizations, were considered in the works of the following scientists: Ernst-Ulrich Petersmann, M. Slobodchikoff, R. Lall, D. Panke, G. Polat, F. Hohlstein, A. Plantey, L. Fawcett, A. Hurrell, E. Vinokurov, A. Libman, S. Williams and others.

The spectrum of research on this issue is quite wide, but the amount of research on this issue is critically low: the need for the effective work of international organizations and compliance of their activities with the statutory goals is mainly emphasized, as well as the activities of individual international organizations are generally analyzed and their insufficiently effective work is pointed out. At the same time, the ways of increasing the efficiency of international organizations, as well as the criteria by which it is possible to determine whether the organization works effectively, are presented very fragmentarily.

Further in-depth analysis and development of scientific approaches and practical mechanisms for determining the prerequisites and grounds for recognizing the work of an international organization as ineffective and the consequences of such decisions are needed. The conceptual apparatus also needs improvement: in modern conditions, it is necessary to revise the very approaches to defining the category "international organization", as well as to develop a methodology for determining the effectiveness of these organizations.

Undoubtedly, the problem of legal provision of the possibility of recognizing the work of an international organization as ineffective, of auditing the activities of an international organization, the periodicity of such an audit, and further ways of increasing the effectiveness of the organization's work or solving the question of the feasibility of its existence is of course very important.

3 Main Content Presentation

3.1 International Organizations and Ensuring International Security

Ensuring international security is the main task of subjects of international law. First of all, of course, this is the task of states as the main subjects of international law and international intergovernmental organizations. It is with the help of international organizations that the governments of various states are trying to solve the biggest problems of humanity - global, collective problems that cannot be solved by a state or a few states, given the comprehensiveness of today's challenges. International intergovernmental organizations were created in part to create an effective system of global self-preservation and development. They generally deal with a wide range of security issues, including arms control, conflict prevention, and ensuring human and citizen rights and freedoms.

From the perspective of international law, an "international organization" is best understood as "an organization established by a treaty or other instrument governed by international law and possessing its own international legal personality" [1]. International organizations1 are legal communities in three respects: they are created by law, they use law as a means of governance, and they must be governed by the rule of law. Accordingly, international law creates, enables and limits international organizations. In the procedural law of organizations, a triptych of accountability procedures is built: transparency, participation and access to justice.

The main international organizations concerned with world peace and security are the United Nations, North Atlantic Treaty Organization, the Organization for Security and Cooperation in Europe and so on. I deliberately do not consider the EU, because in the science of international law there is still a dispute over the legal nature of this entity.

The UN is the main international intergovernmental organization whose main statutory task is to maintain peace and security around the world. Thus, Article 1 of the UN Charter stipulates that: "To maintain international peace and security, and to that end: to take effective collective measures for the prevention and removal of threats to the peace, and for the suppression of acts of aggression or other breaches of the peace, and to bring about by peaceful means, and in conformity with the principles of justice and international law, adjustment or settlement of international disputes or situations which might lead to a breach of the peace" [2].

Unfortunately, today we cannot fully assert that the UN is capable of performing its direct functions. The Russian Federation's full-scale war in Ukraine significantly shook the security situation in Europe and around the world. This war has already been called the largest armed conflict in Europe since World War II. At the same time, we remember that the UN was created precisely after the Second World War in order to prevent in the future those horrors that were brewing then. And today the situation is repeating itself on an even greater scale. The terrorist and military threat from the Russian Federation and its allied states has spread throughout the world: tensions around Taiwan have increased, threats of nuclear strikes from the DPRK and Russia are heard, Iran's actions in the region are aggressive, etc.

In fact, it can be argued that the complex and extremely acute tensions in the world are already working as a catalyst for a potential Third World War and a nuclear disaster. That is why the response of international organizations in the field of maintaining peace

and security should be as quick as possible. The maximum mobilization of all available diplomatic, political and legal resources is necessary, which would reduce tension and find effective mechanisms to stop the aggressive terrorist policy of the specified countries. One of the main organs of the UN, which is called to solve the problems of international security, is the UN Security Council.

The year 2022 became a crisis for the world and the UN - Russia's military aggression against Ukraine caused great destruction on the territory of Ukraine, the death of many not only military personnel, but also civilians. The Russian criminal army has committed and continues to commit numerous crimes of genocide against the Ukrainian people in the occupied territories, forcibly deports civilians to its territory, kills and tortures prisoners of war. Russia has repeatedly threatened a nuclear and chemical disaster on the territory of Ukraine, and its missile attacks not only destroy residential buildings and infrastructure of Ukraine, but also threaten neighboring countries – Moldova and Poland, on whose territory Russian missiles have already landed. At the same time, all of Europe faced a new migration crisis caused by large flows of refugees from Ukraine.

It is quite obvious that as of the middle of 2023, international organizations, including the UN Security Council, have problems with the use of those mechanisms for ensuring world peace that they have in their arsenal. Therefore, there is a need to analyze the effectiveness of this collective body in regulating the military aggression of the Russian Federation in Ukraine.

At the same time, it should be emphasized that the powers of the main UN institutions in the mechanism of maintaining peace and security are extremely broad. The General Assembly and the Security Council - both of these bodies have clearly defined competence in this area. And it is the UN Security Council that is entrusted with the main responsibility for maintaining international peace and security.

According to the UN Charter, the Security Council has extremely broad powers in the prevention of war and the creation of conditions for peaceful and fruitful cooperation between countries. The results of the activities of the Security Council can be considered as a criterion for the effectiveness of the work of the UN. An analysis of the provisions of the UN Charter gives every reason to assert that the Security Council is the only body of the United Nations that has the authority to take preventive or coercive measures on behalf of the United Nations. According to the Charter, the Security Council is responsible for the use of the combined armed forces of UN member states.

Article 43 of the UN Charter defines the procedure for the provision by the UN members of the Security Council of the necessary armed forces, auxiliary means and services on the basis of special agreements concluded by the Security Council with the UN member states upon their subsequent ratification. The Security Council must resolve all issues related to the creation and use of armed forces, relying on the support of the Military Staff Committee, which consists of the chiefs of staff of the permanent members of the Council. But the provisions of Articles 43 and 47 of the UN Charter were not put into effect because of disagreements among the permanent members of the Security Council. In 1947, this committee practically stopped its activities. Since that time, the UN began to improvise in the field of creation and use of armed forces. In particular, a new form of UN activity regarding the maintenance of international peace and security emerged, which is not provided for by the Charter - peacekeeping.

Joining the efforts of states to ensure and maintain peace involves measures such as the prohibition and threat of the use of force in interstate relations, peaceful resolution of international disputes, maintenance of security, coercive measures without the use of armed forces, coercive measures with the use of armed forces, disarmament. We emphasize that despite the declarative presence of effective methods of maintaining peace and security in the world, the broadest of all possible powers in this area - extreme measures - have not been applied.

That is, the elaborately developed and a priori effective mechanism for ensuring peace in the world has not fully worked since the end of the Second World War and since the beginning of the creation of the UN itself and the UN Security Council, respectively. Therefore, the question arises - does the existence of such an organization justify itself, how effectively it performs the functions assigned to it?

And what is most important today is that since the invasion and annexation of the territories of Ukraine by the Russian Federation, the UN has not taken the appropriate measures that it could have taken purely based on its statutory goals and its competence and influence on the international arena, so and considering the arsenal of means that this organization has. The very first steps of the UN Security Council to prevent a war in Ukraine should have been related to Russia's annexation of the Ukrainian Crimea in 2014. However, the specified UN body did not show any effectiveness.

Thus, the Permanent Representative of Ukraine to the UN, Serhiy Kyslytsia, stated that according to the UN Charter, the Secretary General has the right to address the Security Council if he has information that there is a real threat to regional security. I have no doubt that the then General Secretary Ban Ki-moon had information about the movement of Russian troops and the appearance of Russian troops on the territory of Crimea. Nevertheless, he did not ask the Security Council to urgently consider this issue. In his opinion, the UN lost the opportunity to play the role for which it was actually created: to prevent wars, aggression, occupation [3].

Thus, on March 13, 2014, the Verkhovna Rada of Ukraine adopted an Address to the UN, in which it was noted that the Russian Federation is trying to annex part of the territory of Ukraine and will resort to an unprovoked act of aggression. Even then it was obvious that Russia's actions contradicted not only the international norms of maintaining security, but also valid bilateral treaties, as well as the "spirit and letter" of the international guarantees to Ukraine recorded in the Budapest Memorandum. In response to this appeal, the UN initiated a discussion of the issue and a resolution on the issue of Crimea in Ukraine, however, despite the fact that the majority of Security Council members (13 countries) supported the resolution, the Russian Federation, using the right of veto as a permanent member of the Security Council, actually blocked the decision of the Security Council of the UN regarding the settlement of the Ukrainian crisis.

And later, during the annexation of parts of the Donetsk and Luhansk regions of Ukraine, the UN Security Council demonstrated the same level of effectiveness - any attempts by this body to contribute to the settlement of the military conflict on the territory of Ukraine were blocked by Russia. At the same time, Russia, even after large-scale military aggression, genocide of Ukrainians, threats to the whole world with nuclear war and recognition of Russia as a terrorist country by many countries, as of 2023 still

remains a member of the UN. The inability of the UN to even exclude Russia from the list of permanent member states points to the over-bureaucratization of this organization and its ineffectiveness in conflict prevention and resolution.

3.2 Effectiveness of International Organizations

In the legal landscape after 1989, there was a need to adapt international organizations to the new political, military, economic and legal environment, as well as to respond to new requirements for their effectiveness and legitimacy [4]. Efficiency deficits arise not only from wastefulness or mismanagement, but also from the very formulation of legal norms. The most famous example is the situation given in the Resolution of the UN General Assembly of February 16, 2012 No. 66/253 "Situation in the Syrian Arab Republic". Thus, the work of the UN Security Council was effectively blocked through the use (and abuse) of the right of veto by, in particular, the Russian Federation, thereby practically removing the Council from fulfilling its "primary responsibility for maintaining international peace and security" (Article 24 of the UN Charter) [5]. At that time, it was already the fifth time that Russia used its right of veto in relation to draft resolutions on Syria in recent years. Since 1991, the Russian Federation has used a veto in the UN Security Council 31 times, which is almost twice as many as any other permanent member of the Security Council [6].

At the same time, when it comes to the effectiveness of international organizations, it is obvious that the rational use of resources and the influence of international organizations in the world concerns not only issues of security and defense, but also issues of trade, financial stability and countering potential and real threats to the financial sector of the economy, international transportation, etc. In particular, as some researchers, such as Anne Peters, rightly point out, the World Trade Organization is currently covered by hundreds of bilateral and regional trade agreements. This is not only a potential source of WTO inefficiency, but also generates a loss of legitimacy contained in multilateralism [4].

Of course, the current work and results of various international organizations were analyzed. A number of reports and reports were written on this basis. As an example, the following can be cited: "A More Secure World: Our Shared Responsibility," Report of the High-level Panel on Threats, Challenges and Change, 2 December 2004 (UN Doc. A759/565) [7]; "In larger freedom: towards development, security and human rights for all," Report of the Secretary-General, 21 March 2005 (UN Doc. A/59/2005) [8], United Nations, SG Letter, "Report of the Panel on United Nations Peace Operations," (UN Doc. A/55/305-S/2000/809) (the "Brahimi Report") [9]; Secretary-General Letter, "A comprehensive strategy to eliminate future sexual exploitation and abuse in United Nations peacekeeping operations," (UN Doc. A/59/710) (the "Zeid Report") [10] and others.

Scientists also took care of the problems of analyzing the effectiveness of the work of international governmental organizations. In particular, Ernst-Ulrich Petersmann emphasizes that it remains an important task for academics to promote the long-term perspective and public discussion of institutional reforms. These reforms, even if they remain rather ambiguous among politicians, can be implemented in the short term. In his opinion, reforming the WTO seems necessary "in the new millennium to ensure that WTO

members and the world trade system more effectively protect the welfare of consumers and other common interests of citizens, with due respect for general human rights and democratic self-government" [11]. At the same time, the scientist rightly focuses on the fact that the WTO report is limited to the proposal of feasible reforms, and not more significant changes, which, in our opinion, could not receive the necessary support for them to be implemented [12].

At the same time, Michael O. Slobodchikoff concludes that in the matter of resolving territorial disputes, the EU has not been effective in solving all the problems that have arisen in connection with territorial claims both between the member states and the candidate countries of the EU, but in in general, the European mechanism was effective in managing territorial disputes [13].

Today, a full-scale war is going on in Ukraine. And it would seem that this is the only "conflict" in which the Russian Federation is the other party. However, this is not the case. According to the Ukrainianer study [14], the Russian Federation was at war all the time after leaving the USSR. Thus, the Russian Federation took part in the following armed conflicts: 1992–1993 – Russia occupied Transnistria, 1992–1993 – Russia provoked the Abkhaz War, 1994–1996 – The first Russian-Chechen war, 1999–2009 – Second Russian-Chechen war, 2008 – Russian-Georgian war, 2015–2022 – Russia's invasion of Syria, 2014–2022 – Russian-Ukrainian war (Fig. 1).

Fig. 1. Russia's wars over the past 30 years

It is also worth considering the tools by which we determine the effectiveness of international organizations and what this concept means in general. The analysis of scientific literature in the field of determining the satisfactory or unsatisfactory work of international organizations, determining the compliance of their activities with their statutory goals, establishing the priority of work according to the directions determined for them, gives grounds for asserting that the number of studies devoted to the productivity of the activities of international organizations is critically small.

In general, we can say that given the order of creation of most organizations, at the time of their creation and the purpose for which the states cooperate, it is assumed that they fulfill their goals and tasks. At the same time, they perform them to the full extent and in full compliance with the set tasks, as well as that their activity is productive. That is, the efficiency of international organizations and the full compliance of their activities with the statutory goals are taken as a constant.

However, the situation in the world proves the opposite: very high goals are stated in the charters of most international governmental organizations, but in reality we do not see improvement in many areas, this is especially noticeable in the field of maintaining peace and security, in the field of overcoming hunger, solving environmental problems, preventing ecocide, genocide and many others.

If we talk about the definition of the productivity of the work of international organizations, the latter is defined by individual scientists as the extent to which they achieve the stated goals and whether it is done in an economically efficient way that corresponds to a wide range of (state and private) interested parties [15]. However, it is worth noting here that, in our opinion, the efficiency of the organization is its integral feature. It was created in order to be effective in solving certain issues - its statutory goals and objectives. One cannot say that even if the activity of an international organization is unproductive, it has the right to exist. Because a completely legitimate question arises: what is the purpose of an organization that does not fulfill its statutory goals or only half-fulfills them?

How to understand in general whether the activities of an organization are effective or not? In our opinion, the activity of the international institution that achieves the goals set during its creation is effective. It is possible to consider the category of "efficiency" in different ways, but in one way or another it is reduced to the performance, proper performance of the functions assigned to the organization.

In our opinion, the effectiveness of the work of international organizations can be defined as a mandatory and integral feature of an international organization, which is determined by the level of achievement of its statutory goals in order of priority, the level of consideration of the interests of various states and other subjects of international law, and the level of rationality of spending available or resources provided to the organization. In fact, the main idea that we are trying to convey emerges from this definition: if an organization is found to be inefficient, then it has no right to exist. At least in that form, with that structure, goals and tasks, with those resources that it has. And then there are two ways to correct the situation: either the organization must be closed, that is, its activities must be completely stopped. Or (the second way) - in accordance with the problems that this organization has, such an organization can be reformed. The choice of the reformatting mechanism of the international organization depends on the identified gaps in its activities. So, if the organization spends too many resources on performing its tasks, it is necessary to develop a strategy to reduce these costs. If the statutory goals are not achieved at all or are partially achieved, it is necessary to revise these goals and (possibly) change the organizational structure of the organization. It can be a certain "rehabilitation plan" of an international organization.

3.3 Improving the Efficiency of International Organizations

The main task for maintaining peace and security in the whole world is, of course, increasing the role of international organizations in this process. Not declaratively, but the development of a whole mechanism of their effectiveness. It is worth emphasizing once again that international governmental organizations today do not fulfill their functions to the full extent. As for Ukraine, this is evidenced by numerous polls regarding the trust of the Ukrainian people in international organizations or associations.

According to the results of the survey "Wartime Diplomacy. What do Ukrainians think about Ukraine's movement towards membership in the EU and NATO during the war", carried out by LLC "Info Sapiens" on the order of the "New Europe" Center [16], the level of trust in international institutions, in our opinion, is extremely low (Fig. 2). Yes, the highest level of trust is in the EU - 83.8%, NATO - 76%, G7 - 71%, Lublin triangle - 65.5, UN - 56.7% and OSCE - only 42.8%.

Fig. 2. The level of trust of Ukrainians in international organizations

Important in the context of our research are the conclusions made by scientists regarding the potential for increasing the efficiency of international organizations. As Diana Panke, Gurur Polat, and Franziska Hohlstein rightly point out, in general, the effectiveness of problem-solving increases if international organizations are equipped with secretariats capable of autonomous actions that assist states in conducting multilateral negotiations throughout the international organization's policy cycle. For example, such secretarial support reduces transaction and information costs and thus increases the speed and expertise available for decision-making [17]. In addition, problem-solving efficiency is generally considered to be higher when international organizations do not operate primarily by consensus when it comes to decision-making. That is, when a decision is made even when the majority of states agree to it, but there are also those that

do not agree with it. Because due to the large number of players who have the right of veto, conceptual decisions may never be adopted. At the same time, negotiations in the shadow of consensus can also encourage states to work on results with the lowest common denominator [18].

Third, compared to global international organizations, regional international organizations are generally considered to be better at solving problems. This resonates well with the work of regional organizations, which argue that they are better suited for sensitive tasks such as peace and conflict resolution than global international organizations because they are smaller, more homogeneous, closer to the problem on the ground, and therefore better suited to solving such problems than international organizations with more distant members - as rightly noted by Fawcett and Hurrell [20] and Vinokurov and Libman, 2017) [21]. Finally, the effectiveness of international organizations in solving problems increases if it works on the basis of a deliberative diplomatic culture. The more pronounced the practice of discussion among delegates from states, the more likely it is that the exchange of principled positions triggers processes of mutual learning and leads to high-quality results that exceed the lowest common denominator [17].

It is worth noting that the effectiveness of the activities of international organizations is closely related to compliance with the norms of international law by their member states. In particular, if we are talking, for example, about international organizations whose statutory tasks include issues of peace and security, then the members of these organizations must comply, at a minimum, with the norms of international humanitarian law.

Compliance with international humanitarian law is the duty of all UN member states. The UN has appropriate mechanisms to monitor compliance with these norms, including the International Committee of the Red Cross, the International Court of Justice and its specialized tribunals, as well as the UN's subsidiary human rights missions in various countries. Adherence to the norms of international humanitarian law is an important task for ensuring the protection of human rights during military conflicts. The norms of international humanitarian law determine the behavior of military and civilian persons during hostilities, as well as the obligations of states and international organizations regarding their protection.

In order to comply with the norms of international humanitarian law, states must take appropriate legislative and other measures. For example, states must ratify international treaties on international humanitarian law, such as the 1949 Geneva Conventions and their additional protocols, and incorporate international humanitarian law into national law. In addition, states must ensure that their military and others involved in hostilities comply with these norms. At the same time, UN member states are obliged to coordinate their actions with international standards of international humanitarian law, regardless of whether they are participants in armed conflicts or not [21].

The main ways to increase the effectiveness of international organizations, in our opinion, based on the above considerations and positions, are the following. First of all, objective monitoring (audit) of the activities of international organizations is necessary in several aspects: achievement of statutory goals (full or partial), fulfillment of statutory tasks (in full or not), whether there were objective obstacles to achieving statutory goals or the fulfillment of tasks, whether the international organization rationally used its

available resources (human, financial, etc.), whether the international organization used all possible means to fulfill the statutory tasks and achieve the goals. Secondly, it is quite important to analyze the activities of the members of this organization in terms of achieving its goals and objectives, as well as whether the member countries of this or that organization are such as to block its work or reduce the effectiveness of its activities.

4 Conclusions

There are quite a few international organizations in the world. The states transferred part of their immunity to all of them in order to solve global collective issues in various spheres of life. These organizations are funded by the funding of their members. Therefore, the agreed decisions of the participants must be implemented. Today, the issue is that no unified methodology has been developed for determining the effectiveness or ineffectiveness of the work of an international organization. In addition, gaps in the legal regulation of the work of international organizations and their achievement of statutory goals are quite significant in the event that one of the states (or several) no longer corresponds to the political status that they had at the time of the creation of the organization. A clear example is the UN, which was created to maintain peace and security. One of the founding states was the USSR, which at that time was a state that won victory over fascism. Russia was part of the USSR at that time. However, over time, this state has clearly turned into an aggressor state, which definitely does not correspond to the high status of a member of the UN. At the same time, the UN itself, considering the right of veto, cannot do anything.

In this case, there are only 2 ways to get out of this “closed circle”: either to disband the UN and create a new organization that will still be able to effectively contribute to the maintenance of peace and security in the world.

In addition, solving the problem of periodic verification (auditing) of the activities of international organizations for their effectiveness and creating transparent mechanisms for combating the unproductive work of international organizations is extremely important today. In our opinion, it would be optimal to create a special analytical bureau that would assess the effectiveness of the work of international organizations and issue annual analytical reports on their activities with proposals for eliminating gaps in their work and measures to improve their effectiveness.

References

1. Draft Articles on the Responsibility of International Organisations, Annex to GA Res. 66/100, 9 December 2011. https://legal.un.org/ilc/texts/instruments/english/draft_articles/9_11_2011.pdf [in English]
2. United Nations Charter (1945). https://www.un.org/en/about-us/un-charter/full-text [in English]
3. During the annexation of Crimea, the UN lost the opportunity to play the role for which it was created (2020). https://www.radiosvoboda.org/a/news-oon-aneksia-krymu/30839882.html [in Ukrainian]

4. MPIL Research Paper Series No. 2016-01. https://ssrn.com/abstract=2770606 [in English]
5. UN GA Res. 66/253, "The situation in the Syrian Arab Republic B," of 3 August 2012. https://documents-dds-ny.un.org/doc/UNDOC/GEN/N11/474/00/PDF/N1147400.pdf?OpenElement [in English]
6. Statement of the Ministry of Foreign Affairs of Ukraine regarding the illegitimacy of the Russian Federation's presence in the UN Security Council and the United Nations as a whole from December 26, 2022. https://mfa.gov.ua/news/zayava-mzs-ukrayini-shchodo-nelegitimnosti-perebuvannya-rosijskoyi-federaciyi-v-radi-bezpeki-oon-ta-organizaciyi-obyednanih-nacij-u-cilomu [in Ukrainian]
7. A More Secure World: Our Shared Responsibility: Report of the High-level Panel on Threats, Challenges and Change, 2 December 2004. UN Doc. A759/565. https://www.un.org/peacebuilding/content/more-secure-world-our-shared-responsibility-%E2%80%93-report-high-level-panel-threats-challenges-and [in English]
8. In larger freedom: towards development, security and human rights for all: Report of the Secretary-General, 21 March 2005. UN Doc. A/59/2005/. https://digitallibrary.un.org/record/550204 [in English]
9. United Nations, SG Letter, "Report of the Panel on United Nations Peace Operations": UN Doc. A/55/305-S/2000/809. https://peacekeeping.un.org/sites/default/files/a_55_305_e_brahimi_report.pdf [in English]
10. Secretary-General Letter, "A comprehensive strategy to eliminate future sexual exploitation and abuse in United Nations peacekeeping operations": UN Doc. A/59/710. https://documents-dds-ny.un.org/doc/UNDOC/GEN/N05/247/90/PDF/N0524790.pdf?OpenElement [in English]
11. Petersmann, E.-U.: Addressing institutional challenges to the WTO in the new millennium: a longer-term perspective. J. Int. Econ. Law **8**(3), 647–665 (2005). https://doi.org/10.1093/jiel/jgi040
12. Sutherland, P., et al.: The Future of the WTO: Addressing Institutional Challenges in the New Millennium. World Trade Organization, Geneva (2004). https://www.wto.org/english/thewto_e/10anniv_e/future_wto_e.pdf [in English]
13. Slobodchikoff, M.O.: How effective are international organizations at resolving territorial disputes among member states: a look at the European Union. Stud. Chang. Soc.: Compar. Interdiscip. Focus **1**(2) (2012). https://www.researchgate.net/publication/259972398_How_Effective_are_International_Organizations_at_Resolving_Territorial_Disputes_among_Member_States_A_Look_at_the_European_Union [in English]
14. Russia's wars over the past 30 years. https://ukrainer.net/viyny-rosii/ [in Ukrainian]
15. Lall, R.: "Beyond Institutional Design: Explaining the Performance of International Organizations" International Organization, vol. 71, no. 2. Spring 2017, pp. 245–280 (2017). https://doi.org/10.1017/S0020818317000066. https://www.cambridge.org/core/journals/international-organization/article/abs/beyond-institutional-design-explaining-the-performance-of-international-organizations/EA20B0FA16A6AC9AABAFC4E27DCC605B
16. Wartime Diplomacy. What do Ukrainians think about Ukraine's movement towards EU and NATO membership during the war (2023). http://neweurope.org.ua/wp-content/uploads/2023/01/Eurointegration_wartime_ukr.pdf [in Ukrainian]
17. Panke, D., Polat, G., Hohlstein, F.: Who performs better? A comparative analysis of problem-solving effectiveness and legitimacy attributions to international organizations. Cooper. Conflict. **57**(4), 433–456 (2022). https://doi.org/10.1177/00108367211036916
18. Plantey, A.: International Negotiation in the Twenty-First Century. Routledge, New York (2007). [in English]

19. Fawcett, L., Hurrell, A. (eds.): Regionalism in World Politics: Regional Organization and International Order. Oxford University Press, Oxford; New York (1995). [in English]
20. Vinokurov, E., Libman, A.: Re-evaluating Regional Organizations: Behind the Smokescreen of Official Mandates. Palgrave Macmillan, Houndmills (2017). [in English]
21. Williams, S.: International Humanitarian Law: A Handbook for Commonwealth Parliamentarians, p. 313. University of New South Wales, Australia (2022). [in English]

Building Resilience of the Ukrainian Educational System Through International Legal Protection Mechanisms

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Abstract. This research highlights the detrimental effects of the Russian Federation's aggressive actions on the Ukrainian education system, which not only threaten the stability of Ukraine's educational landscape but also the broader European educational realm. Such aggressions have pronounced and lasting repercussions on pedagogy, educational infrastructure, and the overall well-being of the academic community. To address these challenges, the study recommends: (1) immediate cessation of Russia's attacks on Ukraine's educational structures, ensuring continuation of Ukrainian-led education in occupied regions; (2) enhanced monitoring and documentation of these aggressions by law enforcement, national authorities, and international entities; (3) prioritizing the creation of an evidence base through comprehensive, independent expert evaluations, fostering collaborations with global forensic experts and European forensic networks; and (4) directing cases of these armed assaults to the national justice system, which can subsequently be the foundation for international legal appeals, potentially invoking the Rome Statute's provisions concerning deliberate attacks on educational facilities. Ultimately, the study underscores the imperative of international collaboration in fortifying Ukrainian educational institutions, safeguarding the rights to education, and championing the cause of educators and students in these challenging times.

Keywords: public administration · resilience · crisis situation · justice

1 Introduction

Literature Review. As of the end of 2021, Ukraine's national resilience was characterized and described as a delicate mosaic with various gaps and sociopsychological and socio-political weaknesses, strengths, and other peculiarities [1]. The launch of the invasion of Ukraine provoked the most severe military conflict in Europe since 1945 [2, p. 1–8].

The military intervention of the Russian Federation in Ukraine became the reaction catalyst for the operational organization of various aid in European countries [3,

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p. 107–121]. The Ukrainian case showed that recovering resilience is complicated and implemented due to international and national stakeholders. One of the dangerous manifestations of the Russian invasion is the threat to the resilience of the Ukrainian educational and scientific space. The problem that needs an immediate solution is preserving the Ukrainian identity and ensuring the resilience of the academic and research process across Ukraine, including the occupied and de-occupied territories.

According to the Hague Convention, "the territory is considered occupied when it is placed under the authority of the hostile army" [4]. The territories of Donetsk, Zaporizhzhia, Luhansk, and Kherson regions of Ukraine are occupied and partially under the temporary military control of the Russian Federation. The Russian Federation's decisions dated 21.02.2022 and 29.09.2022 regarding the holding of referenda, the assignment of legal status to these regions of Ukraine, and their accession to the Russian Federation are illegal.

The occupation regime requires the aggressor country to ensure a safe educational environment and respect the rights to Ukrainian education for interned persons. In the international legal dimension, the conditions for providing educational services in the occupied territories, requirements for the occupying power to ensure favorable educational conditions, and crimes committed against educational institutions are regulated.

The Fourth Geneva Convention states that the Protection of Civilian Persons in Time of War is the first act that defines the obligation of the occupying state to cooperate with state and local authorities and to promote the proper functioning of educational institutions responsible for the care of children and their education [5]. Article 50 has two vital facts from the qualification viewpoint: 1) the age of the children under protection; 2) the status of educational institutions to which this norm applies. According to the Commentary of 1958 on Article 50 [6, Art. 50]. Children are minors under the age of fifteen, which is a reasonable upper age limit and can therefore be considered a criterion for determination. In addition, this norm also considers the peculiarities of development and the degree of physical and mental abilities of these children. This article's provisions can also be applied to young persons (minors) until adulthood. Thus, subjects of protection include exclusively children who have not reached the age of majority, particularly children of orphanages, preschool educational institutions, schoolchildren, first-year students at higher education institutions who have not reached the age of majority, etc.

Assistance in the proper functioning of educational institutions is an obligation of the occupying authority. According to the Article 50, we shall focus on determining the status of educational institutions providing educational activities in the occupied territories. A wide range of educational, social and medical institutions are considered specifically as children's institutions, for example, children's centres, orphanages, children's camps, and nurseries, medical and social care centres, social protection services, distribution centres, canteens etc.). It is important to highlight the fact that institutions of higher education are not included in this list, although according to the authors, in exceptional cases, they can acquire the status of entities that provide academic and research services to minors (various clubs for schoolchildren at universities, preparatory departments for applicants, first-year students, etc.).

In view of the above, we shall formulate the thesis that educational institutions whose activities are dedicated to the care and education of children enjoy the indisputable right to protection and guarantees for the continuation of the educational process, regardless of the arrival of the occupying authority from the position of the principle of autonomy of educational activity.

2 Main Content Presentation

During armed conflicts, education takes on a special form and importance and confirms its role in achieving peace and security. United Nations in Resolution 2601 dated 29.10.2021 calls on all countries to protect, respect and promote the right to education, including during the war conflicts. Underscoring the gravity of the issue, the United Nations is concerned about the increasing frequency of threats of military attacks on schools and school personnel, including children and teachers, the use of schools for military purposes, and the direct negative impact of military attacks on the safety of students and their ability to enjoy their right to education [7].

Additionally, research on military attacks on the education sector is carried out by the Global Coalition to Protect Education from Attack (after this – "GCPEA"). Since 2014, the organization has been collecting data and analyzing information about the military aggression's impact on Ukrainian educational institutions (New York: GCPEA, 2023) [8]. It should be noted that GCPEA's efforts have made an essential contribution to the issue of military compliance with the rules for ensuring the protection of educational institutions during an armed conflict. For example, according to the Guidelines for Protecting Schools and Universities from Military Use During Armed Conflict, parties to armed conflict are urged to refrain from using schools and universities for any purpose to support their military efforts [9]. While recognizing that particular uses are not inconsistent with the law of armed conflict, all parties shall strive to avoid interfering with the safety and education of students. The guideline identifies six guidelines for the military that serve as safeguards to ensure that they do not interfere with education.

The Ministry of Education and Science of Ukraine continues collecting facts and evidence of the Russian army attacks on educational institutions. According to official statistics, 3327 educational institutions suffered from bombings and shelling. Two hundred sixty-five ones were destroyed [10]. The Ministry of Education and Science assisted in designing the unique website providing information about destroyed educational institutions in the regions of Ukraine. This information is constantly updated.

Educational institutions in the East of Ukraine were the most affected, namely Donetsk (746 educational facilities were damaged), Kharkiv (578 educational facilities were damaged), and Zaporizhzhia regions (202 educational facilities were damaged).

The facts of the deliberate attacks on the educational infrastructure are apparent. On the positive side, it can be noted the initiative of the European Union and the creation of a website for collecting evidence of war crimes against educational institutions within the framework of the "EU Pravo-Justice" project in cooperation with the Office of the Prosecutor General of Ukraine [11].

Law enforcement agencies record facts and collect evidence, and a complete and comprehensive investigation of facilities affected by war crimes and forensic report provisions is carried out by forensic authorities. In this aspect, it is vital to form expert

commissions to conduct joint forensic examinations with the involvement of leading foreign experts from other countries. Given the seriousness of the cases and facilities under investigation, the experience of foreign colleagues will make the expert study more thorough and emphasise its international level. The mechanism for engaging in joint expert activities is not clearly defined in Ukrainian legislation, but that possibility is guaranteed, and using this tool can help solve crimes committed by the Russian Federation. A potential avenue for fostering collaboration in this domain could be developing a collaborative document with the European Network of Forensic Science Institutes. This document would outline the terms of cooperation and assistance in conducting forensic examinations of crimes committed by the Russian Federation in Ukraine.

As reported in the second Ukraine Rapid Damage and Needs Assessment, which spans from 24 February 2022 to 24 February 2023 (after this – RDNA2), a collaborative effort by the World Bank Group, the Government of Ukraine, the European Union services, and the United Nations, in coordination with humanitarian partners, academia, civil society organizations, and the private sector states that 2,772 educational institutions (not less) have suffered partial damage while 454 have been destroyed [12]. In terms of Ukraine's educational infrastructure, this represents 10 percent of all educational institutions across all levels. The extent of damage to educational institutions in Eastern Ukraine is estimated at 64%, and overall, the education sector in Ukraine has incurred losses amounting to at least 0.8 billion US dollars.

In addition to the data above, Ukraine's educational infrastructure has been subjected to military ecocide. The detonation at the Kakhovskaya Hydroelectric Power Plant, orchestrated by Russian forces, resulted in an ecological disaster severely impacting Ukraine's ecosystem and educational facilities. Official reports indicate that flooding affected 80 settlements, presenting a significant hurdle for the education sector. According to the Ministry of Education and Science of Ukraine, the flood zone encompassed 27 preschools, 15 schools, 6 vocational and technical institutions, 15 higher education establishments, and two research institutions affiliated with the National Academy of Sciences of Ukraine.

It can be stated that the main facts of hindering educational activities on the territory of Ukraine include military operations, occupation of the territories of Ukraine, military ecocide (for example, the explosion of the Kakhovskaya HPP). In such circumstances, the educational activity is either completely suspended or continued as far as the organization of the educational process is possible.

Targeted facilities of military attacks were and are educational institutions, in particular, kindergartens, schools, and universities. The Rome Statute of the International Criminal Court emphasizes that severe violations of laws and customs in armed conflicts include acts of deliberately targeting buildings intended for education and other activities, provided that they are not military objectives and are recognized as a war crime as in international, as well as in non-international armed conflicts (Rome Statute of the International Criminal Court, 1998) [13].

In general, all facilities are considered civilian. However, they may acquire the status of military targets under certain circumstances. If there is any doubt about whether a civilian object is used for military purposes, it should be presumed to be civilian.

Therefore, if it is impossible to establish a military threat from the attacking party, this confirms that the object does not have the status of a military target.

In its 2018 Report on Preliminary Examination Activities, the International Criminal Court (ICC) focused on analyzing the conflict in Eastern Ukraine, specifically examining the actions of the occupying power as potential war crimes. This included a violation of Article 8(2)(b)(iv) of the Rome Statute. The ICC conducted a detailed analysis of information related to several specific shelling incidents to determine whether any conduct in these incidents could constitute the war crime of intentionally targeting protected facilities, such as medical and educational facilities, under Article 8(2)(b)(ix) [14].

In order to qualify the actions of the Russian army as a war crime under Article 8 (2)(b)(ix) of the Rome Statute and further review by the International Criminal Court, it is necessary to collect a sufficient amount of comprehensive evidence, prove the presence of signs of a crime and take into account the results of expert research, etc. The main characteristics of a war crime under Article 8 (2)(b)(ix) of the Rome Statute include the following features of the composition of this crime: 1) the attack of educational infrastructure; 2) educational institutions, scientific institutions, other subjects designated for the purposes of education, science, if they were not military objects, became the target of the attack; 3) proving the fact of a deliberate attack on the educational infrastructure; 4) attacks occurred during an armed conflict; 5) persons who carried out an armed attack on these objects were aware of the consequences of their actions [Ibid].

Following Article 618 of the Law of Ukraine "On Amendments to the Criminal Procedure Code of Ukraine and Other Legislative Acts of Ukraine on Cooperation with the International Criminal Court", two bodies are involved in organizing cooperation with the International Criminal Court: the Prosecutor General's Office and the Ministry of Justice of Ukraine. The Office of the Prosecutor General of Ukraine provides the investigation and trial process. It is important to emphasize that it is within the competence of the Ministry of Justice of Ukraine that the entire process of execution of sentences or other decisions of the International Criminal Court belongs.

The process of execution of sentences consists of a set of measures, which, in particular, include: 1) preparation and notification of representatives of the International Criminal Court on the readiness to accept convicted persons to serve a sentence in the form of imprisonment. In addition, the responsible persons of the Ministry of Justice of Ukraine agree with the International Criminal Court on the conditions for the admission of convicted persons; 2) after the verdict of the International Criminal Court, the issue of reception and transfer of persons to serve a sentence is resolved; 3) preparation of a translation of a set of documents received from the International Criminal Court, if they are not drawn up in the state language, etc.

Thus, one of the most important areas of work in the field of justice is to bring the Russian Federation to international legal responsibility for armed aggression, human rights violations and violations of other norms of international law. The existing international legal mechanisms can only partially give a legal assessment of Russia's actions, especially in the context of the extremely limited jurisdiction of international judicial institutions. However, the scale of war crimes and Ukraine's achievements in international negotiations may contribute to the creation of new institutions, for example, the

creation of a special international tribunal that will be able to ensure the principle of inevitability of punishment.

Understanding that the protection of the rights of Ukrainian students to education and security guarantees of higher education institutions to continue providing educational services under Ukrainian training programs is a legitimate demand. However, it is challenging to do this in the conditions of occupation and constant armed attacks. The Ministry of Education and Science of Ukraine provides support to educational institutions under occupation through several measures: distance learning, assistance in the relocation of educational institutions from the occupied territories, a simplified procedure for admission to higher education institutions, etc. The international community and the Ukrainian government are trying to jointly implement urgent support tools through financial, technical, and organizational means to ensure a safe educational environment.

An essential problem in academic and research activity, which remains acute in Ukraine, is discrimination for studying in Ukrainian training programs. Convention against Discrimination in Education dated 14 December 1960 prohibits differences, exclusions, restrictions, or preferences based on race, color, sex, language, religion, political or other beliefs, national or social origin, economic status or birth, and other violations of equality in education [15, Art. 1].

Since 2014, the Russian occupation authorities in the territories of Donetsk and Luhansk regions have discriminated against educators, pupils, students and other persons involved in education for continuing to study under Ukrainian programmes. These facts were recorded by representatives of the Right that Education Initiative that the occupation authorities used education to educate children in certain military, ideological and patriotic views. The Global Coalition for the Protection of Education under Attack (GCPEA) defines "attack on education" as any threat or actual use of force against students, faculty, academics, support staff, and attacks on educational buildings, resources, materials or facilities [16].

Numerous facts testify to the criminal actions of the Russian Federation, which openly creates dangerous conditions for education, implements Russian educational programs, and supports the so-called educational collaborators in the occupied territories of Ukraine.

In 2022, the Federal Law No. 19-FZ dated 17.02.2023 on the integration of education and research systems of Donetsk, Luhansk, Kherson and Zaporizhzhia regions into the legal system of Russia was signed. This law establishes rules that ensure compliance with educational and qualification levels, academic degrees and titles, compliance with the rights of students, and bringing the activities of educational organizations and research institutions in these territories in line with the legislation of the Russian Federation. In addition, the regulatory document establishes the peculiarities of organizing state final certification and admission to study, recognition of educational qualification levels and academic degrees, and also establishes the obligation of all educational institutions to carry out the educational process and research activities under the educational programs obtained in the Ukrainian territories before their accession to the Russian Federation [17].

Given the international legal regulation of the aggressor country's activities in the occupied territory during the war, it can be noted that the occupation regime fails to provide any legal grounds for the application of the occupying country's legal acts.

It is also an obvious fact that the withdrawal of the Russian Federation from the European Convention on Human Rights in 2022 does not terminate the international obligations assumed by the country in relation to violations that have occurred before that moment. The official commentary to Protocol 1 of the European Convention on Human Rights states that no one shall be denied the right to education. In carrying out its functions in the field of education and training, the state shall respect the right of parents to provide such education and training in accordance with their religious and philosophical convictions [18].

The content of Article 2 of Protocol No. 1 [18, Art. 2] does not contain a provision on the language of education. However, the case law clarifies that the right to education shall be provided in the mother tongue, as in the case of Catan and Others v. Moldova and Russia. In this case, the right to education was violated due to the forced closure of educational institutions (schools) as a result of the illegal language policy of the separatist authorities, as well as persecution of individuals for their language after the reopening of these schools. The Grand Chamber of the European Court of Human Rights emphasised the fundamental importance of education for the personal development and future success of a child and recalled the right to receive education in the mother tongue [19].

The Federal Law [17] directly obliges the occupied educational institutions to carry out educational activities in accordance with the laws of the Russian Federation "On Education in the Russian Federation", "On Science and State Scientific and Technical Policy", etc. The provisions of these laws stipulate that the educational process in educational institutions shall be carried out in Russian [20], which contradicts the letter and spirit of the European Convention on Human Rights in relation to Ukrainian educational institutions temporarily under occupation.

The provisions of Article 2 of Protocol No. 1 can also be commented on from the point of view of the existence of restrictions on the right to education, although this provision does not directly provide for any explicit restriction. According to the position of the Grand Chamber of the European Court of Human Rights, if such restrictions exist, they must not violate the essence of the right to education and deprive it of its effectiveness. Any restrictions are legal if they are provided for by law and pursue "legitimate aims" [18].

Students in Ukraine are unable to exercise their right to education in full. It is clear that many factors and restrictions have affected this right. Taking all factors into account, Ukrainian students are divided into four groups: 1) students on the territory of Ukraine, where there are no intense hostilities; 2) students on the territory of Ukraine, where there are hostilities; 3) students who moved to the territory of foreign countries; 4) students on the temporarily occupied territories [21].

Based on the analysis of the illegal activities of the occupation authorities, the authors identify the main instruments of the Russian Federation's obstruction of educational and scientific activities in Ukraine as follows:

War crimes against the educational infrastructure of Ukraine (violation of Article 8(2)(b)(iv) of the Rome Statute).

Adoption of regulations on integration into the Russian educational system through the introduction of Russian educational standards and programmes.

Removal from educational and research activities of Ukrainian employees of educational institutions and their replacement by representatives of the occupation authorities.

Changes in educational programmes, propaganda, imposition of "military education" subjects and distortion of historical facts that deny Ukrainian identity.

The process of restoring the resilience of the Ukrainian academic and research system is currently taking place in a military environment. It should be noted that the situation in Ukraine's academic and research sector is unlikely to return to the pre-war status quo, and thus will change the general approaches to ensuring resilience in the European research and education space, and bring a new approach to restoring resilience.

Measures to restore the resilience of educational institutions should include a set of different tools ranging from financial support, the creation of relevant coordinating state centres, support provided to internally displaced persons, employees of educational institutions, to recording and collecting evidence of crimes committed by the Russian Federation against the educational system of Ukraine.

3 Conclusions

This study demonstrates that the aggression of the Russian Federation against the Ukrainian education system exists and has negative consequences for the safe functioning of both the Ukrainian and European educational space. These attacks have an acute and lasting impact on teaching and learning, educational infrastructure, and the emotional state of the academic community. We strongly believe that restoring the resilience of Ukraine's educational institutions through international legal protection mechanisms shall be applied promptly and with the following guidelines in mind.

First, the Russian Federation must immediately stop its illegal attacks on Ukraine's educational infrastructure and ensure that the educational process continues under Ukrainian training programmes in the occupied territories of Ukraine.

Second, representatives of law enforcement agencies, Ukrainian state authorities and foreign stakeholders shall try to strengthen monitoring and reporting on each fact of armed aggression against educational infrastructure (including information on the type of educational institution, type of attack, person responsible for the attack, etc.)

Third, the formation of an evidence base is an essential element for a successful trial. Conducting independent and complete expert studies with the support of expert institutions in Ukraine and the European expert community will enable attestation of the facts of illegal attacks on the educational infrastructure of Ukraine (conducting various types of forensic examinations). We consider it an urgent task to work out a mechanism for engaging leading forensic experts from other countries with representatives of the European Network of Forensic Science Institutes and to develop a document on cooperation and assistance in conducting forensic examinations in cases of crimes committed by the Russian Federation in Ukraine.

Fourth, court proceedings in cases of armed attacks on educational infrastructure shall be systematically referred to the national justice system. The results of the trial shall be the basis for applying to international bodies for the protection and restoration of rights. In order to protect and restore its rights, Ukraine may in the future rely on the consideration of a case in the International Criminal Court for war crimes, which is qualified under Article 8(2)(b)(iv) of the Rome Statute for deliberate attacks against buildings intended for educational or scientific purposes, provided that they are not military objectives.

The authors believe that overcoming the obstacles faced by universities, addressing the impact on students and faculty, and implementing measures to protect and promote the right to education are essential to ensure the continuity and development of higher education in Ukraine. By adhering to this principle and mobilising international support, the international community can make a significant contribution to building resilient Ukrainian universities and empowering students and faculty in difficult times.

References

1. Teperik, et al.: "Resilient Ukraine – a Delicate Mosaic? Society, Media, Security, and Future Prospects"
2. Kurapov, et al.: "Toward an Understanding of the Russian-Ukrainian War Impact on University Students and Personnel," pp. 1–8
3. Abuseridze, et al.: "Migration From Georgia and Ukraine in the Context of Russian Aggression," pp. 107–121 (2023)
4. Convention (IV) respecting the Laws and Customs of War on Land 1907 Regulations concerning the Laws and Customs of War on Land., art. 42
5. Geneva Convention, "Convention (IV) relative to the Protection of Civilian Persons in Time of War" (Geneva, August 12, 1949)
6. Geneva Convention, "Convention (IV) relative to the Protection of Civilian Persons in Time of War" (Geneva, August 12, 1949), Commentary of 1958, Article 50
7. United Nations Security Council, "Resolution 2601 (2021)," adopted at the 8889th meeting, October 29 (2021)
8. GCPEA, "Attacks on Education and Military Use of Education Facilities in Ukraine in 2022" (New York: GCPEA, 2023)
9. Guidelines for Protecting Schools and Universities from Military Use during Armed Conflict (New York: GCPEA, 2014)
10. Save Schools, "About the Project," Accessed October 26 2023 https://saveschools.in.ua/about-the-project/en
11. Office of the Prosecutor General of Ukraine, "Documenting War Crimes and Crimes Against Humanity Committed by the Russian Military in Ukraine," Accessed Oct 26 2023. https://warcrimes.gov.ua/en
12. Ukraine Rapid Damage and Needs Assessment: February 2022 - February 2023 (English). (2023) Washington, DC: World Bank Group. http://documents.worldbank.org/curated/en/099184503212328877/P1801740d1177f03c0ab180057556615497 Accessed 19 May 2023
13. Rome Statute of the International Criminal Court, adopted July 17, 1998, entered into force July 1, 2002, art. 8. https://www.icc-cpi.int/sites/default/files/RS-Eng.pdf
14. International Criminal Court, Office of the Prosecutor. Report on Preliminary Examination Activities, 2018, Published December 5 (2018)

15. UN Educational, Scientific and Cultural Organisation (UNESCO), Convention Against Discrimination in Education, 14 December 1960, available at: https://www.refworld.org/docid/3ae6b3880.html Accessed 26 Oct 2023
16. Right to Education Initiative, "Caught in the Crossfire," July 20, 2020, https://right-to-education.exposure.co/ukraine
17. Об особенностях правового регулирования отношений в сферах образования и науки в связи с принятием в Российскую Федерацию Донецкой Народной Республики, Луганской Народной Республики, Запорожской области, Херсонской области и образованием в составе Российской Федерации новых субъектов - Донецкой Народной Республики, Луганской Народной Республики, Запорожской области, Херсонской области и о внесении изменений в отдельные законодательные акты Российской Федерации [Legal Specifics for Education and Science Following the Integration of the Donetsk People's Republic, Luhansk People's Republic, Zaporizhzhia Region, and Kherson Region into the Russian Federation, and the Establishment of These New Territories within the Russian Federation, along with Relevant Amendments to Certain Russian Federation Legislative Acts], Federal Law No. 19-FZ of February 17 (2023). http://publication.pravo.gov.ru/Document/View/0001202302170006?index=12
18. European Court of Human Rights. "Guide on Article 2 of Protocol No. 1 to the European Convention of Human Rights. Right to Education." 31 August 2022. https://www.echr.coe.int/documents/d/echr/guide_art_2_protocol_1_eng
19. European Court of Human Rights. "Affaire Catan et autres c. Moldova and RUSSIA." October 19, 2012.
20. "Об образовании в Российской Федерации [On the Education in the Russian Federation]." Federal Law No. 273-FZ of December 29 2012. https://www.consultant.ru/document/cons_doc_LAW_140174/bf7fadb3532c712ccd28cc2599243fb8018ed869/
21. Potapova, et al.: "Аналітичний огляд «ШІСТЬ+» Серйозних порушень проти дітей: виклики та наслідки 9 місяців російсько-української війни 2022 [Analytical Review "Six+" Serious Violations Against Children: Challenges and Consequences of the 9 Months-Long Russian-Ukrainian War 2022]." (2022). https://almenda.org/wp-content/uploads/2022/12/6-plus-seryoznykh-porushen-proty-ditey-9-misyatsiv_Almenda.pdf

The Kremlin's Secret Weapon: How Russian Private Military Companies Are Expanding Moscow's Influence Abroad

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Abstract. Over the previous decade, Russian private military companies (PMCs) have emerged as instruments of warfare and propaganda. This matter has garnered substantial attention, particularly following Russia's annexation of Ukraine, although it had already been a topic of interest among academics, experts, and the media before that. This article delves into the correlation between the Russian government and private military companies within the framework of their escalating deployment as instruments of warfare and propaganda. The authors undertake a case study examining the actions of Russian PMCs and put forth a coordinated international agenda aimed at fortifying national autonomy, tranquility, and steadiness. The study underscores the imperative for international cooperation in tackling the perils and predicaments associated with the utilization of PMCs in contemporary warfare and political manipulation. The findings indicate that the Russian state is increasingly reliant on PMCs as instruments of warfare and propaganda, especially in its endeavors in Ukraine and Syria. The authors assert that the utilization of PMCs has the potential to erode national sovereignty and stability and advocate for international measures to alleviate these risks. In essence, the paper provides valuable insights into the mounting influence of Private Military Companies on global security and international relations. This information is of considerable worth to policymakers, scholars, and other stakeholders seeking to grasp and respond to the evolving role of PMCs in the contemporary world.

Keywords: Russian private military companies · impact of sanctions · Kremlin influence abroad

1 Introduction

In the contemporary globalized world, Russian private military companies are being increasingly employed by the Russian government as a means to extend its military, political, and economic influence worldwide. Following a strategy devised by Russia,

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these companies offer military services to their clients, which include governments and non-state actors. Over the last decade, Russian private military companies have effectively accomplished the objectives set by the Russian government, both inside EU member countries and throughout the world [1].

The use of mercenaries as a foreign policy tool by Moscow has a long and complex history that dates back to the imperial era of Russia. Since then, Russian leaders have relied on the use of mercenary forces to pursue their strategic interests in various conflicts. This practice has continued in modern times, with private military companies being employed by the Russian government in conflicts such as the Syrian civil war and the Ukrainian conflict. During the Napoleonic wars, Cossack brigades were extensively deployed by Imperial Russia to advance Russian interests and suppress peasant uprisings. Later, Tsar Aleksandr II employed mercenaries to balance pan-Slavic fervor against the imperial policy of non-intervention in the Balkan-Ottoman conflict of the 1870s [2]. This approach helped the Russian government to pursue its interests without direct involvement, thereby avoiding potential international backlash. In the late 1930s, Soviet leader Joseph Stalin similarly used mercenary forces to advance the interests of the Republican faction during the Spanish Civil War [3]. This allowed the Soviet Union to support its ideological allies without committing significant resources or risking direct involvement. Since the Soviet Union dissolved, Cossacks have been hired as mercenaries in multiple combat operations. Notably, they have been involved in conflicts such as Chechnya and Transdniestria, as well as the former Yugoslavia [4].

In modern times, the Russian government has continued to use private military companies as a means of pursuing its strategic objectives. In conflicts such as the Syrian civil war and the Ukrainian conflict, these companies have played a significant role in providing military support to the Russian-backed factions. The use of mercenaries in these conflicts has allowed the Russian government to pursue its interests without risking direct involvement or facing international condemnation. The historical context of the use of mercenaries by Moscow sheds light on the enduring appeal of this approach as a foreign policy instrument. By relying on private military companies and other non-state actors, the Russian government can pursue its interests in a way that is less visible and less likely to provoke international backlash. Despite the risks and limitations associated with this approach, it remains a valuable tool in the arsenal of Russian statecraft [5].

The deployment of military contractors by Russia in multiple global conflicts has generated apprehension regarding their engagement and impact. The authors contend that Russia's use of these entities provides certain benefits, as it enables Russia to uphold plausible deniability while simultaneously exercising significant influence over the conflict and its consequences. To support their assertion, the authors cite evidence from the Syrian war, wherein Russia maintained a limited military presence but was still able to intervene and safeguard the afflicted area, bolstering the regime of Bashar al-Assad. Russia's use of military contractors and companies in conflicts is not a new phenomenon, but it has gained more attention in recent years due to their involvement in various conflicts around the world. These organizations are commonly private military or security firms that offer military services to governments or other participants in a conflict. Although these entities may function autonomously from the government, they frequently maintain strong connections to the state and can be employed to advance its strategic goals.

The authors propose that Russia's utilization of military contractors and corporations is a component of a wider plan to exert power and influence without drawing direct international criticism or intervention. They contend that this strategy enables Russia to sustain plausible deniability and evade the expenses linked to a full-fledged military intervention, all while accomplishing its strategic aims.

Considering the aforementioned context, a legitimate question arises: what kind of impact do Russian military companies have on the sovereignty of civilian states as subjects of international law, as well as on their political and economic landscape?

The authors will examine specific instances in the following chapter that pertain to the political, legal, and economic realms in which nations have collaborated to establish a global mechanism that advances a durable political environment, security, and financial system, in order to respond to these and similar inquiries.

2 The Methodological Basis of the Research

The methodology is grounded in existing literature, books, scientific journals, and EU official legal documentation and publications. The research uses a range of scientific techniques to understand the relationship between private military companies and the Russian government such as the analytical method, comparative method, methods of interpreting legal norms, historical method, induction, and deduction methods. The authors of the study analyze specific examples and conduct a detailed investigation of the relevant legal frameworks to better understand the relationship between private military companies and the Russian government. By utilizing these various scientific methods, the study provides a nuanced and comprehensive understanding of the complex dynamics that shape the relationship between private military companies and the Russian government.

In this research, the analytical approach is employed to delve into the operations of Russian private military companies and their connection with the Russian government. The authors scrutinize the diverse range of services rendered by Russian PMCs, encompassing combat operations, training, and logistical support. Moreover, the authors assess the countries where Russian PMCs have been active and examine the repercussions of their actions on regional and international security. Through the application of the analytical method, the authors identify patterns and trends in the undertakings of Russian PMCs and their impact on global affairs. Legal norms are interpreted utilizing methodical approaches to analyze legal documents and regulations, thereby unraveling the implications for Russian PMCs. The historical method is employed to comprehend the evolution of Russian private military companies and their association with the government across time. The authors trace the progression of Russian PMCs from their inception during the Soviet era to their present role as a tool of Russian foreign policy. By examining historical documents and accounts, the authors ascertain pivotal events and decisions that have shaped the development of Russian PMCs. Induction and deduction methods are consistently utilized throughout the research process to guide the study and draw accurate conclusions. The methodology adopted in this research underscores the significance of rigorous scientific inquiry in this particular field of study. It offers a valuable contribution to the existing body of literature on Russian PMCs and their influence on global affairs. The findings of this study hold substantial implications for

policymakers and scholars seeking to comprehend the role of private military companies in shaping international politics and security.

3 The Influence of Russian Private Military Companies on the Military, Economic, and Political Landscape

The relationship between Russian private military companies and the Russian government is complex and varies depending on the goals and intended operations of each company. According to the authors' assessment, Russia utilizes these companies while taking into account its strategic interests. The current chapter focuses on the role of Russian private military companies and their level of influence, particularly in political, economic, and military contexts.

The authors believe that the first step is to examine the status of Russian private military companies within the Russian legal framework and military doctrine. This issue has been prominent in the Russian media since early 2018, with proposals for the legalization of private military companies appearing in the press. However, Putin's spokesperson, Peskov, has stated that the Kremlin has not taken a stance on the matter [6]. Despite their undeniable existence, Russian private military companies remain unregulated by Russian legislation. It is also noteworthy that the 2014 version of Russia's official military doctrine only mentions private military companies in the context of external threats [7]. Additionally, military experts Popov and Khamzatov describe private military companies primarily as a Western phenomenon in their work "On the Future War", without assigning them a particular role in Russia's security policy. Given these facts, the authors believe that the Russian government's stance on this issue is ambiguous, as they are hesitant to regulate private military companies at a legislative level [8]. According to the authors the reason for this hesitation is clear: legalizing private military companies would mean that Russia could no longer use them as a tool to expand its influence.

In the context of a conversation about military influence, the authors consider one of the most influential and well-known private military companies in Russia – the Wagner group. This group is recognized for its involvement in conflicts in Syria, Libya, and Ukraine, and for its particular brutality and cruelty. The group is associated with Russian businessman Yevgeny Prigozhin, who has close connections to Russian President Vladimir Putin. The group has been accused of committing war crimes and violating human rights in Ukraine, Libya, Syria, and the Central African Republic. Wagner's role in the annexation of Crimea in 2014 exposed the hidden agenda of the Russian government. Additionally, their use by the Kremlin in support of rebels in the Donbass region and in support of Assad in Syria is a clear indication of the implementation of Russian national interests. It is worth noting that the European Union imposed sanctions on the Wagner group in 2021 [9], and given the threats to international peace and security, the introduction of a new package of sanctions is being considered [10]. Washington has also prepared a package of sanctions that designates the Wagner group as a transnational criminal organization and accuses it of serious crimes committed in Ukraine [11]. The Russian government denies any association with the group, but political and academic circles no longer dispute that Wagner is a group of mercenaries fighting for Russia. Along with the "Wagnerites", the authors draw attention to the so-called Ramzan Kadyrov, a

Chechen group that is an ally of the Kremlin's aggressive policy and is at war together with the Russian army in Ukraine.

The authors suggest that the unity and consolidated approaches of sovereign states as subjects of international law are an effective mechanism for combating Russian private military companies. To support this point, the authors refer to the resolution passed by the Lithuanian Legislative Assembly, which recognizes the Russian military company Wagner as a terrorist organization. The resolution notes that Wagner fighters receive military equipment from the Russian government and undergo training at the Russian Ministry of Defense, which poses a threat to state and public security [12]. The authors argue that the unified and consolidated approaches of other EU member states and subjects of international law, like Lithuania, can reveal the hidden intentions of the Kremlin.

A systematic and fundamental analysis of the presented issue reveals that Russian private military companies have heterogeneous goals. Some are created by proxies who receive commercial assignments from their clients. The analysis also highlights that Russian private military companies, like any other national labor market, develop and transform depending not only on supply and demand, but also on the cultural, historical, political, and legal environment in which they exist [13]. Despite their differences, they share the common trait of being at the "mercy" of the Russian government, so they must often prove their worth to the government to continue to exist.

The authors argue that Russian private military companies are not solely engaged in military operations but also possess interests in alternative sectors, including energy resources. This enables Russia to augment its sway in specific regions and secure access to valuable natural resources. The authors observe that private military corporations frequently amalgamate their national and commercial interests. To counterbalance this, the authors exemplify Gazprom, a Russian corporation that exerts substantial influence on Russia's foreign policy, particularly within the energy sector. Despite lacking official recognition as a private military company, Gazprom significantly participates in the European energy market, with several European nations depending on Gazprom-controlled Russian natural gas supplies. Consequently, Russia possesses significant leverage in European energy markets, occasionally utilizing it as a political instrument. It is imperative to acknowledge the political and economic implications stemming from Gazprom's dominance over the European energy market, particularly amidst ongoing tensions between Russia and Western nations. The close affiliation between the company and the Russian government, coupled with potential military involvement, engenders concerns regarding the security and dependability of European energy provisions, as well as the potential for political manipulation. As previously alluded to, numerous European countries heavily rely on gas imports from Russia, which Gazprom has previously employed to assert influence and exert pressure on these nations [14]. In both 2006 and 2009, Gazprom suspended gas supplies to Ukraine due to pricing disputes, leading to shortages in multiple European countries. In addition to leveraging natural gas provisions, Gazprom has also forged various geopolitical agreements and partnerships with state energy corporations in nations such as China and Iran, thus enabling Russia to fortify its diplomatic and economic bonds with these states.

Based on the authors' perspective, Gazprom has played a pivotal role in furthering Russia's geopolitical goals in diverse areas such as Central Asia, the Middle East, and Europe. Gazprom has made notable investments in pipeline infrastructure within these regions, facilitating Russia's amplification of its sway in expanding the export of energy resources. Essentially, Gazprom has been utilized as a political tool to advance Russian interests in different areas. This highlights the valid anxieties of nations heavily dependent on Russian gas imports. Russia's command over natural gas provisions and its predominant position in the global energy market have granted it substantial leverage to mold foreign policies. The occurrences discussed demonstrate that Russia employs Gazprom to exert political and economic influence both internally and globally.

In the current setting, the writers also examine the operations of the RSB Organization, a Russian independent military firm that acts as a means to promote Russian national interests. The organization provides a variety of defense and safety solutions to customers worldwide, such as advisory services for security, training, and on-ground assistance to military and law enforcement agencies. Established in 2012, the RSB Organization has participated in multiple conflicts, notably the Syrian civil war, where it aided the Syrian government and played a crucial part in supporting pro-Russian separatists. The group employs highly skilled experts with extensive combat backgrounds, although, similar to other Russian private military firms, it operates with a cloak of secrecy. Despite asserting its legitimacy, the RSB Organization has faced accusations of involvement in illicit undertakings, including smuggling weapons and trafficking humans. Such claims highlight the potential hazards connected to private military firms and raise questions about the adequacy of international regulations governing their activities [15].

The authors argue that the Wagner group and other non-state armed entities lack the requisite resources and capabilities to partake in military operations on par with conventional military units, sans assistance from the Russian government. Consequently, the proposition that these enterprises function autonomously warrants scrutiny, given that they are likely equipped and backed by the Russian government. The prevailing theories surrounding private military companies as autonomous agents in conflicts are predicated on the assumption that they are contracted by states or other entities to execute specific tasks devoid of direct governmental involvement. Nevertheless, the authors posit that this perspective may be simplistic, as private military companies are frequently intertwined with governmental interests and can function as extensions of state authority.

4 The Impact of Sanctions on Russian Private Military Companies and the Kremlin's Foreign Policy

Since 2014, the Eastern part of Ukraine has been ensnared in a relentless surge of armed militants espousing separatist ideologies. Their illicit actions have precipitated a comprehensive crisis that permeates virtually all aspects of societal existence. Consequently, ordinary Ukrainian citizens have become hostages to this armed conflict, finding themselves compelled to abandon their homes and seek refuge not only in other Ukrainian cities but also in foreign lands [16]. Russia's international conduct and geopolitical maneuvers, particularly the invasion of Ukraine and the annexation of Crimea between

February and March 2014, have instigated a significant transformation in its global economic and political relationships. In response to Russia's aggression, the United States of America, the European Union, and their allies have implemented a series of sanctions [17]. However, the extensive array of sanctions can be traced back to the moment of the full-scale Russian invasion of Ukraine on February 24th, 2022 [18].

According to the authors, sanctions encompass punitive measures imposed on a state, government, or individuals with the aim of compelling them to modify their behavior or policies. Sanctions serve as a diplomatic instrument to constrain the actions of the targeted entities or individuals. Nonetheless, the sanctions have engendered a multitude of effects on the operations of private military companies. These punitive measures have curtailed the capacity of these enterprises to engage in financial transactions. For instance, the imposition of US sanctions on Evro Polis, a Russian private military company, has adversely impacted its financial stability and operational effectiveness in Syria. This restriction has posed challenges to the companies' ability to operate efficiently in regions where their presence is necessary, thereby directly influencing Russia's foreign policy. International organizations, such as the United Nations, have also played a significant role in documenting the misconduct perpetrated by Wagner and other private military companies, and it is imperative to sustain these efforts [19]. Moreover, the imposition of sanctions has reverberated throughout the recruitment procedures employed by private military enterprises in Russia. These entities typically recruit retired military personnel, specialized forces, and adept individuals within the relevant field. However, the presence of sanctions has instilled hesitancy among these experts due to apprehensions of becoming targets of the imposed restrictions. Consequently, there has been a scarcity of skilled personnel within these organizations, directly impeding their ability to operate efficiently in foreign nations. This scarcity of personnel has also exerted an influence on Russia's foreign policy, given the pivotal role these companies play in safeguarding the nation's interests abroad. Furthermore, the sanctions have constrained these companies' capacity to acquire advanced weaponry and military equipment. This predicament has placed them at a disadvantage in competing with other private military firms in the market, particularly those originating from Western countries. As a result, there has been a decline in the number of contracts awarded to these companies, leading to direct ramifications for their financial stability. Additionally, the lack of sophisticated equipment has hampered their operational effectiveness in foreign nations, thereby influencing Russia's foreign policy. Finally, the sanctions have cast doubt upon the reputation of these companies. A considerable portion of these enterprises maintains affiliations with the Russian government, which has faced multiple instances of sanctions. These connections have sullied the reputation of these corporations, rendering it arduous for them to secure contracts in foreign territories. The adverse publicity surrounding these entities has further impeded their recruitment endeavors, directly compromising their efficacy in foreign nations.

The authors believe that the European Union's use of mixed sanctions against Russia can be considered a successful example of their implementation. The EU's response to Russia's aggression against Ukraine, which began in February 2022 and included the annexation of several Ukrainian regions, was to impose a series of unprecedented and extensive sanctions against Russia. These measures built upon previously implemented

sanctions from 2014, which were put in place after the annexation of Crimea and the lack of implementation of the Minsk agreements. The sanctions levied by the EU include targeted restrictive measures on individuals, economic sanctions, and visa restrictions, which have been highly effective in limiting Russia's activities. The comprehensive and multi-faceted nature of these sanctions serves as a model for other nations seeking to employ sanctions as a foreign policy tool [20].

However, the use of sanctions as a tool of foreign policy is a contentious issue in international relations. On the one hand, sanctions can be an effective means of pressuring states to change their behavior or comply with international norms. On the other hand, sanctions can have unintended consequences, including strengthening the hand of authoritarian regimes, creating new tensions and conflicts, and eroding human rights and civil liberties. According to the "punishment theory" proposed by Lektzian and Souva, sanctions impose economic harm on target states, which subsequently results in domestic political coercion and compliance with external demands [21]. Scholars have indeed shown that sanctions are more likely to succeed if they are more economically costly to the target state and have hypothesized that a certain level of deprivation induces citizens to challenge the current regime. However, this understanding has been questioned from a number of different perspectives. Public choice scholars have found that the targeting of specific groups – rather than the overall economic costs - accounts for the success of sanctions [22].

Research on autocratic regimes suggests that comprehensive penalties are generally more effective when imposed on democracies, while targeted penalties yield better results against authoritarian regimes [23]. In light of contemporary geopolitical challenges, and within the framework of the theory presented, it is intriguing to consider the compatibility of the sanctions imposed on Russia as an occupying country. The sanctions imposed on Russia have inadvertently provided opportunities for the country to strengthen its diplomatic relationships with other nations facing similar penalties, such as Iran and Venezuela. The Kremlin has actively sought alliances with countries opposed to the United States and Europe, including China. The bolstering of diplomatic ties between Russia, Iran, and Venezuela may result in the formation of a new axis of power that could challenge the dominance of the United States and its allies in global affairs. This development has significant implications for international relations, particularly in regions where the interests of these opposing factions clash. For instance, the formation of alliances based on opposition to the West could exacerbate conflicts in the Middle East, where Iran and Saudi Arabia are already engaged in a proxy war. Moreover, comprehensive penalties may inadvertently strengthen authoritarian rulers instead of undermining them, as they can exploit the external "threat" to garner domestic support (in the cases of Iran and Cuba, studied by Amuzegar [24] and Schreiber [25], respectively). However, the extent to which ruling elites can strategically capitalize on comprehensive sanctions depends on the interplay between these sanctions and other contextual factors, particularly the regime's claims to legitimacy.

Against the background of modern geopolitical challenges, the authors also focus on the issue of Russia-China relations. The ongoing war in Ukraine has brought the Russia-China relationship into sharp focus. China has adopted an ambiguous position on the conflict, expressing support for Ukraine's territorial integrity while also refusing

to join Western sanctions against Russia. Chinese private and state-owned companies have continued to trade with Russian companies that have been sanctioned by the West. According to Russian customs data, the volume of trade of dual-purpose products, which have both civilian and military uses, is much higher than the trade in directly military products. In 2022, Russian imports from China rose by 13% to $76 billion, and exports to China increased by 43% to $114 billion. The decrease in Russia's trade with EU countries has significantly affected the country's revenues since nearly half of the Russian government's annual revenues come from the sales of oil and gas to the EU, which have fallen dramatically due to sanctions [26]. The significance of Russia-China relations in the context of sanctions is twofold. Firstly, the partnership between the two countries allows Russia to reduce its dependence on the West and mitigate the impact of Western sanctions. Secondly, the partnership has enabled China to gain access to Russian military technology and expertise, which it can use to bolster its own military capabilities (In this context, the authors believe that, China's military is continuously expanding its knowledge base by studying the lessons learned from recent conflicts. In particular, China is closely examining the use of force, advanced technologies, and logistical constraints during war. Through this process, China is gaining insights into the performance and capabilities of both "Eastern" and "Western" equipment. This is made possible by the fact that Russia operates weapons systems similar to those in China's possession, while Ukraine utilizes advanced Western equipment. By comparing the performance of these systems in real-world situations, China can better understand the strengths and weaknesses of both "Eastern" and "Western" military technology. This knowledge will likely inform China's future military planning and procurement decisions, enabling it to maintain its position as a formidable military power). This partnership has implications for the balance of power in the region and could potentially challenge Western dominance. However, there are also risks associated with the Russia-China relationship. Firstly, the partnership is based on a shared opposition to the West rather than shared values or interests, which could lead to tensions in the future. Secondly, China's growing economic and military power could potentially challenge Russia's dominance in Central Asia. Finally, the partnership could lead to increased military cooperation between the two countries, which could destabilize the region and potentially lead to conflict. The role of Russian PMCs in expanding Moscow's influence abroad and the Russia-China relationship's implications for the balance of power in the region are critical topics that require close attention. As the world becomes increasingly multipolar, the dynamics of these relationships will continue to shape the international system's future. Therefore, it is essential to understand the complexities of these relationships and their potential consequences.

While sanctions have been imposed on Russia regarding the use of PMCs, the authors argue that a broader strategy is needed to address this issue. One potential strategy is to establish a precise extent of domestic legislation. This entails defining PMCs, outlining explicit authorized services, elucidating prohibited actions, examining the extent to which the law applies and strengthening the international legal framework. To solve these problems, the authors consider carrying out broad consultations with various stakeholders, at the level of international organizations (for example, the UN). Based on these consultations, the subjects of international law will be able to legislate what services

and activities can be provided by private military companies. This would legalize the scope of activities of private military companies and avoid deliberate tension or military conflict. On the basis of this document, adopted at the international level, states will be obliged to implement the presented norms at the domestic level, which will allow introducing the activities of private military companies into the legal field. The authors also consider it necessary to establish an organization responsible for overseeing private military companies (creating institutionalized control mechanisms). This organization will be unequivocally entrusted with regulating this industry. On one hand, it will ensure effective control over private military companies, and on the other hand, it will monitor the implementation of legislation at the national level.

In addition to legal frameworks, I is crucial to engage with affected communities, civil society groups, and other stakeholders through outreach and dialogue. This could involve collaborating with local organizations to raise awareness about the risks and impacts of Russian PMCs and supporting efforts to achieve justice and accountability for those affected. Regulations should create an interlocking legal system that would increase overall control of PMCs' conduct and strengthen accountability by clarifying the applicability of legal regulations and jurisdictions where abuses can be pursued [27].

Overall, a comprehensive approach that combines targeted sanctions, international legal frameworks, and public outreach can effectively address the threat posed by Russian PMCs. The authors determine that a coordinated strategy of global actors, including EU member states, the UK and the US, is needed, focusing on a wide range of diplomatic, intelligence, financial, military and other actions. With such approaches, Russia will face an obstacle, it will no longer be able to expand its influence and pursue an aggressive policy, including in relation to neighboring states.

5 Comparative Analysis of Russian and US Private Military Companies

In this comparative analysis, the authors contend that Private Military Companies in the United States and Russia exhibit pronounced disparities attributable to their respective historical, legal, and operational contexts. Through a comprehensive examination of these contexts, the authors believe that a nuanced understanding of these differences emerges, shedding light on the unique dynamics of each country's PMC industry.

The authors assert that a critical facet of this divergence lies in the legal status of PMCs. In the United States, it is observed that PMCs operate within a well-defined legal framework, and the authors believe that this regulatory environment imposes rigorous constraints on their activities. This, in turn, necessitates the acquisition of licenses and adherence to strict statutory requirements. In Russia, a distinct contrast is noted, where the legal status of PMCs remains ambiguous. Here, the authors believe that the Russian government's propensity to unofficially allow certain PMCs to function in limited capacities, particularly in regions aligned with Russian interests, creates an environment marked by plausible deniability, muddling the distinction between state affiliation and private enterprise. Russian reports on Wagner PMC come from sources not aligned with the state. One, Fontanka, a St Petersburg website, has mounted several high-profile investigations. In one of its earliest investigative reports, from late 2015, Fontanka traced

Wagner PMC's origins to an entity it named as the Slavonic Corps (Slavyansky Korpus) [28]. Several hundred Russian personnel were reportedly active in Syria in 2013. They were led by Vadim Gusev and Yevgeny Sidorov, two of the "Russian managers" of another PMC, Moran Security Group. In a report from early 2016, Fontanka set out further findings in relation to Wagner PMC's reported operations both in Ukraine and in Syria [29]. For example, the report described the origins of the name: "Wagner" as the callsign of camera-shy founder Dmitry Utkin, whom it described as a "Third Reich" sympathiser who had taken to wearing a Wehrmacht helmet on operations in Luhansk. Fontanka identified Utkin as a reserve Lt-Col who until 2013 had been commander of the 700th Separate Spetsnaz Detachment in Pechory, Pskov Region, part of the 2nd Separate Spetsnaz Brigade of the Main Intelligence Directorate [30].

Regarding oversight and control, the authors observe that the United States employs a multifaceted system of governmental scrutiny over PMCs. The authors believe that various agencies, such as the Department of State, Department of Defense, and Department of Commerce, wield regulatory authority commensurate with the nature of PMC operations. This multi-agency oversight, they contend, ensures a measure of transparency and accountability. Conversely, in Russia, the authors note that PMCs, exemplified by entities like the Wagner Group, enjoy conspicuous ties to the Russian military and intelligence apparatus. The authors believe that this integration into state interests, often leveraged for Russia's foreign policy objectives, fosters a climate where the boundaries between ostensibly private endeavors and state-driven objectives become increasingly blurred.

The international operations of PMCs represent another key point of divergence, as the authors observe. In the United States, they believe that PMCs have established a global presence, securing contracts from diverse clients, including governments, international organizations, and private corporations. Their multifaceted roles encompass security, logistics, training, and advisory functions in conflict zones and various geopolitical regions. In stark contrast, the authors observe that Russian PMCs, particularly the Wagner Group, have primarily been associated with operations in regions aligned with Russian strategic interests. This, they believe, often results in opaque operations that defy precise delineation of roles and affiliations, further serving Russia's foreign policy objectives.

Turning to the issue of public awareness and scrutiny, the authors acknowledge that US-based PMCs, such as Blackwater (now Academi), have garnered substantial media attention and public scrutiny. They contend that these dynamics have ignited spirited debates concerning the ethical and operational implications of deploying private military contractors in military and security contexts. In contrast, the authors note that Russian PMCs have maintained a more discreet profile, often evading extensive media coverage and public awareness. They observe that the Russian government, in many instances, disavows any official involvement in their operations, cultivating an environment characterized by secrecy and limited public knowledge.

Lastly, the authors emphasize organizational characteristics and operational scale as a distinguishing factor. They note that US PMCs tend to be substantial, well-established entities boasting a diverse repertoire of capabilities, encompassing logistics, intelligence, security, and training functions. In contrast, the authors observe that Russian PMCs typically exhibit a more compact and specialized profile, emphasizing security and combat-related roles.

In conclusion, the authors underscore the critical influence of historical, legal, and operational contexts in shaping the profiles of Russian and US PMCs. They contend that while US PMCs navigate within a well-regulated framework and maintain a global presence, Russian PMCs often exist in a nebulous realm, characterized by a closer alignment with state interests, a lower public profile, and a more limited operational scope. These distinctions, the authors assert, underscore the multifaceted landscape of private military contracting, marked by evolving dynamics and ongoing debates regarding their utility and implications, particularly in the context of Russia's use of PMCs for foreign policy objective.

6 Conclusions

According to the arguments presented in the article, Russian private military companies have become a critical component of Russia's foreign policy toolkit. The authors argue that the involvement of the "Wagnerites" in the annexation of Crimea in 2014 marked the first clear instance of the Kremlin's use of these PMCs to advance its foreign interests. Furthermore, the authors cite the Wagner Group's involvement in the conflict in the Donbass region and in support of the Assad regime in Syria as additional examples of how Russia leverages these PMCs to achieve its national objectives.

The authors also highlight the factor of denial and the profitability of these PMCs as key factors in their success. On the one hand, by using PMCs, Russia is able to expand its military, political, and economic influence in the world. On the other hand, by engaging in military actions in Ukraine and Crimea, as well as conducting operations to influence politics in other countries, Russia has demonstrated its willingness to openly violate international law and disregard generally recognized rules for achieving strategic goals.

The authors argue that Russian PMCs have become an essential tool in the Kremlin's foreign policy arsenal, allowing Russia to pursue its national interests while bypassing international norms and regulations. By exploring the history and current use of these PMCs, the authors shed light on the evolving landscape of modern warfare and the role that private actors play in shaping international politics.

The authors discuss the use of Russian private military companies for strategic purposes, arguing that they offer several advantages to Russia. These advantages include their cost-effectiveness compared to regular military forces, their ability to respond more effectively to field changes or issues, and their ability to avoid official losses that could lead to conflicts within Russia or international attention. Additionally, by using private military companies, Russia can deny direct involvement in the conflict and dismiss allegations of such involvement.

The use of PMCs raises questions about the evolution of modern warfare and the role that private actors play in shaping international politics. The authors suggest that the growing use of PMCs by states is indicative of a shift towards hybrid warfare, which combines conventional military tactics with irregular warfare tactics. Hybrid warfare is characterized by the use of a range of military and non-military tools, including propaganda, cyberattacks, and proxy warfare.

To address this issue, the authors recommend a multifaceted approach. First, international law should be strengthened to regulate the operation of Russian private military companies. Second, targeted sanctions could be imposed against companies involved in supporting these companies and individual participants in them. Third, diplomatic pressure can be used to hold the Russian government accountable for supporting private military companies. Finally, the international community can provide support to affected countries through training, resources, and humanitarian assistance. Such actions can be of a preventive nature, which, on the one hand, will deter Russian aggression, and on the other hand, stop the external influence of the Kremlin abroad.

References

1. Doxee, C., McQueen, E., Katz, B., Jones, S.G., Moye, J.: Russia's corporate soldiers: the global expansion of Russia's private military companies. United States: Center for Strategic and International Studies (2021)
2. Heraclides, A., Dialla, A.: The Balkan crisis of 1875–78 and Russia: between humanitarianism and pragmatism. In: Humanitarian Intervention in the Long Nineteenth Century: Setting the Precedent, (pp. 169–196). Manchester University Press (2015). https://doi.org/10.2307/j.ctt1mf71b8.14
3. Wills, M.: The International Brigades. JSTOR Daily (online magazine), JSTOR (digital library) (2022). https://daily.jstor.org/the-international-brigades/?highlight=The%20International%20Brigades
4. Van Herpen, M.H.: Putin's Wars: The Rise of Russia's New Imperialism. Rowman & Littlefield Publishers, United States (2014)
5. Schroeder, E., Wilde, G., Sherman, G., Herr, T.: Hackers, Hoodies, and Helmets: Technology and the changing face of Russian private military contractors. Atlantic Council (2022)
6. Aptekar, P.: Stoit li legalizovat ChVK? Vedomosti (2018, January 18). https://www.vedomosti.ru/opinion/articles/2018/01/18/748171-legalizovivat-chvk
7. Neelov, V.: Tsep dlia psov voiny. Chastnye voennye kompanii v Rossii: opyt deiatelnosti i perspektivy legalizatsii. Vzgliad (2017). https://vz.ru/opinions/2017/7/21/879652/p2/ Accessed May 2 2023
8. Popov, I., Khamzatov, M.: The War of the Future. NATO Defense College (2017)
9. Council of the EU (2021). EU imposes restrictive measures against the Wagner Group. Press release. https://www.consilium.europa.eu/en/press/press-releases/2021/12/13/eu-imposes-restrictive-measures-against-the-wagner-group/
10. Council of the EU (2023). Wagner Group: Council adds 11 individuals and 7 entities to EU sanctions lists. Press release. https://www.consilium.europa.eu/en/press/press-releases/2023/02/25/wagner-group-council-adds-11-individuals-and-7-entities-to-eu-sanctions-lists/
11. U.S. Department of the Treasury (2023). Treasury Sanctions Russian Proxy Wagner Group as a Transnational Criminal Organization. https://home.treasury.gov/news/press-releases/jy1220
12. The Seimas of the Republic of Lithuania (2023). The Seimas: "Russia's private military company Wagner is a terrorist organisation". https://www.lrs.lt/sip/portal.show?p_r=35403&p_k=2&p_t=284067&p_kade_id=9
13. Flohr, A., Rieth, L., Schwindenhammer, S., Wolf, K.D.: Variations in corporate norm-entrepeneurship. Why the home state matters. In: M. Ougaard & A. Leander (Eds.), Business and Global Governance, (pp. 56–235). London: Routledge (2010)
14. Riley, A.: Gazprom set the Russian invasion of Ukraine in motion. Atlantic Council (2022)
15. Briston, J.: Russian Private Military Companies: An Evolving Set of Tools in Russian Military Strategy. Foreign Military Studies Office (2019)

16. Ahapova, O.V.: Administrative and Legal Principles of the Activities of the National Guard of Ukraine. Qualifying scientific work as the manuscript. The thesis for a candidate's degree (PhD) by the specialty 12.00.07 "Administrative law and procedure; financial law; informational law" (08 - Jurisprudence). Kharkiv National University of Internal Affairs, V. N. Karazin Kharkiv National University, Kharkiv (2017)
17. Abuseridze, G., Agapova, O.: The Effect of Sanctions Against the Background of the Russian Occupation of Ukraine. In: Nechyporuk, M., Pavlikov, V., Kritskiy, D. (eds.) Integrated Computer Technologies in Mechanical Engineering - 2022: Synergetic Engineering, pp. 475–481. Springer Nature Switzerland, Cham (2023). https://doi.org/10.1007/978-3-031-36201-9_41
18. Abuseridze, G., Agapova, O., Paliani-Dittrich, I., Grasis, J., Kavelidze, E.: Migration From Georgia and Ukraine in the Context of Russian Aggression: In: Alaverdov, E., Bari, M.W. (eds.) Handbook of Research on the Regulation of the Modern Global Migration and Economic Crisis:, pp. 107–121. IGI Global (2023). https://doi.org/10.4018/978-1-6684-6334-5.ch007
19. Doxsee, C.: Putin's Proxies: Examining Russia's Use of Private Military Companies.2154 Rayburn House Office Building (2022)
20. European Council (2023). EU sanctions against Russia explained. https://www.consilium.europa.eu/en/policies/sanctions/restrictive-measures-against-russia-over-ukraine/sanctions-against-russia-explained/ Accessed: May 7 2023
21. Lektzian, D., Souva, M.: An institutional theory of sanctions onset and success. J. Conflict Resolut. **51**(6), 848–871 (2007)
22. Bergeijk, P.A.G., van.: Economic Diplomacy, Trade, and Commercial Policy: Positive and Negative Sanctions in a New World Order. Edward Elgar, Aldershot/Brookfield, V T (1994)
23. Carles, B., Svolik, M.: The foundations of limited authoritarian government: institutions and power-sharing in dictatorships. J. Politics **75**(2), 300–316 (2013)
24. Amuzegar, J.: Adjusting to sanctions. Foreign Aff. **76**(3), 31–41 (1997)
25. Schreiber, A.P.: Economic coercion as an instrument of foreign policy: U.S. economic measures against Cuba and the Dominican Republic. World Politics **25**(3), 387–413 (1973). https://doi.org/10.2307/2010117
26. Shay, S.: The effects of the war in Ukraine on the US-China relations. Secur. Sci. J. **4**(1), 54–67 (2023). https://doi.org/10.37458/ssj.4.1.4
27. Center for Civilians in Conflict: PRIVATIZING WAR: The Impact of Private Military Companies on the Protection of Civilians. Issue brief (2022). https://civiliansinconflict.org/wp-content/uploads/2022/12/CIVIC_PMC.pdf
28. Korotkov, D.: «Славянский корпус» возвращается в Сирию ("Slavonic Corps Back in Syria"), Fontanka.ru, 16 October 2015. https://www.fontanka.ru/2015/10/16/118/
29. Korotkov, D.: Они сражались за Пальмиру ("They fought for Palmyra"), Fontanka.ru, 28 March 2016. https://www.fontanka.ru/2016/03/28/171/
30. Giles, K., Akimenko, V.: Use and utility of Russia's private military companies. Conflict Studies Research Centre (2019)

Correlation of Norms of International Law Within the Framework of the WTO Law: Conflicts Between Treaties

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Abstract. This paper presents a comprehensive analysis of the correlation between international law norms and the legal framework of the World Trade Organization (WTO). The study aims to provide an in-depth understanding of the mechanisms available for resolving conflicts between treaties within the WTO's legal framework and their implications for the functioning of the system. The paper evaluates the effectiveness of these mechanisms in practice and the complexities of disputes and court decisions that have shaped the current landscape of international trade.

The analysis centers on two main mechanisms for resolving conflicts between treaties: the doctrine of lex specialis and the principle of systemic integration. The former is a rule of interpretation that directs courts to apply a more specific treaty provision over a more general one, while the latter seeks to interpret treaties in a way that promotes coherence and consistency across the legal system.

The paper concludes that the resolution of conflicts between treaties is crucial for the stability and predictability of the international trading system. The analysis presented in this paper is relevant for scholars, policymakers, and practitioners working in the field of international trade and commerce. It offers valuable insights into the challenges and opportunities associated with the intersection of international law and the legal framework of the WTO, and provides a basis for further research in this area.

Keywords: conflicts between treaties · dispute settlement system · international legal system

1 Introduction

The relationship between international law and the World Trade Organization is a complex and often contentious issue. While the WTO is a powerful institution in shaping global trade policies, its rules must be interpreted and applied in a way that is consistent with broader principles of international law. This requires a careful analysis of the interaction between different norms of international law, as well as the conflicts that may arise between these norms and the rules of the WTO [1].

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According to the author, the World Trade Organization, responsible for governing trade rules among member countries, plays a pivotal role in shaping global trade policies. Nevertheless, the application of WTO's regulations must align with broader principles of international law, encompassing human rights, environmental protection, and labor standards. When conflicts arise between these norms and WTO rules, member countries face the delicate task of balancing their commitments under different treaties and agreements. The WTO operates within an intricate network of international legal norms, which can occasionally clash. To ensure coherence and consistency in the application of international law, it is crucial to thoroughly analyze the interaction between different legal regimes and potential conflicts. This is especially significant in the context of the WTO, where member countries must reconcile their obligations under WTO agreements with their broader commitments within other international treaties and agreements.

The law of the WTO is complex and specialized. It deals with a broad spectrum of issues, ranging from tariffs, import quotas and customs formalities to intellectual property rights, food safety regulations and national security measures [2]. The norms of international law are an essential component of the WTO's legal system. The WTO agreements are based on and reflect the principles and rules of international law. These include customary international law, general principles of law, and the provisions of other international agreements. WTO members are required to comply with these norms in their trade relations with other members.

For instance, the principle of non-discrimination, which is one of the cornerstones of the WTO system, is based on the principles of international law. Under this principle, WTO members are required to treat all other members equally and not to discriminate between them. This principle is reflected in the WTO agreements, particularly in the General Agreement on Tariffs and Trade (GATT) and the Agreement on Trade-Related Aspects of Intellectual Property Rights [3].

The author aims to determine how the relationship between international law norms is regulated and the WTO's place within it. Is the WTO an independent system or an integral part of a unified legal framework? With this premise in mind, in the following chapters, the author seeks to delve deeper into the intricacies of specific disputes and court rulings that have shaped the current landscape of international trade. Through careful analysis and evaluation, the author seeks to provide a comprehensive understanding of the role that the World Trade Organization plays within the broader context of the international legal system.

2 The Methodological Basis of the Research

The methodological foundation of this article encompasses several pivotal elements, including legal analysis, case studies, empirical data, comparative analysis, an interdisciplinary approach, and a normative standpoint. Central to this approach is the methodology of legal analysis, wherein the author scrutinizes international legal principles, treaties, and cases to substantiate their arguments. This approach relies on established legal norms and principles, such as the 'lex specialis derogat lex generalis' principle, to examine conflicts between legal norms. In addition to legal analysis, the article employs case studies as a fundamental methodological tool. Real-world examples from international trade disputes, such as the Indonesia - Autos, Argentina - Hides and Leather, and

Brazil - Retreaded Tyres disputes, serve to elucidate and reinforce the complexities and challenges associated with conflicts of norms in international law. A comparative analysis method is also evident, as the author draws distinctions between international law and domestic law. Specifically, the author contrasts the absence of a clearly defined hierarchy in international law with the hierarchical structures commonly found in domestic legal systems, highlighting the distinctive features and intricacies of international legal norms. Empirical data plays a significant role in the article's methodology, incorporating factual information related to the US-China trade war, including aspects such as tariffs, economic repercussions, and rulings by the World Trade Organization. This empirical data provides a practical context for the theoretical discussions within the article and strengthens the author's arguments.

Furthermore, the article adopts an interdisciplinary approach by considering broader geopolitical and economic dimensions. While legal analysis forms the core of the methodology, insights from international relations and economics are integrated, particularly when discussing the changing global dynamics and the shift from a unipolar to a multipolar world order. From a normative perspective, the author takes an ethical and policy-oriented stance, proposing potential reforms for the World Trade Organization and advocating for fair trade practices and the active involvement of developing countries. This normative dimension underscores the article's aim to contribute to constructive discourse and policy considerations. By adopting this comprehensive methodology, the research aims to provide a deeper understanding of the WTO's position within the international legal system and its impact on member states' international obligations.

3 The Legal Framework of Conflicts in International Law: An Analysis of the Narrow Definition and Presumption Against Conflict

The author points out that, unlike domestic law, international law lacks a strictly defined hierarchy. This lack of hierarchy is evident in the relationship between international treaties and customary law. Specifically, both international treaties and customary law occupy the same level in the hierarchy of legal norms, with neither being superior to the other. This is unsurprising, as the International Court of Justice has consistently affirmed that customary international law and treaty norms carry similar legal weight. In many cases, customary norms serve to fill gaps in international treaties [4].

Frequently, the same issue is regulated by different legal norms within the same hierarchy. This situation is easily resolved when one of the norms falls under the category of a "special norm" while the other is considered "general." In such cases, the legal principle of "lex specialis derogat lex generalis" is applied [5]. However, complications arise when there are parallel norms with equal legal force, resulting in conflicts between contracts. Based on the above, the issue of collision norms will be discussed below with specific examples.

In instances where questions regarding potential treaty conflicts have arisen, WTO adjudicators have often initiated their assessments by determining whether there exists an actual conflict that would trigger the application of priority clauses, the lex specialis principle, or Article 30 of the Vienna Convention. In this context, WTO adjudicators have

developed and applied a relatively narrow definition of a "conflict." They have found, in numerous cases, that overlapping obligations can coexist cumulatively. Panels and the Appellate Body have not readily assumed the existence of conflicts among the WTO agreements or between the WTO agreements and other international treaty obligations. To support this argument, the author provides additional analysis, drawing from cases such as Indonesia - Autos, Argentina - Hides and Leather, and Brazil - Retreaded Tyres disputes.

The first dispute in *Indonesia- Autos* [6], Indonesia invoked the principle of *lex specialis* in support of its argument that the subsidy measures at issue were governed exclusively by Article XVI of the GATT and the SCM Agreement, and were not also subject to Article III of the GATT (or, for the same reason, the TRIMs Agreement). The Panel rejected Indonesia's argument on the grounds that there is no conflict between these sets of provisions:

In considering Indonesia's defence that there is a general conflict between the provisions of the SCM Agreement and those of Article III of GATT, and consequently that the SCM Agreement is the only applicable law, the author recalls that in public international law there is a presumption against conflict. This presumption is especially relevant in the WTO context since all WTO agreements, including GATT 1994 which was modified by understandings when judged necessary, were negotiated at the same time, by the same members and in the same forum. In this context we recall the principle of effective interpretation pursuant to which all provisions of a treaty (and in the WTO system all agreements) must be given meaning, using the ordinary meaning of words.

In international Law for a conflict to exist between two treaties, three conditions have to be satisfied. First, the treaties must have the same parties. Second, the treaties must cover the same substantive subject-matter. Were it otherwise, there would be no possibility for conflict. Third, the provisions must conflict, in the sense that the provisions must impose mutually exclusive obligations. Technically speaking, there is a conflict when two (or more) treaty instruments contain obligations which cannot be complied with simultaneously. Not every such divergence constitutes a conflict, however. The *lex specialis derogat lex generali* principle which is inseparably linked with the question of conflict between two treaties or between two provisions (one arguably being more specific than the other), does not apply if the two treaties deal with the same subject from different points of view or applicable in different circumstances, or one provision is more far-reaching than but not inconsistence with, those of the other. In such a case it is possible for a state which is a signatory of both treaties to comply with both treaties at the same time. The presumption against conflict is especially reinforced in cases where separate agreements are concluded between the same parties, since it can be presumed that they are meant to be consistent with themselves, failing any evidence to the contrary [7].

The author also analyses *Argentina - Hides and Leather and Brazil - Retreaded Tyres disputes.*

Based on the analysis of the above panels, author argues that the narrow definition of conflict arguably prevailing in international law is legally inappropriate and leads to contradictions. By contrast, this article has argued that an adequate definition of conflict of norms (i) has to be a wide one that includes incompatibilities between permissions

and obligations, permissions and prohibitions, and obligations and prohibitions; and (ii) has to rely on the 'test of violation', since the criterion of 'joint compliance', which is regularly employed in legal theory and domestic law and which has also been used in WTO panel practice, does not produce unequivocal results [8].

In the same context the author focuses on the clearest case of modern trade tension between the *US and China* that challenged the WTO putting its flexibility in question [9]. Trade aspects have been key between these two countries since the establishment of diplomatic relations. The normalization of trade relations between them began in 2000 through the Clinton Act with China, and a year later, the US assisted China in joining the WTO. Since 2006, China has become the largest US trading partner after Canada.

Already in 2008, China became the largest creditor to the United States, and the economies of the two states became more and more interdependent, but some tensions also appeared.

Under the Trump administration, the US imposed tariffs on Chinese products, accusing China of stealing intellectual and technological property and forcing foreign companies to transfer technology.

The trade war has negatively impacted both economies, leading to a higher prices for US consumers and contributing to a slowdown in China's economic growth. In total, the US currently applies tariffs exclusively to Chinese goods worth $362 billion, while China applies tariffs exclusively to US goods worth $185 billion. China brought this case to the WTO's DSU, which recently ruled that tariffs imposed by the US in 2018 that triggered the escalation in tensions between the two countries, were inconsistent with the international trade rules as the US failed to justify the alleged technology theft. The panel claims that the US did not provide evidence on how the Chinese goods and services affected by the tariffs received benefits from the so-called unfair practices. Therefore, the US could not prove that the tariffs were justified. The WTO stated that the ruling only applies to the original case brought by China, as China's retaliation has not been challenged by Washington.

In January 2020, Trump and the Chinese Prime Minister signed an agreement to end a two-year trade war. The agreement lowered tariffs on Chinese imports. China is also committed to protecting intellectual property.

In September 2020, the WTO circulated the dispute panel report in the case brought by China in "United States-Tariff Measures on Certain Goods from China". The Panel concludes that: conformity with the chapeau of measures that they have found not to be provisionally justified under various subparagraphs of Article XX od DSU. The parties have not reached a mutually satisfactory solution within the meaning of Article 12.7 of the DSU, or otherwise relinquished their rights to pursue WTO dispute settlement action on the measures at issue in this dispute. The document also states that the Panel is very much aware of the wider context in which the WTO system currently operates, which is one reflecting a range of unprecedented global trade tensions. Accordingly, recalling Article 3.7 of the DSU that highlights that the aim of the dispute settlement system is to achieve a positive solution to a dispute, the Panel expresses its ongoing encouragement to the parties [10].

Ultimately, it can be stated that the trade war affected not only the two countries, but also the global economic picture. The author believes that countries should reconsider

their economic policies and choose to protect their own market, rather than intervene in global trade processes.

The author attaches special importance to the role of the WTO in the process of trade stability. He argues that the role of the WTO as the umpire in trade disputes has been greatly threatened by the US-China trade war. With the burst of the US-China trade war, it is observed that there is an urgent need for DSU reform particularly through the incorporation of a retrospective monetary compensation. The author believes, that although this would increase the trust of the member states in dispute settlement system it may not be the only solution for preventing the trade wars. With the global tension brought about by the trade war between the US and China there is a perfect timing for reforms in the WTO to strengthen the multilateral trading system. Trade relations should be conditional on shared approaches to governance. The benefits of multilateral trade cooperation should be extended only to countries that adhere to the tenets of the liberal international economic order, which means societies that are democracies, respect certain fundamental rights, have market-based and reform-oriented economies, and are at peace [11].

The Author concludes that the international system, which was characterized by unipolarity from the point of view of US leadership, today has changed and lost its unipolar appearance. Since China's rise to the pinnacle of power, the United States has become a rival state that threatens its hegemony and maintains spheres of influence. The world is no longer unipolar, heading to multipolarity. The author gives preference to fair trade in conformity with trade standards, and engagement of developing countries to promote their economic revival and welfare.

4 The Role of the WTO in the International Legal System

According to the author, the determination of the place of the World Trade Organization in the international legal system serves only one purpose - to identify the international legal framework under which international trade law develops as well as the volume of international obligations of states in view of specific jurisdictions.

According to the literature, international trade law is an integral/subordinate part of international law. This appears to be a special law in relation to general international law. If international law is the primary source of international norms and principles, then the constituent norms and principles of the WTO law itself derive from international law [12].

While the WTO is a rules-based organization with its own legal framework, it is not an isolated system and must operate within the broader context of international law. At its core, the WTO is governed by a set of multilateral trade agreements that have been negotiated and signed by member countries. These agreements establish a set of rules and principles that govern international trade, such as non-discrimination, reciprocity, and transparency. However, these agreements cannot address every potential trade dispute that may arise, nor can they provide detailed guidance on how to interpret and apply their provisions in every circumstance. To address these gaps, the WTO relies on international law to supplement and interpret its own legal framework. For example, when interpreting the WTO agreements, the DSB may consider the relevant provisions

of other international agreements or customary international law. This approach allows the WTO to draw on the broader body of international law to fill gaps in its own legal framework and ensure that its decisions are consistent with international legal principles.

International law also plays a critical role in the resolution of disputes within the WTO. When member countries bring a dispute to the DSB, the panel or appellate body responsible for hearing the case must consider both the relevant provisions of the WTO agreements and any relevant rules or principles of international law [13]. This ensures that WTO decisions are based not only on the specific provisions of the agreements but also on broader principles of international law, such as the principle of good faith, the principle of estoppel, and the principle of non-retroactivity. International law provides an important mechanism for enforcing WTO decisions. If a member country fails to comply with a decision of the DSB, the complaining party may seek authorization from the DSB to take countermeasures against the non-compliant country. However, any such countermeasures must be consistent with international law, and the complaining party must demonstrate that it has exhausted all other available means of resolving the dispute.

In addition, international law is the primary framework through which gaps in WTO law are filled and decisions are made by the Dispute Resolution Body. The author bases this point of view on the second part of Article 3 of the DSU which states that the interpretation of treaties concluded under the WTO must take into account the customary approach of international law. A clear example of this is the classic *US-Shrimp case* [14], in which the Appellate Body stated that Article 31 of the Vienna Convention had acquired the status of a norm of customary law, in particular, this article of the Vienna Convention, as a rule of general interpretation of the treaty norm, was used by all parties to the dispute, including third parties. The rule acquired the status of a customary norm. Consequently, since this rule is considered part of customary international law, it must necessarily be applied by the Dispute Settlement Body when interpreting the agreement referred to in the WTO founding treaty as stated in Article 3 of the DSU. Hence, the author concludes that provision reaffirms the WTO's view that WTO agreements should not be viewed in "clinical isolation" from international public law. To further strengthen his position, the author cites the case of *Japan - Alcoholic Beverages II* [15]. In the present case, the Appellate Body has confirmed that Article 32 of the Vienna Convention had acquired the status of a rule of customary international law, therefore Article 3.2 of the DSU obliges the Appellate Body to interpret the constituent instruments of the WTO in accordance with customary international law. This position further strengthens the author's position that international trade law is an integral part of international law.

Considering the information presented in this article and the analysis of specific cases, the author comes to the conclusion that the WTO dispute settlement system, on the one hand, obeys the rules of the WTO itself, and on the other hand, takes into account the practice of international law when resolving disputes. This underlines the WTO's commitment to the international legal system. While the WTO has established its own rules and procedures for dispute resolution, it also recognizes the importance of broader principles of international law in shaping its decisions. This approach reflects a commitment to the overarching goal of promoting a more stable and predictable global trading system, while also upholding the principles of fairness and equity in international relations. By considering specific cases and examining the interplay between these two legal

regimes, the author demonstrates the complexity of the issues at stake, and highlights the importance of balancing competing interests and priorities in the pursuit of a more just and sustainable global trade order.

5 Conclusion

The author believes that determining the place of the WTO in the international legal system serves to identify the international legal framework within which international trade law develops and the extent of international obligations of states within specific legal contexts. While the WTO's role in the global trade system is crucial, critiques of the organization's policies and practices persist. Consequently, an ongoing dialogue and engagement among scholars, practitioners, and policymakers are necessary to ensure that the WTO operates in a manner beneficial to all member states. The author also contends that determining the place of the WTO in the international legal system helps to identify the volume of international obligations of states in view of specific jurisdictions. This assertion stems from the fact that the WTO is a legal entity that possesses the power to enforce its rules and regulations. Therefore, the WTO's decisions have a significant impact on the legal obligations of member states in the international trade arena. The norms of international law are an essential part of the WTO legal system and are closely linked to the obligations of WTO members. The WTO system is designed to ensure that trade flows smoothly, predictably, and freely, and is founded on the principles of non-discrimination, transparency, and the rule of law. The author's main argument revolves around the idea that examining the evolution of the system through a law and politics framework might yield better insights. This is primarily because, firstly, a significant amount of politics, particularly in the form of consensus decision-making, plays a crucial role in facilitating a robust dispute settlement mechanism (more politics leads to more law). Secondly, the presence of strong politics is essential to support an effective dispute settlement mechanism (more law requires more politics). Within this context, the perceived imbalance between the judicial branch and the political branch of the World Trade Organization (WTO), characterized by the automaticity in the dispute resolution process versus consensus in the political decision-making process, becomes logically explicable. If a robust dispute resolution system is in place, meaning there are extensive legal provisions, a corresponding amount of political consensus is needed. Therefore, consensus is a necessity. The WTO requires increased political engagement, more contestation, and greater openness.

The author claims that conflicts arising from international agreements are commonplace in international law, but the World Trade Organization takes a cautious and meticulous approach in addressing such conflicts. It is recommended by the author that the WTO should continue to adhere to this approach by adopting a narrow definition of conflict, considering overlapping obligations, adhering to the principle of effective interpretation, and presuming the absence of conflict in public international law unless proven otherwise. Additionally, the author suggests that the WTO should actively promote coherence and integration between various legal regimes to ensure the establishment of a unified international legal system. The author's recommendation is that the WTO should continue to implement its current approach to conflicts between international agreements.

The author also proposes that the WTO takes steps to promote coherence and integration between different legal regimes to ensure a unified system of international law. This will help to address conflicts between agreements and maintain the smooth functioning of the international trading system.

References

1. Messenger, G.: The Development of World Trade Organization Law: Examining Change in International Law. Oxford University Press, United Kingdom (2016)
2. Abuseridze, G.: International trade in the context of the COVID-19 pandemic. In: Information Resources Management Association (ed.) Research Anthology on Macroeconomics and the Achievement of Global Stability, pp. 1322–1335. IGI Global (2023). https://doi.org/10.4018/978-1-6684-7460-0.ch071
3. Davey, W.J.: Non-discrimination in the World Trade Organization: The Rules and Exceptions. Brill, Netherlands (2012)
4. Pauwelyn, J.: The role of public international law in the WTO: how far can we go? AJL **95**, 535 (2001)
5. Pauwelyn, J.: Conflict of Norms in Public International Law: How WTO Law Relates to Other Rules of International Law. Cambridge University Press (2003)
6. Panel report Indonesia-Autos, para.14.28. See also Sir Ian Sinclair, The Vienna Convention on the Law of Treaties, p. 97 (1984). https://www.wto.org/english/tratop_e/dispu_e/54r00.pdf
7. Abuseridze, G.: The Role of the WTO in the Development of International Trade: History, Problems and Perspectives of International Trade Law. Rīga: Rīga Stradiņš University, p. 60 (2021). https://doi.org/10.25143/prom-rsu_2021-15_dt
8. Cook, G.: A Digest of WTO Jurisprudence on Public International Law Concepts and Principles. Cambridge University Press (n.d.)
9. The U.S.-China Trade War: Global News Framing and Public Opinion in the Digital Age. Michigan State University Press, United States (2022)
10. WTO panel issues report regarding US tariffs on Chinese goods. https://www.wto.org/english/tratop_e/dispu_e/543r_conc_e.pdf. Accessed 5 Jan 2021
11. Abuseridze, G., Agapova, O.: The effect of sanctions against the background of the Russian occupation of Ukraine. In: Nechyporuk, M., Pavlikov, V., Kritskiy, D. (eds.) 2022 Integrated Computer Technologies in Mechanical Engineering, ICTM 2022. LNNS, vol. 657, pp. 475–481. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-36201-9_41
12. Soprano, R.: WTO Trade Remedies in International Law: Their Role and Place in a Fragmented International Legal System. Taylor & Francis Group, United Kingdom (2020)
13. A Handbook on the WTO Dispute Settlement System. Cambridge University Press, India (2017)
14. Appellate Body Report *US-Shrimp*, paras. 130-1. https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds58_e.htm
15. Japan - Taxes on Alcoholic Beverages ("Japan - Alcoholic Beverages II"), WT/DS8/R, WT/DS10/R, WT/DS11/R, adopted 1 November 1996, para. 6.23, Modified by the AB Report, WT/DS8/AB/R, WT/DS10/AB/R, WT/DS11/AB/R, DSR 1996:I, 125, p.16

Decision Support Algorithm at the Life Cycle Stages of Medical Devices Based on the Application of Markov Process

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Abstract. With the development of information technology, large volumes of data are generated at all stages of the product life cycle, which need to be managed - collected, transmitted, and processed - to support decision-making. Consideration of the uncertainties associated with relevant information is important in risk analysis and management. This is especially true in decision-making due to the diversity of stakeholders at life cycle stages and the resulting different attitudes towards expected benefits. The decision to use a medical device in the context of a specific clinical procedure requires that residual risks be balanced against the expected benefits of the procedure. In this paper, the uncertainties that arise are modeled based on the Markov Chain theory. The maximum likelihood method is used. The problem of refining estimates of the transition probabilities of a Markov chain is formulated as a quadratic programming problem. The problem of constructing an algorithm is being solved, which allows using all the information to estimate the values of transition probabilities and has an iterative structure of the calculation process. Research results can be used to manage the risks associated with the use of medical devices at life cycle stages.

Keywords: Medical Device · Health Technology · Value of Information · Engineering Risk Analysis · Optimum Decision Making · Regulation · Markov Decision Processes · Product Life Cycle

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1 Introduction

Safety and quality are "non-negotiable issues" for medical devices [1, 2]. As information technology develops, large volumes of data are generated that need to be managed—collected, transmitted, and processed—to support decision-making in the creation of high-quality medical devices [3], quality management [4], and safety of healthcare services [5, 6]. All stakeholders should understand that the use of a medical device involves a certain level of risk, even after the risks have been reduced to an acceptable level. Risk management concepts [6, 7] are particularly important for medical devices due to the diversity of stakeholders, including clinicians, healthcare delivery organizations, governments, industry, patients, and members of the public. According to the requirements, each stakeholder may differently assess the acceptability of risks in relation to the expected benefits. At the same time, regulatory requirements [5] are becoming increasingly stringent throughout the entire life cycle of a medical device, including service life and delivery. The decision to use a medical device in the context of a specific clinical procedure requires that residual risks be balanced against the quality of the evidence against the expected benefits of the procedure. At the same time, the quality of data plays a decisive role in the effectiveness of decision-making. Consideration of the uncertainties associated with relevant information is important when analyzing and managing risks for medical devices in accordance with ISO 14971 [8]. Therefore, the challenge arises of constructing an algorithm to take into account all the uncertainties regarding the risks associated with medical devices.

The purpose of the research in this work is to develop decision-support methods for optimal management actions that take into account information uncertainty at the stages of the life cycle of medical devices when using them for their intended purpose.

2 Review

With the widespread adoption of medical technologies, risk management has become increasingly important to ensure the health and safety of patients [9]. To varying degrees, countries around the world pay active attention to adverse events associated with medical technologies [10]. Health information technology (HIT) is changing the way the industry operates and has already begun to reduce waste and promote improved health outcomes [11]. As information technology advances, large volumes of data are generated that need to be managed—collected, transmitted, and processed—to support decision-making. Since the purpose of decision-making is to rank alternative decisions with respect to their expected utility, it is natural that additional information that can be obtained from the available data should be used.

The paper [12] discusses the management of adverse events associated with medical devices (MDAE), which is one of the most important aspects of improving the management of the quality and safety of medical care. MDAE monitoring is considered an important part of medical device life cycle management in terms of early detection, prevention and intervention of risks associated with medical devices. According to international legislation [13], medical devices are classified as low, medium and high risk levels. Higher risk values indicate that the event should be treated more carefully.

The classification of medical products is based on the vulnerability of the human body, taking into account the potential risks associated with the products [3, 14, 15]. This approach allows you to use a set of criteria that can be combined in different ways to determine, for example, the duration of contact with the body, the degree of invasiveness and the ratio of local and systemic effects. The risks associated with compatible medical devices should be managed in a manner consistent with the characteristics and intended use of the compatible medical devices [16].

For any particular medical device, other standards or regulations may require specific risk management techniques. In these cases, it is also necessary to follow the requirements set out in these documents. Decisions made by stakeholders regarding medical devices are typically subject to significant uncertainty. This uncertainty, in turn, means that we do not know with certainty what effect various alternative solutions will have, and this poses a rather serious problem for decision-makers. The perceptions of each stakeholder may vary depending on their cultural background, the socioeconomic and educational level of the relevant society, and the actual and perceived health status of the patient [17].

How risk is perceived also takes into account other factors, such as whether the exposure to the hazard or hazardous situation is involuntary, preventable, arising from an artificial source, due to negligence, arising from a poorly understood cause, or directed at a vulnerable group in society. As a means of managing and reducing some of the underlying uncertainties, decision-makers are increasingly using the ability to monitor the performance of a medical device and the overall infrastructure through various technological means. The key to this scenario is to consider all possible measurement results based on a given probabilistic model of the results. Thus, optimizing decisions about how to collect additional information is an effective means of helping to improve decisions about how to collect information before it is actually acquired (Fig. 1).

An in-depth discussion of the representation of information in decision analysis is provided by Nielsen et al. [18], in which information is divided into five types depending on the relationship between information and decisions:

– information is current and accurate;
– information is relevant, but inaccurate;
– information is not important;
– information is relevant, but incorrect;
– the flow of information is interrupted or delayed

In this way, the information collected informs decisions about actual outcomes and thus helps reduce the impact of epistemic uncertainty on the uncertainty associated with the various available decision alternatives. In some cases, complete information of interest may not be fully captured when making decisions. This should be adequately taken into account when formulating decision-making scenarios in which information must be divided into different types depending on the state at the time of decision-making [5]. In addition, the optimal time for making a decision may be missed due to a time delay in the information processing process and thereby lead to aggravation of losses [12].

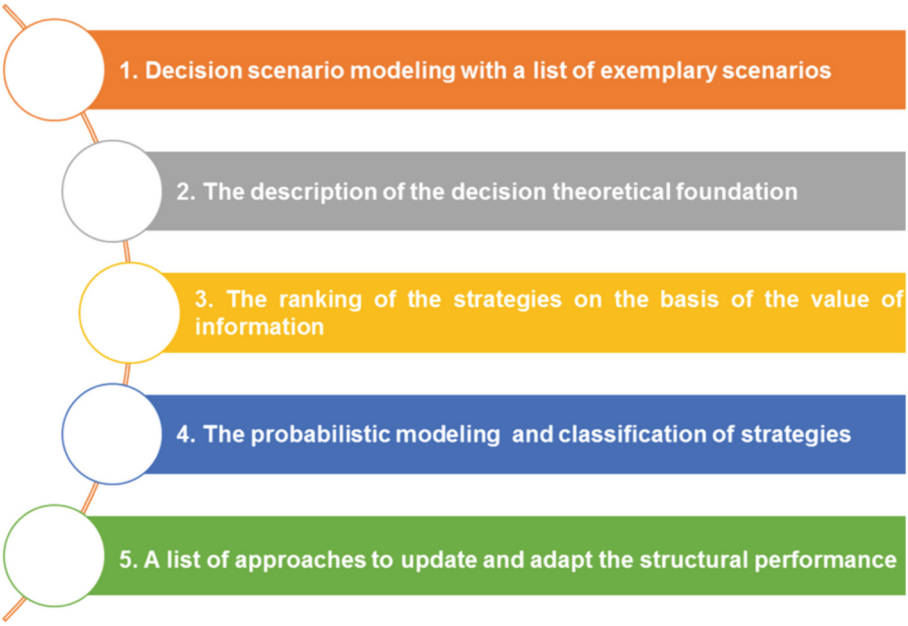

Fig. 1. The decision algorithms in modern decision support system.

This point is worth paying attention to, since the amount of information obtained from measurements of engineering structures can be quite significant, and processing the information in real time may be almost impossible. Central is the question of how often to process the collected information, as well as the impact of possible delays associated with processing the information.

The concept of value of information (VoI) [12] provides a theoretical framework for quantifying the potential benefits of additional information, derived from Bayesian decision theory, which has received much attention in recent years. Based on the concept of VoI, decision-makers can quantify the potential benefits of additional information (Fig. 2) and thus determine whether appropriate information collection campaigns, such as measurements, should be carried out.

Recently, widespread attention has been paid to VoI in sequential decision analysis to model a life cycle management scenario, including development, production, operations and maintenance.

To a certain extent, VoI analysis can also be considered as a special sensitivity analysis that is used to obtain the optimal selection of information to reduce uncertainty in the system. The question of how to properly model information is key in VoI analysis, and two cases of information types are proposed [19]: perfect information, xp, and imperfect information, xip. The difference between the two types of information concerns the uncertainty associated with the information itself. Perfect information, as the term suggests, can directly reflect the true state of the variable θ without any uncertainty; this would correspond to an ideal situation, but, as will be discussed later, is still a useful consideration. Accordingly, imperfect information refers to the case where the additional

information associated with the state of the target variable θ is either indirect or due to random noise, as is usually the case in real experiments, sampling, etc.

Fig. 2. The assessment of the value.

Uncertainties arising from the measurement process as well as data analysis can be modeled based on Markov Chain theory. Markov chains [20, 21] are widely used as a decision-making model related to the formation of a maintenance strategy, inventory management, product release management, quality control, etc. Successful solution of problems is associated, first of all, with knowledge of the characteristics of Markov chains in the form of a matrix of transition probabilities.

In this case, up to a certain point in time t_i it is possible to observe the implementation of random processes that describe the controlled parameters, and then information about their behavior arrives discretely in the form of empirical unconditional distributions over the states of the Markov chain.

Therefore, the task arises of constructing an algorithm that would allow the use of all information to estimate the values of transition probabilities and would have an iterative structure of the calculation process. Obviously, until moment t_i, the transition probabilities should be assessed on the basis of maximum likelihood. The question is how to use the incoming additional (albeit poorer in comparison with the implementations of a random process) information about the behavior of the Markov chain to correct the estimates found up to the moment t_i. The need for such clarification may arise for various reasons, due, for example, to changes in the operating conditions of medical equipment, inaccuracy of preliminary estimates, the emergence of information that directly or indirectly affects the values of some (not necessarily all) elements of the transition probability matrix, etc.

The collection of all possible additional information can be modeled as a vector of random variables X with a given (possibly subjective) probability distribution. In this case, the potential benefits associated with collecting additional information are called the expected value of information (EVI). Let us show that such a possibility exists, and we will formulate the solution algorithm in the form of a mathematical programming problem.

3 Research Methodology

The set of all possible additional information can be modeled as a vector of random variables X with a given (possibly subjective) probability distribution. In this case, the potential benefits associated with collecting additional information are the expected value of information (EVI).

Let us consider EVI, which is approximated by an ergodic Markov chain of the 1st order and has a domain of definition divided into F disjoint segments – states 1,2,…, F. Let n independent sequences of measurements be obtained at times t_{k-1} and t_k, $k = 1, 2, \ldots$. Estimates of the values of transition probabilities found based on the maximum likelihood method have the form

$$\tilde{p}_{ij}(t_k) = \frac{n_{ij}(t_k)}{n_i(t_{k-1})} = \frac{n_{ij}(t_k)}{\sum_{s=1}^{F} n_{is}(t_k)}, \tag{1}$$

and the values of estimates of the unconditional probabilities of being in state i at moment t_k, $i = 1, 2, \ldots, F$.

$$\widetilde{\pi}_i(t_k) = \frac{n_i(t_k)}{\sum_{s=1}^{F} n_s(t_k)} = \frac{n_i(t_k)}{n}, \tag{2}$$

where $n_{ij}(t_k)$ is the number of realizations recorded at moment t_k in state j, provided that at moment t_{k-1} the initial state was i; $n_i(t_{k-1})$ – number of realizations at time t_{k-1} in state i. From the normalization condition it is known that

$$\sum\nolimits_{i=1}^{F} \widetilde{\pi}_i(t_k) = 1 \tag{3}$$

Let us assume that at the next time t_{k+1} based on the control results, only $\widetilde{\pi}_j(t_{k+1})$, $j = 1, 2, \ldots, F$ can be estimated. For the ergodic chain under consideration, the system of equations must be satisfied

$$\sum\nolimits_{i=1}^{F} \pi_i(t_k) \cdot p_{ij}(t_k) - \pi_j(t_{k+1}) = 0, j = 1, 2, \ldots, F \tag{4}$$

However, if the unconditional probabilities $\pi_i(t_k)$ and $\pi_j(t_{k+1})$ in Eq. (4) are replaced by statistical estimates $\widetilde{\pi}_i(t_k)$ $\widetilde{\pi}_j(t_{k+1})$, then in the general case the equality is violated. Let there be corrections $\Delta p_{ij}(t_k)$ such that (4) is satisfied. Then we get

$$\sum\nolimits_{i=1}^{F} \widetilde{\pi}_i(t_k) \cdot \left[\tilde{p}_{ij}(t_k) + \Delta p_{ij}(t_k)\right] - \widetilde{\pi}_j(t_{k+1}) = 0, j = 1, 2, \ldots, F \tag{5}$$

Let's denote

$$\tilde{p}_{ij}(t_k) + \Delta p_{ij}(t_k) = p_{ij}(t_{k+1}) \tag{6}$$

Let us impose conditions on the choice of corrections $\Delta p_{ij}(t_k)$. Due to the fact that $p_{ij}(t_{k+1})$ are conditional probabilities, they should simultaneously.

– to be non-negative

$$p_{ij}(t_{k+1}) \geq 0 \text{ for everyone } i;\ j = 1, 2, \ldots, F \tag{7}$$

– satisfy the requirement imposed on the elements of the row of the stochastic matrix

$$\sum_{j=0}^{F} p_{ij}(t_{k+1}) - 1 = 0, i = 1, 2, \ldots, F \tag{8}$$

– satisfy the system of Eqs. (5) for the existence of an ergodic Markov chain

Since the number of independent Eqs. (5) and (8) is less than the number of unknowns, there is an infinite set of values $p_{ij}(t_{k+1})$ satisfying these conditions. To reduce uncertainty, we choose corrections $\Delta p_{ij}(t_k)$ so as to minimize the quadratic form

$$g^* = \sum_{i=1}^{F} \sum_{j=1}^{F} \left[p_{ij}^*(t_{k+1}) - \tilde{p}_{ij}(t_k) \right]^2 = \min_{i,j} \sum_{i=1}^{F} \sum_{j=1}^{F} \left[p_{ij}(t_{k+1}) - \tilde{p}_{ij}(t_k) \right]^2 \tag{9}$$

Subject to the system of equations

$$\sum_{j=1}^{F} p_{ij}(t_{k+1}) - 1 = 0, i = 1, 2, \ldots, F \tag{10}$$

$$\sum_{i=1}^{F} \tilde{\pi}_i(t_k) \cdot p_{ij}(t_{k+1}) - \tilde{\pi}_j(t_{k+1}) = 0, j = 1, 2, \ldots, F$$

$p_{ij}(t_{k+1}) \geq 0$ for everyone $i;\ j = 1, 2, \ldots, F$.

The formulated problem (9), (10) belongs to the class of quadratic programming problems for which there are solution algorithms [20].

Note that the choice of the objective function in the form of quadratic (9) is not the only possible one. Other options are

$$\min_{ij} \sum_{i} \sum_{j} \left[p_{ij}(t_{k+1}) - \tilde{p}_{ij}(t_k) \right], \tag{11}$$

$$\min \max_{ij} \left[p_{ij}(t_{k+1}) - \tilde{p}_{ij}(t_k) \right] u\ m.\partial. \tag{12}$$

Their study is an independent task.

The result of the solution will be the estimates of the elements of the transition probability matrix, calculated taking into account additional information in the form of an unconditional distribution over the states of the Markov chain at the moment t_{k+1}.

In the above formulation, the question of the appropriateness of clarifying the estimates is essential. It follows from the fact that the values of $\tilde{\pi}_j(t_{k+1})$ are statistical estimates of the unconditional probabilities $\pi_j(t_{k+1})$, and, therefore, the violation of equalities in the system of Eqs. (4) will be determined, with one on the other hand, by significant differences in the values of p_{ij} at moments t_k and t_{k+1} and, on the other hand, by errors due to the finite number of measurements.

Let us turn to the system of Eqs. (5) and transform it to the following form:

$$\sum_{i=1}^{F} \widetilde{\pi}_i(t_k) \cdot \Delta p_{ij}(t_k) = \widetilde{\pi}_j(t_{k+1}) - \widehat{\pi}_j(t_{k+1}), j = 1, \ldots, F \tag{13}$$

where

$$\widehat{\pi}_j(t_{k+1}) = \sum_{i=1}^{F} \widetilde{\pi}_i(t_k) \cdot \tilde{p}_{ij}(t_k)$$

predicted value $\pi_j(t_{k+1})$; $\widetilde{\pi}_j(t_{k+1})$ – estimate based on measurement results.

It is obvious that if the difference in (13) is determined only by errors due to a finite number of observations, then there is no possibility for further refinement. Therefore, it is advisable to introduce corrections $\Delta p_{ij}(t_k)$ as long as the difference in (13) is significant in a statistical sense. When the difference becomes insignificant, the p_{ij} values found in the previous step are used for further calculations. To assess the significance of the difference in (13), you can use the Smirnov criterion [22–25], which evaluates the difference between two empirical distributions.

The algorithm for estimating and refining the values of transition probabilities consists of three parts. In Part I, an assessment is carried out using the maximum likelihood method using expressions (1) and (2), Part II checks the feasibility of clarifying the transition probabilities based on the Smirnov criterion, Part III is a quadratic programming algorithm that allows you to solve problem (9)−(10).

Let us dwell in more detail on parts II and III. Checking the feasibility of specifying p_{ij} is as follows.

Two hypotheses are considered:

- H_0: distributions $\widetilde{\pi}_j(t_{k+1})$ and $\widehat{\pi}_j(t_{k+1})$ do not differ from one another;
- H_1: differences in the distributions $\widetilde{\pi}_j(t_{k+1})$ and $\widehat{\pi}_j(t_{k+1})$ are significant;

For all j, the difference modules are calculated.

$$\left|\delta_j\right| = \widetilde{\pi}_j(t_{k+1}) - \widehat{\pi}_j(t_{k+1}) \tag{14}$$

and determine $\Delta = max\left|\delta_j\right|$.

At a given level of significance β is calculated

$$\Delta_\beta = \sqrt{-\frac{1}{2} \cdot \frac{m+n}{mn} \cdot ln\beta}, \tag{15}$$

where m, n is the number of implementations based on which the values of $\widetilde{\pi}_j(t_{k+1})$ and $\widehat{\pi}_j(t_{k+1})$. Were estimated.

If $\Delta > \Delta_\beta$, then the hypothesis H_0 is rejected and, therefore, it is necessary to continue to refine the estimates of p_{ij}. If $\Delta \leq \Delta_\beta$, then hypothesis H_0 is considered true. In the latter case, for use at time t_{k+1}, the values p_{ij} found at the previous time t_k are selected. However, it should be noted that obtaining such a result should not lead to the exclusion of subsequent tests of hypotheses H_0 and H_1. After entering new values $\pi_j(t_{k+s})$, $s > 1$, it is necessary to still use part II of the algorithm, since a significant difference may appear. When solving a quadratic programming problem, the Lagrange multiplier method is used.

4 Results

At the moment t_k m = 100 realizations, maximum likelihood estimates were obtained

$$\|p_{ij}(t_k)\| = \begin{pmatrix} 0.40 & 0.40 & 0.20 \\ 0.60 & 0.30 & 0.10 \\ 0.10 & 0.10 & 0.80 \end{pmatrix}$$

and the vector $\left\{\widetilde{\pi}_i(t_k)\right\} = \{0.30; 0.60; 0.10\}$. At time t_{k+1}, estimates of the vector values $\left\{\widetilde{\pi}_i(t_{k+1})\right\}$ were obtained based on $n = 50$ measurements and amount to $\left\{\widetilde{\pi}_i(t_{k+1})\right\} = \{0.10; 0.40; 0.50\}$. Predicted values of the vector $\left\{\widetilde{\pi}_i(t_{k+1})\right\} = \{0.490; 0.310; 0.20\}$, and accordingly $\left\{\left|\delta_j\right|\right\} = \{0.39; 0.09; 0.30\}$.

At $\beta = 0.1$, m = 100, n = 50

$$\Delta_\beta = \sqrt{-\frac{1}{2} \cdot \frac{100 + 50}{100 \cdot 50} \cdot ln0.1} \approx 0.19$$

Then $\Delta = \max_j \left|\delta_j\right| = 0.39 > \Delta_\beta = 0.19$, which means it is necessary to clarify the values of transition probabilities at time t_{k+1}. The calculation results using the quadratic programming algorithm have the form

$$\|p_{ij}(t_k)\| = \begin{pmatrix} 0.291 & 0.390 & 0.319 \\ 0 & 0.471 & 0.529 \\ 0.129 & 0 & 0.871 \end{pmatrix}$$

Here are the final calculation results for a 4 × 4 matrix

$$\|p_{ij}(t_k)\| = \begin{pmatrix} 0.40 & 0.20 & 0.20 & 0.20 \\ 0.30 & 0.10 & 0.10 & 0.50 \\ 0.80 & 0.10 & 0.10 & 0 \\ 0.60 & 0.20 & 0.10 & 0.10 \end{pmatrix}$$

$$\left\{\widetilde{\pi}_i(t_k)\right\} = \{0.30; 0.20; 0.10; 0.40\}$$

If $\left\{\widetilde{\pi}_i(t_{k+1})\right\} = \{0.10; 0.40; 0.40; 0.10\}$, then

$$p_{ij}(t_{k+1}) = \begin{pmatrix} 0 & 0.412 & 0.393 & 0.195 \\ 0 & 0.506 & 0.494 & 0 \\ 0 & 0 & 0.583 & 0.417 \\ 0.250 & 0.438 & 0.312 & 0 \end{pmatrix}$$

Thus, the use of additional information in the form of unconditional distributions makes it possible to clarify the values of transition probabilities of 1st order Markov chains.

5 Conclusions

The paper examines the combination of a Markov decision process and the concept of value of information to develop an optimal solution for managing the risks associated with the use of medical devices at life cycle stages. Because the uses of medical devices are diverse and interrelated within the context of a specific clinical procedure, information is important to assess the conformity of medical devices. When operating medical devices (devices, instruments, equipment) up to a certain point in time t_i, it is possible to observe the implementation of random processes describing the controlled parameters, and then information about their behavior is received discretely in the form of empirical unconditional distributions over the states of the Markov chain. However, the source of information may be unknown and may often come from possible competing or alternative systems. The paper examines the problem of constructing an algorithm that would allow the use of all information to estimate the values of transition probabilities and would have an iterative structure of the calculation process. Until moment t_i, transition probabilities are assessed on the basis of maximum likelihood. The need to clarify incoming additional information arises for various reasons, due to changes in operating conditions, inaccuracy of preliminary estimates, and the appearance of information that directly or indirectly affects the values of some (not necessarily all) elements of the transition probability matrix. A solution algorithm is formulated in the form of a mathematical programming problem. To this end, a new big data approach is presented as a means of developing probabilistic representations that makes full use of prior available knowledge and information collected through observations.

References

1. Bianchini, E., Mayer, C.C.: Medical device regulation: should we care about it? Artery Res. **28**, 55–60 (2022)
2. Makhoul, N.: Review of data quality indicators and metrics, and suggestions for indicators and metrics for structural health monitoring. ABEN **3**, 17 (2022)
3. Trishch, R., Sichinava, A., Bartoš, V., Stasiukynas, A., Schieg, M.: Comparative assessment of economic development in the countries of the European union. J. Bus. Econ. Manag. **24**(1), 20–36 (2023)
4. ISO 15225:2016 Medical devices – Quality management – Medical device nomenclature data structure
5. ISO 45001:2018 Occupational health and safety management systems — Requirements with guidance for use
6. Chen, B., Tian, Y., Tian, H., et al.: Current situation and improvement of medical device adverse event monitoring in hospitals. Chin. J. Med. Instrum. **33**(19), 49–51 (2020)
7. Trishch, R., Nechuiviter, O., Hrinchenko, H., Bubela, T., Riabchykov, M., Pandova, I.: Assessment of safety risks using qualimetric methods. MM Sci. J. 6668–6674 (2023)
8. ISO 14971:2019 Medical devices – Application of risk management to medical devices
9. ISO/TR 24971:2020 Medical devices – Guidance on the application of ISO 14971
10. ISO 14971:2019 Medical devices—Application of risk management to medical devices
11. IEC 62366-1:2015/Amd 1:2020 Medical devices — Part 1: Application of usability engineering to medical devices — Amendment 1
12. ISO/IEEE 11073-10101:2020 Health informatics – Device interoperability – Part 10101: Point-of-care medical device communication – Nomenclature

13. Resnic, F.S., Majithia, A.: Postmarket medical device safety: moving beyond voluntary reporting. BMJ Qual. Saf. **27**(3), 174–175 (2018)
14. Trishch, R., Cherniak, O., Kupriyanov, O., Luniachek, V., Tsykhanovska, I.: Methodology for multi-criteria assessment of working conditions as an object of qualimetry. Eng. Manage. Prod. Serv. **13**(2), 107–114 (2021)
15. Ginevicius, R., Trishch, R., Remeikiene, R., Gaspareniene, L.: Complex evaluation of the negative variations in the development of lithuanian municipalities | Kompleksinis lietuvos savivaldybių plėtros neigiamų pokyčių vertinimasıo. Transform. Bus. Econ. **20**(2), 635–653 (2021)
16. Kruse, C.S., Stein, A., Thomas, H., et al.: The use of electronic health records to support population health: a systematic review of the literature. J. Med. Syst. **42**, 214 (2018)
17. Sun, J., Pan, J., Jin, Y., et al.: Establishment of a medical device adverse event management system for hospitals. BMC Health Serv. Res. **22**, 1406 (2022)
18. Kupriyanov, O., Trishch, R., Dichev, D., Bondarenko, T.: Mathematic model of the general approach to tolerance control in quality assessment. In: Tonkonogyi, V., Ivanov, V., Trojanowska, J., Oborskyi, G., Pavlenko, I. (eds.) InterPartner 2021. LNME, pp. 415–423. Springer, Cham (2022). https://doi.org/10.1007/978-3-030-91327-4_41
19. Bolognani, D., Verzobio, A., Tonelli, D., Cappello, C., Glisic, B., Zonta, D.: Quigley J quantifying the benefit of structural health monitoring: what if the manager is not the owner. Struct. Health Monit. **1**, 17 (2018)
20. Zhang, W.H., Lu, D.G., Qin, J., et al.: Value of information analysis in civil and infrastructure engineering: a review. J. Infrastruct. Preserv. Resil. **2**, 16 (2021)
21. IEC 61165:2006 Application of Markov techniques
22. Ginevičius, R., Trišč, R., Remeikienė, R., Zielińska, A., Strikaitė-Latušinskaja, G.: Evaluation of the condition of social processes based on qualimetric methods: the COVID-19 case. J. Int. Stud. **15**(1), 230–249 (2022)
23. Ginevičius, R., Trishch, R., Bilan, Y., Lis, M., Pencik, J.: Assessment of the economic efficiency of energy development in the industrial sector of the European union area countries. Energies **15**(9), 3322 (2022)
24. Trishch, R., Maletska, O., Hrinchenko, H., Artiukh, S., Burdeina, V., Antonenko N.: Development and validation of measurement techniques according to ISO/IEC 17025:2017. In: Proceedings of the 8th International Conference on Advanced Optoelectronics and Lasers, pp. 715–720, Sozopol (2019)
25. Cherniak, O., Trishch, R., Kim, N., Ratajczak, S.: Quantitative assessment of working conditions in the workplace. Eng. Manage. Prod. Serv. **12**(2), 99–106 (2020)

Minimising the Risks of Foreign Influence in Research and Academic Context

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Abstract. This study addresses the pressing issue of foreign influence risks in academic and research institutions, crucial hubs for innovation and technological progress. In navigating the delicate balance between openness and national interests, the research focuses on dependencies on foreign resources, technologies, and intellectual property. Employing a comprehensive methodology, including qualitative and quantitative approaches, the study conducts a systematic literature review and comparative analysis across countries and regions.

The findings, validated through qualitative content analysis and triangulation, offer practical insights to enhance internal due diligence processes and establish screening measures. The aim is to protect research autonomy amidst financial dilemmas, technological dependencies, and intelligence vulnerabilities. In a rapidly evolving global landscape, these recommendations contribute to safeguarding national security and maintaining a competitive edge.

Keywords: Foreign Influence · Risk Assessment · Academic Institutions

1 Introduction

Academic and research institutions are at the frontline of intellectual openness, scientific novelty and international engagement. The challenge nowadays is that academia, and scientific institutions drive innovation, research, and technological progress which is instrumental for national interests and sovereignty [1]. Science has historically been a domain marked by international competition, enabling nations with economic, technological, military, and other strategic advantages over their competitors. As a result, science assumes a crucial role as a strategic element of national security. By fostering the development of cutting-edge technologies and maintaining scientific prowess, nations can safeguard their interests, effectively respond to threats, and maintain a competitive edge in an ever-changing global landscape [2].The aim of this study is to evaluate different approaches to the mitigation of risks of foreign influence in universities and scientific institutions. The research will focus on analysing the dependence on foreign resources,

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technologies, raw materials and intellectual property. Through this analysis, the study aims to provide suggestions on how to strengthen internal due diligence processes within these institutions and establish screening measures to protect research autonomy.

Methodology and Methods. To assess the risks of foreign influence in academic and research institutions, the article employs a comprehensive methodology that combines qualitative and quantitative approaches. The study utilizes a multidisciplinary framework, drawing on expertise from various fields such as international relations, economics, security studies, and academia. The methodology begins with a systematic literature review, encompassing relevant academic articles, reports, and case studies on the subject.

The research also incorporates a comparative analysis of different countries and regions to examine variations in the risks of foreign influence across contexts. This analysis considers factors such as national policies, regulatory frameworks, and geopolitical dynamics. To ensure rigor and validity, the study employs qualitative content analysis. The findings are then triangulated to ensure consistency and reliability across different data sources. Overall, this mixed-methods approach allows for a comprehensive assessment of the risks of foreign influence in academic and research institutions, considering various dimensions such as financial dilemmas, technological dependencies, and intelligence vulnerabilities.

Research Results and Discussion. In the ever-evolving landscape of academia and research institutions, the issue of foreign influence has gained significant attention. The article delves into the multifaceted nature of several risks as Financial Dilemmas and Technological Dependencies.

2 Financial Dilemmas

The innovation and advance in academic and research endeavours requires a considerable and solid financial basis. It is commonplace that the foreign funding becomes an integral part of the financial portfolio of ambitious academic and research institutions. However, the dependency of universities and scientific institutions on foreign funding may create several risks depending on the context and funding sources involved: first, the risks associated with diminished research autonomy; second, the risks linked to capacity development; third, reputational and sanction-related risks, and fourth, the risks of adverse foreign influence. Further four main financial dilemmas will be provided in the context.

2.1 Risks of Diminished Research Autonomy

The loss of autonomy and control may occur when the institution becomes heavily reliant on foreign funding. It could result in losing institutional autonomy and control over research agendas because donors may impose their research priorities, redirecting resources away from essential but less financially attractive areas of study, limiting the institution's ability to address local or societal needs and constraining intellectual exploration. Donors may seek to advance their agendas, potentially leading to censorship, self-censorship, or bias in research outcomes [3]. One instance that exemplifies

the potential loss of scientific autonomy due to heavy reliance on foreign funding is the controversy surrounding Confucius Institutes, funded by the Chinese government and established in various universities worldwide to promote the Chinese language and culture. However, there have been criticisms and concerns raised about Confucius Institutes imposing restrictions on specific sensitive topics, such as Tibet, Taiwan, and human rights, to align with the political agenda of the Chinese government. Critics argue that the financial dependence on the Chinese government may lead to donors imposing their research priorities, diverting resources away from vital but less financially lucrative areas of study [4].

2.2 Shifting Research Priorities

Foreign funding often comes with specific areas of interest or strategic goals, which may not align with the institution's broader research agenda. As a result, research efforts could be redirected toward topics aligned with the funding priorities, narrowing focus and neglecting less popular or commercially viable but equally valuable research fields. This can lead to a distortion of research priorities, favouring commercially viable or politically desirable topics for the funding source while neglecting other important areas of scientific inquiry [5]. It may hinder the pursuit of long-term and fundamental scientific knowledge in favor of short-term or applied research that aligns with the interests of the funding sources. An example of foreign actors shifting research priorities is the concerns of Huawei Technologies Co., Ltd., about potential influence over research agendas due to Huawei's strategic goals and areas of interest. One such instance occurred in the United Kingdom, where Huawei established research partnerships with several universities to develop and explore 5G technology until the UK government reviewed Huawei's role due to national security concerns [6]. This decision led to a shift in research priorities, with institutions having to reassess their collaborations and potentially redirect their focus to alternative technologies or areas of study.

2.3 Risks of Capacity Development

Relying heavily on foreign funding sources can make universities and scientific institutions vulnerable to economic and geopolitical shifts. Changes in political alliances, economic downturns, or shifts in foreign policies can result in sudden funding cuts or the withdrawal of support, leading to financial instability and uncertainty [7]. A Harvard Business Review points out that geopolitical risk has a negative impact on private-sector innovation investment [8]. The presence of uncertainty related to geopolitical factors is identified as a key driver behind this trend. Moreover, heavy dependence on foreign funding may undermine and limits the capacity building and sustainability. If the resources are primarily channeled through foreign institutions or researchers, limiting investment in building local research capabilities, it can severely impact national scientific capabilities in the long term.

2.4 Reputational and Sanction-Related Risks

Some funding sources may have ethical implications or conflicts of interest that can impact research integrity [9]. For instance, funding from industries or corporations with

vested interests in certain outcomes may influence research findings, potentially compromising scientific objectivity [10] and the public's trust [11]. Sanction-related risks receiving foreign funding refer to the potential negative consequences that can arise due to economic sanctions imposed by one country or group of countries on another. For example, during Russo-Ukrainian war, several Russian universities and research institutions were sanctioned [12]. It's essential for scientific institutions to consider these sanction-related risks and to navigate the legal and regulatory frameworks to ensure compliance. Being associated with a sanctioned country may also result in reputational risks for scientific institutions.

2.5 The Risks of Adverse Foreign Influence

The risks of hostile foreign influence in academic and research institutions refer to the potential threats posed by foreign actors who seek to manipulate or exploit these institutions for their own strategic or political objectives [13]. For instance, China's military-civil fusion doctrine blurs the boundaries between civilian and defense universities and researchers, giving rise to concerns regarding transparency and accountability when it comes to Chinese institutions seeking international collaborations [14]. Depending on the funding source, universities and scientific institutions may be subject to political pressure or influence from the donor country, leading to restrictions on research topics, censorship of findings, or interference in academic freedom, compromising the integrity and independence of the institution [15]. Intellectual property theft from academic and research institutions to gain unauthorized access to valuable intellectual property, research findings, or sensitive technologies is very realistic [16]. Espionage and information gathering from academic and research institutions allegedly occurs to gather classified or sensitive information related to national security, defence, or strategic technologies [17]. This challenge is also related to China's National Intelligence Law, which requires entities and individuals to cooperate with intelligence operations [14].

Recognising and effectively managing the financial risks associated with foreign funding is therefore essential for universities and research institutions. By diversifying funding sources, implementing transparent policies and safeguards, and fostering collaborations based on shared values and goals, the potential risks of dependence on foreign funding can be mitigated.

Next step to assess the risks of Foreign Influence in Academic and Research Institutions is Technological Dependencies approach.

2.6 Dependencies on Foreign Technologies

In today's interconnected and technologically advanced global landscape, international academic and scientific collaboration heavily relies on foreign technologies as well. And this technological approach or challenge could be overviewed from the development and as well risk perspective. In the article authors try provide broader interpretations of foreign technologies and dependencies in the process of assessing the Risks of Foreign Influence in Academic and Research Institutions.

The reliance on external sources for technologies, equipment, materials, and intellectual properties brings forth significant risks for universities and scientific institutions.

Interdependence in technologically "flat world" is a part and parcel of mutually beneficial international academic and scientific engagement. However, overdependence of universities and scientific institutions on foreign technologies, equipment, materials, and intellectual properties exposes them to two primary risks. First, there are the risks related to research capabilities. If access to critical technologies, equipment, or materials is compromised or disrupted, it can hinder research projects, limit innovation, and impede scientific progress. Second, similarly to financial dilemmas, the technological dependencies ay create reputational and hostile foreign influence risks, including the possibility of undue influence on research agendas, compromised academic freedom, or the manipulation of research outcomes to align with foreign interests.

Heavily dependency on foreign know-how and intellectual property can make universities and scientific institutions vulnerable to geopolitical shifts, resulting in sudden access denial to certain knowledge and intellectual properties. BREXIT has profoundly affected British science, including reduced access to EU research funding, diminished collaboration opportunities, and restrictions on the mobility of researchers. The withdrawal from the EU has disrupted the flow of research funding and limited participation in EU research programs, impacting the availability of resources for scientific projects. Additionally, the exclusion from specific EU collaborations has hampered knowledge exchange and hindered the ability of British scientists to engage in international scientific partnerships [18]. Besides, the heavy reliance on foreign technologies, materials, equipment, and personnel without sufficient investment in building local research capabilities can have detrimental effects on national scientific capabilities in the long term. Consequently, the nation may become overly dependent on external sources, leading to a diminished ability to innovate, conduct cutting-edge research, and address critical scientific challenges independently. This highlights the importance of balancing foreign collaborations with strategic investments in local research capacity to ensure sustainable scientific progress and maintain scientific autonomy. One more important aspect of Dependencies on Foreign Technologies is security of Supply of critical technologies, equipment, or materials. When it is compromised or disrupted, it can hinder research projects, limit innovation, and impede scientific progress. For example, in 2019, the United States Geological Survey conducted a study on the criticality of rare earth elements, highlighting the need for a secure and diversified supply of these materials for the country's technological advancement and national security. The study emphasized the importance of developing domestic production capabilities, promoting recycling, and fostering international collaborations to ensure a stable supply of critical resources [19].

The reputational and risks of hostile foreign influence could be overwide as additional aspect of Dependencies on Foreign Technologies. Any critical dependencies on foreign actors or foreign technologies can undermine the autonomy, competitiveness, and resilience of scientific institutions while also compromising national security by creating opportunities for foreign influence or disruption. One notable case illustrating the impact of critical dependencies on foreign actors and technologies involves using Chinese-made telecommunications equipment, specifically in developing and implementing 5G networks. Several countries, including the United States and certain European nations, have prohibited the use of equipment from Chinese companies like Huawei and ZTE

due to concerns regarding potential foreign influence. This case underscores the significance of countries and scientific institutions carefully evaluating and managing their reliance on foreign actors and technologies to safeguard autonomy, competitiveness, and resilience [20]. It emphasizes the need to strike a balance between technological progress and considerations of national security, taking into account the potential risks associated with foreign influence or disruption. It must be noted, that for instance, reputational risks arise when universities and scientific institutions utilize foreign technologies and materials sourced or manufactured through practices involving human rights violations [21], environmental insecurity, or violations of international sanctions and embargoes. By engaging in such practices, institutions expose themselves to potential reputational damage due to their association with unethical, harmful, or legally prohibited activities. Using prohibited technologies and materials can harm collaborations with partners and may result in exclusion from international research networks, impeding scientific progress.

Strategic dependencies must be noted as well in the context of foreign influence, as dependencies on foreign technologies present significant risks [22]. For instance, relying heavily on specific disruptive technologies like 5G networks, where viable alternatives are scarce, can leave institutions strategically vulnerable [23]. Another example is the storage of critical data on foreign-controlled cloud platforms. Such dependencies create opportunities for political pressure or influence from the donor country, leading to constraints on research topics, suppression.

It is vital for universities and scientific institutions to recognise and proactively manage the risks associated with dependence on foreign technology. By doing so, they can effectively mitigate potential vulnerabilities and strive to improve their research capabilities, maintain their reputations and protect themselves from undue foreign influence. To this end, institutions may need to diversify their resource procurement strategies, strengthen internal governance mechanisms, promote transparency in their operations, and foster collaborations that prioritise research integrity and academic independence. These measures will contribute to creating a resilient and robust research environment that safeguards the institutions' autonomy and enables them to excel in their pursuits.

2.7 Foreign Investment Screening

According to UNCTAD data, in total, from 1995 to 2022, at least 37 countries introduced new regulatory frameworks for the screening of investments that include national security consideration [24], some of nations also applied foreign investment screening to scientific institutions and academia. Indicators of potential risks include investments originating from a hostile foreign government or state-owned entity, investments from entities involved in espionage or other hostile activities, and investments accompanied by specific conditions or requirements that may influence the direction or outcome of the research. Identifying foreign investment risks associated with foreign debts, investments, grants, joint funding, and other forms of foreign sources' financial, intellectual and technological support is essential in evaluating the foreign influence in universities and scientific/research institutions.

Numerous countries have initiated efforts to counter economic espionage and theft of intellectual property. These initiatives specifically target the illicit acquisition of sensitive research data from universities and research institutions [25]. In 2021, the UK government adopted legislation [26] to protect academic freedom and research integrity, including measures to increase transparency and disclosure of foreign funding sources and to strengthen the powers of research institutions to prevent and respond to attempts at foreign interference. UK established dedicated advisory body - the UK Research Collaboration Advice Team to provide guidance and support to researchers and higher education institutions who believe their work may have national security implications [27].

Guidelines and recommendations tailored for scientific institutions and academia play a vital role in promoting best practices and security awareness, fostering a culture of vigilance and responsibility within the academic community [28]. In 2019, the UK's Universities Minister issued guidance for universities on managing risks associated with foreign funding, including the need for due diligence, transparency, and disclosure. The UK's Trusted Research Guidance for Academia offers valuable insights and actionable recommendations to assist scientific institutions in upholding security standards and protecting sensitive research.

Mandatory screening for foreign investments in specific areas is crucial to ensure national security. For instance in Latvia [29], legally identified sensitive domains such as disruptive technologies, dual-use technologies [30], and other sensitive areas undergo thorough scrutiny to mitigate potential risks and safeguard national interests. In today's context, where every invention can have dual-use purposes, scientists play a crucial role in identifying research projects critical to national security [31]. Identifying dependencies on foreign technologies, software, hardware, raw materials, or intellectual properties that could pose threats to scientific institutions and national security is a complex task [32]. These dependencies may be deeply ingrained within research and operational processes, making them challenging to recognize and assess. It requires a comprehensive evaluation of supply chains, research collaborations, licensing agreements, and technology transfers to identify potential vulnerabilities. One example of measures taken to protect national security is prohibiting using Huawei technologies in research. Several countries, including the United States [33] and some European nations, have implemented restrictions on the use of Huawei equipment in sensitive research areas, particularly in telecommunications and critical infrastructure [23]. An example of critical dependencies on foreign minerals and raw materials necessary for research is the reliance on rare earth elements in various scientific fields, including electronics, renewable energy, and advanced materials [25]. Heavy dependence on China for these crucial materials poses potential risks to research and development efforts in other nations. Disruptions in the supply chain, export restrictions, or geopolitical tensions could result in limited availability and increased costs, hampering scientific advancements and technological innovation in affected countries.

Indirect strategic dependencies on foreign technologies may not be immediately apparent but can have significant implications for scientific institutions and national

security. For example, reliance on cloud computing services hosted by foreign companies or utilizing software frameworks developed by foreign entities can create vulnerabilities and potential risks. Indirect dependencies introduce challenges in terms of regulatory compliance, technological interoperability, and long-term sustainability. An example of indirect dependencies can be seen in the efforts of Europe to reduce its reliance on Chinese pharmaceutical products [7]. However, it is crucial to acknowledge that India, often considered an alternative source, relies heavily on China for various pharmaceutical inputs, including raw materials, active pharmaceutical ingredients, and critical components necessary for medicine production. Contributions in kind, such as donating equipment and technologies, or granting access to foreign data analytical capabilities for research purposes, carry inherent risks. While these contributions can provide valuable resources and expertise, they pose concerns regarding data security, intellectual property protection, and potential influence or access to sensitive research findings. One case that has attracted attention involves MGI (Molecular Genetics Instrumentation), a subsidiary of the Chinese genomics firm BGI (Beijing Genomics Institute), and the scrutiny of its donated genetic sequencing equipment to research institutions globally. The donation of equipment by MGI has sparked concerns regarding data security, intellectual property protection, and the potential for foreign influence or access to sensitive research findings [34]. Experts have expressed apprehensions about the possibility of the donated equipment facilitating data collection and the potential transfer of valuable genetic information to MGI or its affiliated entities [35]. It is crucial for institutions to carefully assess and address these risks by implementing robust safeguards and protocols.

The purpose of foreign investment review is to make informed decisions that safeguard the integrity and autonomy of research, promote transparency, protect academic independence and maintain research integrity. In many countries, foreign investment screening in educational institutions includes a framework of regulations and guidelines aimed at preserving the integrity of academic research by preventing undue foreign influence. This process involves assessing the risks associated with foreign investment, such as the source of funding, purpose, conditions and potential impact on research outcomes. Integrating risk assessment and raising awareness of strategic competitors and different types of dependencies at all organizational levels is crucial.

3 Recommendations

Research provides recommendations for improving risks associated with hostile foreign influence and reducing dependencies on foreign funding and technologies while maintaining academic and research excellence, which is part of national security.

A comprehensive system should be set by the regulations, implemented at all levels and appropriately resourced. Setting clear guidelines and tasks for tracking foreign investment sources, which are the primary sources of foreign funding for universities and scientific institutions, including government grants, international foundations, philanthropic organizations, corporate sponsorships, and collaborations with foreign institutions. Besides, structuring it as an in-house internal control system, approving the regulation, allocating resources and defining responsibilities. Internal oversight mechanisms of the acceptance of foreign funding should not only consist of supervision or

ethics boards but should be integrated into the risk assessment at all levels, also involving non-academic staff and students and employees. It is important to provide and ensure adequate education and training for scientists, academic personnel, and staff members is crucial to raise awareness and understanding of the risks of hostile foreign influence. By equipping individuals with the necessary knowledge and skills, they can become more vigilant in identifying and addressing potential threats. These educational programs should be comprehensive and cover risk assessment, data security, intellectual property protection, responsible research practices, and compliance with relevant regulations and policies. By fostering a culture of awareness and providing the tools and resources necessary to navigate these risks, universities and scientific institutions can enhance their resilience and safeguard their missions.

One more crucial recommendation is introducing robust compliance processes, including conducting thorough due diligence on the origins of the technologies and materials they utilize, ensuring compliance with ethical sourcing and sustainability and international sanctions, and actively monitoring and reviewing supply chains to prevent the use of prohibited resources.

Structuring systematic, regular cooperation with the relevant state institutions responsible for national security is another way how to protect particular risks. National security institutions using data-based analytical tools to identify funding markers and patterns have better toolboxes to timely indicate the trends in foreign investments, including the total amount and the scale of dependence on foreign financing [36].

Diversifying funding sources, minimizing critical dependencies and strengthening domestic research funding mechanisms. Universities and scientific institutions should diversify funding sources, reducing over-reliance on a single foreign funding source by actively seeking funding from a diverse range of domestic and international sources.

Besides, facilitate cooperation in basic science only with like-minded partners sharing the same values [37]. Collaboration with a wide range of like-minded international partners fosters creation of a resilient scientific technologic diverse ecosystem, helping broaden research perspectives and reducing the risk of hostile influence on research priorities.

It is important to foster public funding and support, as science is a part of national sovereign capabilities. Increased public funding to create scientific technologic ecosystems for research and higher education, reducing national dependencies on external risks. As well as minimize critical dependencies on foreign equipment, software and technologies, intellectual property, and skills by facilitating the creation of national scientific capability. Vigilant monitoring, risk assessment, and proactive measures are crucial in identifying and mitigating dependencies to safeguard scientific institutions and national interests.

It is recommended to work on policy interventions to enhance technology sovereignty and strategic autonomy and in specifically work on the protection measures like export controls, foreign direct investment screening, negative lists, and research security measures as well as to promote measures to strengthen domestic capabilities and performance.

To execute government technology sovereignty concept to disrupt existing scientific technologic ecosystems and facilitate cooperation in basic science only with like-minded

nations, the private sector, scientists and academia have to create in-house comprehensive risk assessment and screening systems. Other challenge is the dual-use nature of many advancements, where everyday items can also be weaponized.

In contrast to the state control approach during the Cold War, the current landscape requires scientific institutions and academia to take on more responsibility for self-control and self-evaluation, as the traditional mechanisms may not be sufficiently forward-looking and adaptable.

By adopting these measures, universities and scientific institutions can successfully navigate the complex interplay between national security, funding security, and academic freedom. This proactive approach empowers institutions to enhance their resilience and effectively assess and mitigate risks associated with foreign dependencies. Simultaneously, it allows institutions to maintain a diverse research portfolio that aligns with national sovereignty and contributes to societal benefit. Through careful evaluation of funding sources, robust risk management strategies, and the cultivation of strong partnerships, scientific institutions can strike a balance that safeguards both their integrity and the broader interests of the nation they serve.

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References

1. The OECD's Science, Technology and Innovation Outlook 2023: Enabling Transitions in Times of Disruption OECD. Innovation in Science, Technology, and Industry: Scoreboard. OECD Publishing (2021)
2. National Research Council (US) Committee on a New Government-University Partnership for Science and Security. Science and Security in a Post 9/11 World: A Report Based on Regional Discussions Between the Science and Security Communities. National Academies Press (US), Washington (DC). PMID: 20669431 (2007)
3. Läänemets, M.: Academic Co-operation with the People's Republic of China: Dangers and Temptations. International Center for Defence and Security, Tallinn, p. 3 (2020). https://icds.ee/en/academic-co-operation-with-the-peoples-republic-of-china-dangers-and-temptations/
4. Robison, A.: Academic Freedom and the Confucius Institutes. The Diplomat (2018). https://thediplomat.com/2018/02/academic-freedom-and-the-confucius-institutes/
5. Bero, L.A.: Tobacco industry manipulation of research (2005). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1497700/
6. Press release. Huawei to be removed from UK 5G networks by 2027 (2020). https://www.gov.uk/government/news/huawei-to-be-removed-from-uk-5g-networks-by-2027
7. European Health Union: Commission proposes pharmaceuticals reform for more accessible, affordable and innovative medicines. European Commission (2023). https://ec.europa.eu/commission/presscorner/detail/en/IP_23_1843
8. Vivek, A., Deng, W., Habib, A.: Research: When Geopolitical Risk Rises, Innovation Stalls (2022). https://hbr.org/2022/03/research-when-geopolitical-risk-rises-innovation-stalls
9. Stoff, J.: Should Democracies Draw Redlines around Research Collaboration with China? A Case Study of Germany (2023). https://researchsecurity.org/resources/

10. Heffernan, M.: University reputations risk being tarnished by business links. Financial Times (2018). https://www.ft.com/content/33adaa9e-43ad-11e8-93cf-67ac3a6482fd
11. Merkle, O.: Corruption risks in research funding in developing countries. U4 Helpdesk Answer 2017, p. 16 (2017). https://www.u4.no/publications/corruption-risk-research-funding.pdf
12. USA Department of Treasury. With Over 300 Sanctions, U.S. Targets Russia's Circumvention and Evasion, Military-Industrial Supply Chains, and Future Energy Revenues (2023). https://home.treasury.gov/news/press-releases/jy1494
13. White House Office of Trade and Manufacturing Policy. How China's Economic Aggression Threatens the Technologies and Intellectual Property of the United States and the World (2018). https://trumpwhitehouse.archives.gov/briefings-statements/office-trade-manufacturing-policy-report-chinas-economic-aggression-threatens-technologies-intellectual-property-united-states-world/
14. Joske, A.: The China Defence Universities Tracker. Exploring the military and security links of China's universities, pp. 6, 11 (2019). https://www.aspi.org.au/report/china-defence-universities-tracker
15. Babones, S.: It's Time for Western Universities to Cut Their Ties to China. Foreign Affairs (2020). https://foreignpolicy.com/2020/08/19/universities-confucius-institutes-china/
16. Ivanov, H.: Research Collaboration with High-Risk Countries: What Does the UK Public Think? The Henry Jackson Society (2023). ISBN: 978-1-909035-76-8. https://henryjacksonsociety.org/wp-content/uploads/2023/04/HJS-Research-Collaboration-with-High-Risk-Countries-Report.pdf
17. White House. How China's Economic Aggression Threatens the Technologies and Intellectual Property of the United States and the World. White House Office of Trade and Manufacturing Policy. SBN-10: 1722711027 (2018)
18. UK scientists warn of 'catastrophic' impact of funding cuts. The Guardian (2021). https://www.theguardian.com/science/2021/mar/31/uk-scientists-funding-cuts-grants-foreign-aid
19. United States Geological Survey. Critical Mineral Resources of the United States: Economic and Environmental Geology and Prospects for Future Supply (2019). https://pubs.usgs.gov/sir/2019/5155/sir20195155.pdf
20. Flamini, R.: National Security Risks and 5G Networks: Perspectives from Europe. The German Marshall Fund of the United States (2021). https://www.gmfus.org/publications/national-security-risks-and-5g-networks-perspectives-europe
21. O Brien, C.M.: Commission Proposal for a Regulation on prohibiting products made with forced labour on the Union market: The issue of remedies (2023). https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/702583/EXPO_BRI(2023)702583_EN.pdf
22. NATO Strategic Concept, p. 13 (2022). https://www.nato.int/cps/en/natohq/topics_210907.htm
23. Implementation of the 5G cybersecurity Toolbox. European Commission (2023). https://digital-strategy.ec.europa.eu/en/library/communication-commission-implementation-5g-cybersecurity-toolbox
24. The evolution of FDI screening mechanisms: Key trends and features. United Nations (2023). https://unctad.org/publication/evolution-fdi-screening-mechanisms-key-trends-and-features
25. USA China Initiative (2019), National Security and Investment Act: guidance for the higher education and research-intensive sectors (2023)
26. National Security and Investment Act 2021 (NSI Act) (2021). https://www.legislation.gov.uk/ukpga/2021/25/contents/enacted

27. National Security and Investment Act: guidance for the higher education and research-intensive sectors (2023). https://www.gov.uk/government/publications/national-security-and-investment-act-guidance-for-the-higher-education-and-research-intensive-sectors/national-security-and-investment-act-guidance-for-the-higher-education-and-research-intensive-sectors
28. Guidelines To Counter Foreign Interference in The Australian University Sector. University Foreign Interference Taskforce (2021). https://www.education.gov.au/guidelines-counter-foreign-interference-australian-university-sector
29. National Security Law. Article 37. Latvian Law (2001). https://likumi.lv/ta/en/en/id/14011-national-security-law
30. BBC news: UK blocks University of Manchester sensor deal with Chinese company (2022). https://www.bbc.com/news/technology-62243424
31. Hundreds of UK academics investigated over weapons links to China. The Times (2021). https://www.thetimes.co.uk/article/hundreds-of-uk-academics-investigated-over-weapons-links-to-china-bpcks76bv
32. Universities have 'risky' ties to China. The Times (2023). https://www.thetimes.co.uk/article/universities-have-risky-ties-to-china-h5cjtw05q
33. The Clean Network. U.S. Department of State (2021). https://2017-2021.state.gov/the-clean-network/index.html
34. Sharma, Y., Black, R.: Scrutiny surrounds genetic sequencing giant, as US and Australia investigate equipment donation. ABC News (2021). https://www.abc.net.au/news/2021-02-09/scrutiny-surrounds-giant-genome-sequencing-firm-bgi/13126514
35. The Chinese company MGI, which donated to the Children's Hospital Foundation, has come under the attention of the Security Service. Baltic News (2023). https://baltics.news/2023/05/07/the-chinese-company-mgi-which-donated-to-the-childrens-hospital-foundation-has-come-under-the-attention-of-the-security-service/
36. EU toolbox on 5G Cybersecurity (2020). https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_127
37. Meyers, Z., Springford, J.: UK science and technology after Brexit: How to fix it. Center for European Reform (2022). https://www.cer.eu/publications/archive/policy-brief/2022/uk-science-and-technology-after-brexit

Social Network Communication and Reading Practices of Ukrainian High School Students

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Abstract. The article reveals the peculiarities of reading practices of Ukrainian high school students compared to their communication on social networks. The empirical part of the article is based on the results of a study conducted in September-October 2023 using the method of in-depth semi-structured interviews with ten Ukrainian high school students. The participants of the study ranked social network communication or movies in the first place, while literature was ranked second or third, and video games were more often ranked fourth. It is noted that high school students did not provide categorical comparative assessments of social network communication and literature in an "either/or" format, as their contents are completely different. High school students noted not only a negative but also a positive impact of social network sites on their reading practices, since they have the opportunity to find any necessary literature on the Internet; social networks provide useful information about various literary texts. The results of the content analysis of school textbooks on Ukrainian and foreign literature for 10th and 11th grades revealed the absence of literary works of the genres preferred by high school students. The genre attractiveness of the school literature curriculum can become a powerful "pull" factor for students compared to the "push" influence of social network sites. It is concluded that it is necessary to reform school curriculum of Ukrainian and foreign literature to make them more consistent with the literary genre preferences of Ukrainian high school students.

Keywords: Reading Practices · Literary Genre · Social Networks · High School Students · Communication

1 Introduction

In a society of electronic media, reading practices are becoming less popular and are increasingly replaced by communication on visualized social networks. According to N. Mirzoeff, the fragmented culture we call postmodernism can be better represented and understood visually, whereas nineteenth-century culture was classically represented by newspapers and novels [1, pp. 3–4]. Contemporary sociology of literature increasingly

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cites data on the catastrophic decline in the number of students who like to read and read a lot, and this applies not only to reading practices related to the school curriculum but also to independent (independent, leisure) reading practices [2–5]. One of the reasons for these changes is the increased interest of students in social network communication, which they spend a lot of time on every day. While Western sociology pays considerable attention to the problem of the depopularization of reading practices and the development of programs for the development of students' reading skills, this issue is marginalized in Ukrainian studies. Therefore, there is a need to study the reading practices of Ukrainian students in comparison with their communication on social media and find out what factors can influence the popularity of their reading practices. The purpose of the article is 1) to identify the peculiarities of Ukrainian high school students' reading practices in comparison with their communication on social networks; and 2) to find out whether there is a correspondence between high school students' genre preferences and the actual genre content of the school curriculum in Ukrainian and foreign literature. We consider this correspondence as a pull factor, while the priority of social network communication – as a push factor for high school students' reading practices.

The sociology of literature is understood as the study of the process of reading, which includes the social interaction of readers, critics, and authors of literary texts, as well as the study of the influence of sociocultural factors on the formation of reading practices and the development of literary genres in a given society. Many sociologists study literary works to identify sociological concepts and ideas that can influence the formation of a certain style of thinking among readers. P. Bourdieu introduced the concept of "literary field" (a type of the broader category of "social field", which has many variations: political, economic, artistic, scientific, religious, etc.). If the "field" is understood as a relatively closed and autonomous subsystem that functions independently of external influences and has its own regularities, rules and norms, hierarchy and dynamics of development, then the "literary field" as a type of "field" aims to construct the cultural tastes of the public (readers), which in turn can influence its thematic and genre diversity [6]. The literary field is a dynamic structure that should respond to changes in the preferences and tastes of the "consumers" of literary products and, on the other hand, influence the formation of cultural tastes in this group.

The sociology of reading deserves special attention because it considers the process of reading as an active interaction between the communicator (the author of the text) and the receiver (the reader). In the modern sociology of reading, a great deal of attention is paid to the study of the process of the formation of reading skills in children of preschool age because such components of reading practices as love for books, reading speed, and completeness of understanding of literary texts significantly affect the overall academic performance of children at school [7, 8]. Research by J. Hattie, T. Dörfler, and C. Artelt shows that differences in reading skills among students in primary school widen the gap in students' academic achievement. Moreover, parental involvement in this process is considered to be the most important factor in the development of children's reading skills [9, 10]. When parents (especially mothers) spend a lot of time reading interesting books with their children, it has a significant impact on the formation of their reading practices, which then determines their academic success. As demonstrated by P. Bourdieu, S. Sirin, and P. Davis-Kean, there is a certain relationship between parents' cultural capital (their

level of education and general cultural knowledge) and their children's reading skills: the higher the parents' education, the higher their children's reading skills and school performance, which can be seen as an example of educational inequality that schooling can help to correct [11–13].

C. Whitten, S. Labby, and S. Sullivan have found that students' propensity to read literature of their own choosing (pleasure reading) has a positive effect on their academic performance, not only in the study of languages and literature but also in history and mathematics [5]. C. Whitten, S. Labby, and S. Sullivan have shown that the practice of "reading for pleasure" can partially neutralize the pattern according to which medium-high socioeconomic status and a fairly high level of parental education influence the academic performance of their children. It turned out that "reading for pleasure" practices have an even greater impact on students' academic achievement than their parents' status and education [5, p. 50], which in turn can help neutralize educational inequality among students. At the same time, it has been found that the number of students who enjoy independent reading is insignificant. In a study by C. Whitten, S. Labby and S. Sullivan, which surveyed 65 American high school students aged 15–17, only 29% of such students were found [5, p. 54]. According to various studies, girls are more motivated to read than boys [14–16].

M. Tegmark, T. Alatalo, M. Vinterk, and M. Winberg studied the impact of two forms of reading motivation on students' academic achievement: autonomous (self-determined) and externally imposed (controlled). It is assumed that autonomous motivation is highly likely to predict success in reading, while controlling motivation negatively affects reading results [16, 17]. As indicators of autonomous motivation, M. Tegmark, T. Alatalo, M. Vinterk, and M. Winberg used the following statements: "I read because I know it is important to me"; "I read because I am a reader". The following statements were chosen as markers of externally controlled motivation to read: "I read so that I don't look bad in the eyes of others" and "I read because the teacher makes me read" [4, p.102]. In their study (N = 259 Swedish students in grades 6 and 9), it was found that students are mainly driven by externally controlled motivation to read literature, and ninth graders are even more guided by it than sixth graders. Thus, in contrast to independent (leisure) reading, which is driven by autonomous motivation, the practices of in-class reading are more related to controlled motivation [4, p. 114]. It has also been found that students would read much more if they were assigned interesting texts, had the opportunity to choose literary works, and if more time was devoted to reading at school [4, p. 101].

In the sociology of literature, there are three groups of factors that influence students' reading practices: the quality and content of literary texts (vocabulary, syntax, plot, genre) [18–20]; students' personal and social characteristics (memory, attention, cognitive motivation, family influence) [21, 22]; and the context of learning (quality of teaching and atmosphere at school) [22]. All three groups of factors are dynamic, i.e. they can be changed: it is possible to change the curriculum of school and extracurricular reading and make it more interesting so that students enjoy reading not only the literature they choose but also the literature offered by the school curriculum; it is possible to develop a student's personal and cognitive abilities, and the school can play a significant role in this process; it is possible to optimize the school atmosphere and

improve the quality of teaching so that the teacher's professional skills and effectiveness can become a model for students. If children's reading skills are not developed over time, they may have long-term problems that become more difficult to solve the older they get. For example, S. Main, S. Hill, A. Paolino, D. Smart, G. Youssef, A. Sanson, and others have shown that poor reading skills are associated not only with students' low academic achievement but also with their long-term future failure in professional and social life [23, 24].

M. McLuhan explains why there is a connection between active reading practices and academic achievement: reading shapes analytical thinking, teaches focusing on a particular literary plot for a long time, and encourages reflection on what has been read [25]. However, in the era of electronic media, reading practices are being replaced by practices of perception of visual messages, which in turn form the so-called "mosaic thinking", which results in the child's inability to focus for a long time on some semantic object and a tendency to constantly change information content, which should be visualized first and foremost [25].

2 Method of Research

Our study was conducted using a semi-structured in-depth interview with ten high school students studying at schools in Kharkiv (at the time of the interview, 5 of them were in Kharkiv, 2 were in other cities of Ukraine, and 3 were abroad due to the Russian-Ukrainian war). All study participants had a sufficient (7–9 points) and high (10–12 points) level of school performance: 6 study participants have a high level of school performance, and 4 have a sufficient level. Most of them read on average 5–6 h a week (although one high school student reads only 20 min a month, and one of the girls reads 5 h a day). The sample of the study consisted of boys and girls aged 15–17 (girls – 6, boys – 4), because, according to E. Erikson's identity theory, the period of adolescence (15–19 years) is a key stage in the development of personality, when all previously formed life norms and values (including those related to reading practices) are either questioned or reasserted [26]. According to the theory of personality socialization by T. Parsons [27], the age period from 15 to 18 years is formative, as during this time the basic life values of a person are formed, which can change very slowly.

The average duration of the interview was 12 min (minimum – 9, maximum – 18). All interviews were conducted using the ZOOM platform because, although all respondents are residents of Kharkiv, only five of them were in the city at the time of our investigation, and a real meeting with them could be dangerous. In order to meet the ethical standards of conducting sociological research, participants were informed that they could stop the interview at any time and not answer questions that might not be of interest to them. Before the interview, almost all participants asked to read the text of the interview and then agreed to participate in it. No participant refused to answer any questions, so all interviews were completed. With the permission of the research participants, all interviews were audio-recorded and then verbally transcribed. After all interview texts were recorded, they were structured by coding each interview question; all interviews were analyzed both individually and in comparison to each other. The responses of the research participants to each interview question were collected in separate blocks,

followed by qualitative content analysis and interpretation of their content. The empirical material was collected from September 18 to October 9, 2023.

3 The Results of Research

3.1 Reading Practices and Communication on Social Networks

To find out whether social networking sites have really replaced reading practices in modern society, high school students were asked to rank the following genres: literature, movies, video games, and social networking sites. The majority of students ranked social networking sites or movies first, while literature was ranked second or third, and video games were more often ranked fourth. Two girls prioritized literature, and two boys prioritized video games. Students most often cited two reasons why social network communication is important to them: 1) informational (due to the need to keep in touch with friends, teachers, and parents in order to receive necessary information in a timely manner) and 2) communicative (related to the need for social communication, especially with friends, given the lack of time for real meetings). At the same time, high school students did not provide categorical comparative assessments of social network communication and literature in an "either/or" format, as their contents are completely different and therefore not comparable. To summarize the high school students' responses, the purpose of literature is to develop imaginative thinking, imagination, and memory; to evoke vivid emotions; to provide certain standards of behavior and life values that can be imitated in one's own life; to increase vocabulary; to broaden one's language skills and horizons; and to shape one's worldview; to enjoy and even get good grades when reading school literature:

"I think that when you read fiction, but I'll take fiction as an example… For example, The Count of Monte Cristo… As for the character, I really liked the way he achieved his goal and so on. So I really liked his character traits, and sometimes I use them – not even sometimes, but in most situations in my life" (Artem, 16).

"*Literature is sometimes needed not only for entertainment: when you have to read something for school to get a good grade, to answer questions in class, but sometimes just for fun, just to enjoy the book"* (Inna, 16).

"I think that every book (no matter what genre it is, fiction or non-fiction) gives some impetus for reflection… And I think that if you fantasize or imagine something, it cannot affect you in a bad way, and every book develops us somehow" (Diana, 17).

"After reading, I learn some new words that make my speech more beautiful, and in general, I learn some interesting facts that I can use later in communication and that can make me more interesting to others. I think everyone should read because it helps you be smart. You can't just get knowledge from movies or video games" (Vivian, 17).

Despite the fact that social networks take up a lot of time in the daily lives of high school students and despite the fact that, in their opinion, reading practices have actually become less popular among modern teenagers, some study participants emphasized that social networks cannot compete with literature (apparently due to the incompatibility of their tasks, functions, and cultural significance). High school students noted not only a negative but also a positive impact of social network sites on their reading practices, since a modern person has the opportunity to find any necessary literature on the Internet

and is not dependent on buying printed texts; in addition, social networks provide useful information about various literary texts.

"I still like fiction more than any SMS. Because people on Viber don't write me anything as interesting" (Sofia, 16).

"The same social networks as Telegram, Instagram and TikTok have BookTok and Bookstagram, and there are many people from different countries who share book recommendations… Social networks affect different people differently; for those who like to read, they only have a good effect; for those who hate to read… Since they don't like to read anyway, the gadgets probably don't affect them that much" (Diana, 17).

"A lot of people have started to read because books have become more accessible to everyone. It's not a problem to find the book you want" (Roman, 16).

When asked if their attitudes toward literature changed during adolescence (after the age of 14), most high school students answered in the affirmative. High school students began to value reading practices more; one of the reasons for this change is a more conscious perception of reading practices as those that can no longer be completely controlled from the outside (by teachers or parents) but are chosen independently for the purpose of self-improvement. To use the terminology of M. Tegmark, T. Alatalo, M. Vinterek, and M. Winberg [4], we can say that the study participants are guided more by autonomous motivation for reading practices than by external control, and this should have influenced their changed attitude toward fiction in adolescence. The majority of high school students reported that they often chose books to read on their own (outside the required curriculum), although some students reported that they were recommended books by friends, parents, or teachers. Since the participants in our study have sufficient and high academic performance, we can assume that there is a correlation between their academic performance and regular reading practices (on average, they read 5–6 h per week). However, this should be verified by quantitative research.

"When I was very young, I thought reading was boring, but with time, as I got older, I started to like it, and now I read every night before going to bed" (Vivian, 17).

"I used to not like reading at all, but now sometimes I can take a book and sit for a long time and read a lot" (Polina, 15).

However, our conclusion that high school students' attitudes toward literature change positively during adolescence needs additional verification, as it contradicts the results of the study "Reading in the Context of Media Consumption and Life Construction" (N = 1800 children), according to which "a loss of interest in reading is observed in high school: children from the age of 14 start reading less often or stop reading altogether (an increase in the share of answers 'never' and 'several times a year' at the expense of the share of answers 'daily' and 'several times a week')" [28, p. 94]. The difference in the data may have been influenced by the fact that we interviewed students with good and high school grades, studying in secondary schools in Kharkiv, whose students traditionally have a high level of knowledge. In the future, it would be desirable to conduct differentiated studies comparing the attitudes towards reading practices of students with different academic performance attending schools with different profiles and levels.

3.2 Reading Practices of Ukrainian High School Students and Genre Content of the School Literature Curriculum

In our study, we tried to answer the question: is there a correspondence between the literary preferences of high school students and the genre content of the Ukrainian and foreign high school literature curricula? The answer to this question is important because students choose and enjoy reading those literary works that belong to their favorite genres, so the absence (or insignificant representation) of such works in the school curriculum may explain why students have started to read less. This factor may be no less important than the influence of modern technology and social networking sites.

We asked two questions about this problem: "Which literary genres do you like best?" and "Which literary genres do you think are most popular among your peers?" As it turned out, the favorite literary genres of Ukrainian high school students are science fiction, fantasy, thrillers, detective stories, and romance novels. Some students mentioned classical drama and popular science literature (economics). In order to find out whether these genres are represented in the school curriculum of Ukrainian and foreign literature for grades 10 and 11, we conducted a content analysis of these programs based on the following indicators: 1) the number of hours devoted to the study of literary works of a given genre in the school curriculum; 2) the percentage of literary works of a given genre (in relation to works of all genres) in the textbook (see Tables 1 and 2).

As can be seen, Ukrainian literature textbooks for 10th and 11th grades do not present any genres that students like at all (except for Oles Honchar's "Modry Kamen" in the 11th grade textbook, which is written in the genre of a love story and is allocated 2 h (or 4.3% of the total study time in the discipline) (Table 1).

The textbooks of foreign literature for 10th and 11th grades also do not contain the genres preferred by high school students. Thus, there is a discrepancy between the literary genre preferences of Ukrainian high school students and the actual genre content of the curriculum of Ukrainian and foreign literature for grades 10 and 11 (Table 2).

We believe that this discrepancy may have contributed to the fact that not all high school students enjoy reading and to their negative attitudes toward the school literature program. Although the school literature curriculum is interesting and may appeal to literary experts, it does not take into account the literary tastes of those for whom it is intended.

Most of the participants in our study noted two problems with the school literature curriculum: first, that it is "boring", and second, that it is imposed on students (forced to read) without giving them the opportunity to choose more attractive texts and without taking into account young people's literary preferences.

"Many children and teenagers stop reading altogether because of school literature, because they don't like it" (Sofia, 16).

"I can say that the school curriculum puts pressure on what we read. In general, I very, very rarely like books from school literature" (Vivian, 17).

"The school curriculum focuses on every student reading the same thing. But everyone has a different opinion about it, because different people read different books, and the school curriculum is the same, so many people may not like something" (Oleksandra, 15).

Table 1. Literary works in textbooks on Ukrainian literature for 10th and 11th grades (according to the program of R. Movchan), in number of hours of study per year and %.

Genres	Textbook for 10th grade		Textbook for 11th grade	
	Number of hours to study	% to works in all genres	Number of hours to study	% to works in all genres
A social novel-chronicle	5	9.4	–	–
A social and psychological novel	5	9.4	3	6.5
Comedy	4	7.5	–	–
Poems	23	43.5	21	45.6
Psychological short story/narrative	13	24.5	2	4.3
A philosophical short story	3	5.7	2	4.3
A marinist novel	–	–	3	6.6
Humor and satire	–	–	5	10.9
A prose poem	–	–	2	4.3
An adventure novel	–	–	3	6.6
Publicistics	–	–	3	6.6
A love story	–	–	2	4.3
Total	53	100	46	100

"I wouldn't say that the school curriculum is oppressive; it's usually interesting! But of course, it's much more interesting to read what you choose because you know your taste" (Inna, 16).

"I think that before I started choosing my own books, I was under a lot of pressure from the school curriculum. And I understand that it does not depend on the teachers. But I remember when we were in the seventh grade, there was a story about the mermaid, but it was very, very strange, and we were told that it was contemporary literature, but it was probably the worst contemporary book I've ever read in my life… I think literature in school is very pressured. It was not a very good experience for me. I did not read. And one of the reasons is school literature. I was not interested in it. And it seemed to me that there were no books in the world that I wanted to read because, at school, they were uninteresting and sad" (Diana, 17).

Table 2. Literary works in textbooks on foreign literature for 10th and 11th grades (according to the program of O. Nikolenko), in number of hours per year and %.

Genres	Textbook for 10th grade		Textbook for 11th grade	
	Number of hours to study	% to works in all genres	Number of hours to study	% to works in all genres
An epic poem	2	6.7	–	–
A poem	2	6.7	–	–
Tragedy	3	10	3	11.5
A romantic satirical story	3	10	–	–
Poems	7	23.2	6	23
A social and psychological novel	6	20	–	–
Drama	3	10	2	7.7
A historical and psychological novel	2	6.7	–	–
A teenage story	2	6.7	–	–
A philosophical short story	–	–	2	7.7
A philosophical novel	–	–	4	15.4
A dystopian novel	–	–	2	7.7
A story-parable	–	–	2	7.7
Story	–	–	5	19.3
Total	30	100	26	100

In an electronic media society, it is no longer possible to simply forbid students from using electronic devices and communicating on social networking sites, forcing them to read more. We believe that the best way to encourage reading is to provide students with literary works that appeal to them in terms of genre, plot, and ideas. Perhaps the genre attractiveness of the school literature curriculum can become a more powerful "pull" factor for students than the "push" influence of social networking sites.

4 Conclusions

In order to prevent social network communication from completely replacing reading practices and making them completely unpopular among Ukrainian high school students, it is necessary to reform school curricula in Ukrainian and foreign literature and include

more literary works of genres that high school students like (science fiction, fantasy, detective stories, and love novels). The task of the school literary curriculum should be not only to familiarize students with classical literary works for the purpose of their general cultural development but also to engage students in reading because reading practice develops analytical, critical, and imaginative thinking and, as Western researchers have shown, correlates with children's academic performance in the humanities and sciences.

Since students prefer to read books that they find on their own (guided by autonomous rather than controlled motivation to read), it is advisable to provide students with more opportunities to choose works from Ukrainian and foreign literature, which may help ensure that not only leisure but also school reading practices are carried out "with pleasure" rather than under external coercion. In this case, the quality and effectiveness of students' reading practices can only increase.

In the future, it would be desirable to conduct a large-scale quantitative study of Ukrainian schoolchildren's reading practices, which would differentiate the effectiveness of students' reading practices depending on their age, gender, school performance, and interest in the humanities or sciences. It is interesting to find out which agents of reading skill development (parents, teachers, and friends) and at what age children are more effective in shaping their reading skills. In addition, it is advisable to study whether higher education has a corrective function in the development of students' reading practices; whether students begin to read more and more regularly at university compared to the school period of their lives; or, conversely, whether students who do not like to read remain indifferent to reading practices in later periods of their lives.

References

1. Mirzoeff, N.: An Introduction to Visual Culture. Routledge, New York (1999)
2. Merga, M.K.: Should silent reading feature in a secondary school English programme? West Australian students' perspectives on silent reading. Engl. Educ. **47**(3), 229–244 (2013)
3. Swanson, E., et al.: Literacy and text reading in middle and high school social studies and English language arts classrooms. Read. Writ. Q. **32**(3), 199–222 (2016)
4. Tegmark, M., Alatalo, T., Vinterek, M., Winberg, M.: What motivates students to read at school? Student views on reading practices in middle and lower-secondary school. J. Res. Reading **45**(1), 100–118 (2022)
5. Whitten, C., Labby, S., Sullivan, S.: The impact of pleasure reading on academic success. J. Multidiscip. Grad. Res. **2**(4), 48–64 (2016)
6. Bourdieu, P.: In: Randal Johnson (ed.). The Field of Cultural Production: Essays on Art and Literature. Columbia University Press (1993)
7. Antipkina, I., Kuznetsova, M., Kardanova, E.: What factors help and hinder children's progress in reading? Educ. Stud. **2**, 206–233 (2017)
8. Zakharov, A., Kapuza, A.: Parental teaching-to-read practices and children's reading literacy according to PIRLS. Educ. Stud. **2**, 234–257 (2017)
9. Hattie, J., Dörfler, T., Artelt, C.: Individual differences in reading development: a review of 25 years of empirical research on Matthew effects in reading. Rev. Educ. Res. **84**(2), 203–244 (2014)
10. Herbers, J.E., Cutuli, J.J., Supkoff, L.M., et al.: Early reading skills and academic achievement trajectories of students facing poverty, homelessness, and high residential mobility. Educ. Res. **41**(9), 366–374 (2012)

11. Bourdieu, P.: The school as a conservative force: scholastic and cultural inequalities. In: Eggleston, J. (ed.) Contemporary Research in the Sociology of Education, pp. 32–46. Methuen, London (1974)
12. Davis-Kean, P.E.: The influence of parent education and family income on child achievement: the indirect role of parental expectations and the home environment. J. Fam. Psychol. **19**(2), 294–304 (2005)
13. Sirin, S.R.: Socioeconomic status and academic achievement: a meta-analytic review of research. Rev. Educ. Res. **75**(3), 417–453 (2005)
14. Becker, M., McElvany, N.: The interplay of gender and social background. A longitudinal study of interaction effects in reading attitudes and behavior. Br. J. Educ. Psychol. **88**(4), 529–549 (2018)
15. McGeown, S., Goodwin, H., Henderson, N., Wright, P.: Gender differences in reading motivation: does sex or gender identity provide a better account? J. Res. Reading **35**(3), 328–336 (2012)
16. Wigfield, A., Gladstone, J.R., Turci, L.: Beyond cognition: reading motivation and reading comprehension. Child Develop. Perspect. **10**(3), 190–195 (2016)
17. Troyer, M., Kim, J.S., Hale, E., Wantchekon, K.A., Amstrong, C.: Relations among intrinsic and extrinsic reading motivation, reading amount, and comprehension: a conceptual replication. Read. Writ. **32**(5), 1197–1218 (2019)
18. Benjamin, R.G.: Reconstructing readability: recent developments and recommendations in the analysis of text difficulty. Educ. Psychol. Rev. **24**(1), 63–88 (2012)
19. Bataeva, E.: Motivational content analysis of primary school textbooks on literature in context of D. McClelland's theory. Educ. Sci. J. **20**(1), 136–151 (2018)
20. Mesmer, H.A., Cunningham, J.W., Hiebert, E.H.: Toward a theoretical model of text complexity for the early grades: learning from the past, anticipating the future. Read. Res. Q. **47**(3), 235–258 (2012)
21. Vaknin-Nusbaum, V., Tuckwiller, E.: Reading motivation, well-being and reading achievement in second grade students. J. Res. Reading **46**(1), 64–85 (2023)
22. Wu, R., Liu, F., Situ, X., Huang, W.: "Reading A book, by A Gain in Your Wit" How to cultivate high school students' sustainable reading: a multi-factor analysis. Heliyon **9**, e23333 (2023)
23. Main, S., Hill, S., Paolino, A.: Improving the reading skills of struggling secondary students in a real-world setting: issues of implementation and sustainability. Austr. J. Learn. Difficult. **28**(1), 73–95 (2023)
24. Smart, D., Youssef, G.J., Sanson, A., Prior, M., Toumbourou, J.W., Olsson, C.A.: Consequences of childhood reading difficulties and behaviour problems for educational achievement and employment in early adulthood. Br. J. Educ. Psychol. **87**(2), 288–308 (2017)
25. McLuhan, H.M.: Understanding Media: The Extensions of Man. MIT Press, London and New York (1994)
26. Erikson, E.: Childhood and Society, 2nd edn. W. W. Norton & Company, New York (1993)
27. Parsons, T.: The Social System. Routledge, London (2005)
28. Volosevych, I., Shurenkova, A.: Reading in the context of media consumption and life design (2020). https://drive.google.com/drive/folders/1KCC8ZkOAXTWInqRTRchHzpVzUhKtxSf5. Accessed 10 Nov 2023

The System of Protection of Social Rights in Ukraine and the EU: European and National Dimension

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Abstract. The article presents a comparative analysis of the legal mechanism of protection of the social rights system in Ukraine and the European Community. The authors explored a number of key concepts, in particular, the concepts of protection, social rights, protection of social rights in Ukraine and the EU. The basic means of legal regulation of social rights at the international and national levels are outlined. The peculiarities of normative consolidation of social rights in the countries of the European Union, normative consolidation in the national legislation for the purpose of adaptation of effective norms and mechanisms of the developed countries are considered. It is claimed that the fundamental rights and responsibilities, protection of such rights are enshrined in the Constitution of Ukraine, the Law that has the highest force. The most important issues of maintaining the maximum allowable level of implementation of a number of social rights of citizens, in particular, in a pandemic, as well as the protection of social rights of participants in the anti-terrorist operation were raised as relevant in this work.

Keywords: protection · social protection · social rights · protection of social rights · anti-terrorist operation participants · coronavirus

1 Introduction

Human protection is the basis of the existence of any democratic society, and the formation of a democratic state means the recognition of their absolute power as the main goal of maintaining the proper state, further evolution and balance of interests of civil society and the state.

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Ukraine is on the path to joining the European Union, in which countries have developed models of social protection. This necessitates the study and generalization of existing experience of developed countries for use in practice in domestic legislation.

2 Literature Review

Certain issues of the legal nature of social rights, their features and criteria for their classification have been considered in the works of the following scholars: Byk T., Fedorova, A.L., Kovbasyuk Yu. V., Kovtun V.I., Rabinovich P.M., Skakun O., Turuta O.V., Volkova O.M. and others.

Research on the protection of social human rights has always been of interest to scientists in different periods of science development. However, the number of studies of the mechanism of social rights protection on the example of Ukraine and the EU is rather low. In addition, today, in the context of a full-scale war, the issue of social rights protection has become more relevant, and the massive violations of human rights in general raise serious concerns about the possibility of finding an effective mechanism for their protection. Research on the recognition and prospects for the protection of social rights in the context of full-scale wars and cataclysms is rather fragmented. There are currently no conceptual studies on the development of an effective mechanism for the protection of social human rights in the context of the Russian-Ukrainian war.

Scientific approaches and practical mechanisms for determining optimal mechanisms for the protection of social human rights require further in-depth analysis and development. It is important to study the experience of EU countries in this regard. The issue of means of legal regulation of social rights at the international and national levels is also important. The main goal of scholars today should be to identify ways to adapt effective norms and mechanisms of developed countries.

3 Main Content Presentation

3.1 The Concept and Legal Nature of Social Rights

One of the principles of the United Nations is the obligation to raise the level and qualitative characteristics of life of the population, care and concern for those in need. Given the European integration in Ukraine, most spheres of life are being reformed, including social protection. However, reforms in the field of social protection are impossible without improving or adjusting national legislation to bring it into line with existing international instruments, as the perfection of the legal mechanism means its ability to meet these needs [1].

In Art. 22 of the Universal Declaration of Human Rights stipulates that “Everyone, as a member of society, has the right to social security and is entitled to realization, through national effort and international co-operation and in accordance with the organization and resources of each State, of the economic, social and cultural rights indispensable for his dignity and the free development of his personality” [2].

Social rights and mechanisms for their protection are increasingly being developed at both the national and international universal and regional levels. At the beginning of

the XXI century, most democracies in Europe and the world, declaring themselves the rule of law or states that have embarked on this path of development, recognize and consolidate the need to build a welfare state [3].

Despite the critical situation in Ukraine in this area and the need for large-scale reform of the social protection system, bringing domestic legislation in line with European social standards. Therefore, the study of international mechanisms for the protection of social human rights, international social standards and the process of their implementation in Ukraine are important for the further development of the country. The creation of a social sphere linked to a dignified life and well-being is one of the main tasks of the Council of Europe, and social policy is enshrined in the Maastricht Treaty as one of the priorities of the European Union. Strengthening the protection of social rights is also within the UN [3].

A step towards adapting the institution of social policy was the ratification by Ukraine on September 14, 2006 of the European Social Charter (revised), which entered into force on February 1, 2007. The provisions of this Charter protect such important social rights as the right to work safe and healthy working conditions, the right to fair remuneration, the right to form organizations and to conclude collective agreements, the right of children and adolescents to protection, the right to social security and health care, the right to social and medical assistance, the family's right to social, legal and economic protection, including children and adolescents, the right of men and women to equal opportunities and equal treatment in matters of employment, the right to protection of migrant workers and their families, etc. [4].

The Association Agreement between Ukraine, of the one part, and the European Union, the European Atomic Energy Community and their Member States, of the other part, prioritizes the gradual rapprochement of the Parties based on common values and close privileged ties, as well as deepening Ukraine's connection with EU policy and its participation in programs and agencies [5].

Given the threats (terrorism, transnational crime, nuclear proliferation, environmental issues, etc.), the issue of social rights has taken "almost central place" [6].

It should be borne in mind that the definitions of "protection of social rights" and "social protection" are interrelated, but not identical concepts [7]. The protection of social human rights should be considered, first of all, on the protection of the whole complex of human and civil rights - as the restoration of violated rights. The specialized literature defines the social rights of a person as his "opportunities to exercise their abilities to ensure a decent standard of living for themselves and their families, employment and in cases provided by law opportunities to claim from the state certain material benefits" [8].

Going directly to the protection of social rights, it is first necessary to find out what they are. Thus, social rights in the scientific literature are considered as certain human capabilities that are necessary for its existence and development in specific historical conditions, are determined by the achieved level of human development and should be common, equal for all people [9]. Or, as opportunities (freedom) of the individual and the citizen to freely dispose of their labor, use it independently or in accordance with the employment contract, i.e. the right to free labor (choice of activity, harmless working

conditions, guaranteed minimum wage, etc.), the right to social provision, recreation, education, decent standard of living, etc." [10].

Social rights are also called the realization of which is connected with the satisfaction of the most important social needs of a person: the right to work, to proper, safe and healthy working conditions, to a salary not lower than that determined by law; the right to timely remuneration for work; right to strike; on holiday; for housing; a sufficient standard of living for themselves and their family members; the right to health care, medical assistance and medical insurance; the right to social protection, including the right to provide them in case of complete, partial or temporary disability, loss of bread-winner, unemployment due to circumstances beyond their control, as well as in old age and in other cases provided by law [11].

We consider the latter definition to be the most appropriate, as it most widely reveals the concept of social rights. As for the concept of "protection", it is often identified with "protection". Thus, the word "protection" is defined as patronage, protection, support [12].

V.M. Vedyakhin, believes that the right should be protected not only in the case of an offense, but also in the presence of a threat of violation of rights and legitimate interests [13].

The concept of "protection" is defined as that "protects, serves as a defense; protects by protecting". And "protection" is explained by the concept of "protect" [14].

3.2 International Standards of Legal Regulation and Security of Social Rights

The concept of social human rights was mentioned in such international legal acts as the Universal Declaration of Human Rights in 1948, the European Social Charter in 1961 (revised in 1990), the European Social Security Code in 1964, and the International Covenant on Civil and Political Rights. UN 1966, European Convention on Social Security 1972, European Convention on the Legal Status of Migrant Workers 1977, etc.

According to these acts, the basic social rights include the right to social security, work, leisure, adequate living standards, medical care, education, housing, the right of working migrants as well as members of their families to security and behalf, and so on.

The European Social Charter (1961) supplemented its previous European Convention on Human Rights. The Charter contains such social rights as: the right to work, fair working conditions, fair remuneration, social service, social and medical aid, exercise of social facilities, etc.

The ECC is a unique modern agreement not only for the scope of enshrined social and economic rights, but also for the established control mechanism, which provides for two main procedures: common to all participants - consideration of state reports and optional - consideration of collective complaints, which is attended by 27 states. As a result of consideration of the reports of the states, conclusions may be adopted by the European Committee of Social Rights. In cases of inaction of states on the adopted negative conclusions, the Committee of Ministers may adopt recommendations, pointing out the inconsistencies established by the Committee on Social Rights with national provisions or practices of the Charter. Based on the results of the review of collective complaints, the European Committee of Social Rights can make a decision on the merits, and the

Committee of Ministers in a resolution recommends the respondent state to bring its legislation and/or practice in line with the Charter [15].

New modern views on the fundamental nature of social rights have made it possible to develop and adopt in 2008 an Optional Protocol to the International Covenant on Economic, Social and Cultural Rights. For the first time at the universal level, the Protocol provided for a procedure for dealing with complaints of violations of the rights enshrined in the Covenant, in particular, the right to social security, including social insurance, fair wages, paid leave and leave for women who have given birth, the right to safe and healthy working environment, education, health, etc.

The Protocol provides that everyone has the right at the universal level to complain about violations of fundamental social, economic and cultural rights. Applicants under Article 2 of the Protocol may be any person, which sojourn under the jurisdiction of a State Party or a group of persons or persons acting on their behalf; the procedure of consideration of interstate communications is also fixed [3].

In 2009, the Protocol was signed by Ukraine, whose representatives proclaimed that the accession of our country to this document demonstrates the continuity of Ukraine's desire to fully realize and guarantee human rights and freedoms, including economic, social and cultural. However, the issue of ratification of the Protocol has not been considered for more than 4 years since its signing. Thus, states at the international level confirm their understanding of human rights as a single set of civil, political, socio-economic and other rights as indivisible and interdependent, which is reflected in international instruments [3].

An important step towards the protection of social rights was the adoption of The European Disability Strategy (2010) for 2010–2020. The main objectives of the Strategy are: "1. Accessibility: to make goods and services accessible to people with disabilities and to promote the market for assistive devices. 2. Participation: to ensure that people with disabilities enjoy all the benefits of EU citizenship; remove obstacles to equal participation in public life and leisure; promote the provision of quality community-based services. 3. Equality: combating discrimination on the grounds of disability and promoting equal opportunities. 4. Employment: significantly increase the share of people with disabilities working in the open labor market. 5. Education and training: to promote inclusive education and lifelong learning for students and students with disabilities. 6. Social protection: promoting decent living conditions, combating poverty and social exclusion. 7. Health: Promote equal access to health care and facilities. 8. External actions: promoting the rights of people with disabilities in the framework of EU enlargement and international development programs" [16].

Also important is the development of the European Pillar of Social Rights in 2017. "The main provisions of this declaration include: child care and child support. Children have the right to affordable and quality preschool education. Children have the right to protection from poverty. Children from disadvantaged backgrounds have the right to specific measures to promote equal opportunities; Social Protection. Regardless of the type and duration of their employment, workers and, under comparable conditions, the self-employed have the right to adequate social protection; unemployment benefits. The unemployed have the right to adequate support for the revitalization of public employment services for (re) integration into the labor market and adequate unemployment

benefits for a reasonable duration, in accordance with their contribution and national eligibility rules. Such benefits are not an obstacle to a quick return to work; minimum income. Everyone who lacks sufficient resources has the right to adequate assistance with a minimum income that ensures a dignified life at all stages of life and effective access to goods and services. For those who are able to work, the minimum income benefit must be combined with incentives to (reintegration into the labor market; old-age and retirement income. Retired workers and self-employed people are entitled to a pension according to their contributions and ensuring an adequate income Women and men have equal opportunities to acquire pension rights, everyone in old age has the right to resources that ensure the dignity of life, health care. Everyone has the right to timely access to quality, preventive and curative medical care of appropriate quality; inclusion of people with disabilities. People with disabilities have the right to income support that provides a decent life, services that enable them to participate in the labor market and society, and a work environment adapted to their needs. Long-term care. Everyone has the right to affordable, long-term care services, including childcare and community-based services. Housing and assistance to the homeless. Access to social housing or housing assistance of adequate quality should be provided for those in need. Vulnerable people have the right to appropriate assistance and protection from forced evictions. The homeless will be provided with appropriate shelters and services to promote their social inclusion. Access to basic services Everyone has the right to access basic services of adequate quality, including water, sanitation, energy, transport, financial services and digital communications. For those in need, there should be support for access to such services" [17].

3.3 National Mechanisms for the Protection of Social Rights

The formal definition of the goals of Ukraine's social policy integration into EU standards was facilitated by the adoption of the Partnership and Cooperation Agreement between Ukraine and the European Communities and their Member States (1994), the EU Common Position on Ukraine (1994), and the EU Common Strategy on Ukraine. 1999), the EU-Ukraine Action Plan (2005), the EU-Ukraine Association Agenda (2009), the Joint Declaration of the Prague Partnership on the Eastern Partnership (2009), and other Council Decisions EU declarations and EU documents, which provided for the creation of the foundations of mutually beneficial socio-economic, scientific, technical, cultural cooperation with Ukraine [5].

One of the first legal acts that actually legalized the legal basis for the functioning of mechanisms for the security of social human rights in Ukraine, was the Law of the USSR "On Economic Independence of the Ukrainian SSR" from 03.08.1990 № 142-XII, which among the main goals of economic independence ensuring social protection of every citizen of Ukraine, and also provided that the state provides social protection of citizens. Among the further stages of the formation of mechanisms for the protection of social human rights is the Concept of social security of the population of Ukraine, approved by the Verkhovna Rada of 21.12.1993 № 3758-XII, which laid the foundations of legal and regulatory framework for social security and compliance with state guarantees of social and economic rights. citizens [7].

The function of guaranteeing the protection of human and civil rights, freedoms follows from the task of the Constitutional Court of Ukraine (Article 147 of the Constitution, Article 2 of the Law "On the Constitutional Court of Ukraine" of 16.10.1996 № 422/96-VR): to guarantee the supremacy of the Constitution throughout the country, including norms on human rights and freedoms. The role of the Court in the protection of constitutional rights and freedoms of man and citizen is more clearly stated in the article on the constitutional appeal (Article 42 of the Law "On the CCU"). Finally, an important guarantee of human and civil rights and freedoms are the norms enshrined in the Constitution (Articles 157, 159) on the establishment by the Court of preliminary control over the compliance of a bill amending the Constitution [7].

Social rights and their protection in Ukraine are defined in the Constitution of Ukraine. Thus, in Part 4 of Art. 13 of the Constitution of Ukraine states: "The state provides protection of the rights of all subjects of property and economic rights, social orientation of the economy. It should be noted that the norms of the Constitution of Ukraine contain both elements of social rights and directly establish them. Yes, Art. 23 "Everyone has the right to the free development of his personality, provided that the rights and freedoms of others are not violated, and has responsibilities to a society in which the free and comprehensive development of his personality is ensured", Art. 28 "Everyone has the right to respect for his dignity", 36 "Citizens of Ukraine have the right to freedom of association in political parties and public organizations to exercise and protect their rights and freedoms and to satisfy political, economic, social, cultural and other interests, except for restrictions established by law in the interests of national security and public order, public health or protection of the rights and freedoms of others", Art. 39 "Citizens have the right to assemble peacefully, without weapons and to hold meetings, rallies, marches and demonstrations, which are notified in advance by the executive authorities or local governments", Art. 41 "Everyone has the right to own, use and dispose of their property, the results of their intellectual, creative activities" and so on.

It is necessary to name separately Art. 46 of the Constitution, which stipulates that citizens have the right to social protection, which includes the right to provide them in case of complete, partial or temporary disability, loss of breadwinner, unemployment due to circumstances beyond their control, as well as in old age and in other cases provided by law; Art. 47 Everyone has the right to housing. The state creates conditions under which every citizen will be able to build housing, buy it or rent it; Art. 48 Everyone has the right to an adequate standard of living for himself and his family, including adequate food, clothing and shelter; Art. 49 Everyone has the right to health care, medical assistance and medical insurance [18].

3.4 Social Protection of Certain Categories of Citizens

Today, the main problems that need to be addressed immediately in the outlined issues are the protection of social rights of members in the anti-terrorist operation (ATO), today called the Joint Forces Operation (JFO).

Legal regulation of social support of ATO participants is aimed at forming an effective system of ensuring their social rights and freedoms, in particular regarding psychological support, financial assistance, spa treatment, guarantees of education, prosthetics in case

of loss of functional properties of limbs, provision of vehicles, benefits in the payment of certain types of services, pensions, housing or land, observance of labor rights, in particular regarding the preservation of jobs and average earnings while participating in the anti-terrorist operation, etc. [19].

However, in the regulations providing for social protection of ATO participants, according to experts, there is a coexistence of "Soviet" (social security, benefits, social and compensation benefits) and the latest European approach (social services, social work). Most social standards remain declarations due to the obsolescence and ineffectiveness of existing social protection mechanisms, non-targeting, equalizing and inconsistency of the social protection system with the real needs of Ukrainian society, inefficiency and non-transparency of the system of budget financing of social expenditures of the state, debatable direct effect of constitutional norms on social rights [19].

Constitutional regulation of social protection of anti-terrorist operation participants is carried out on the basis of the Constitution of Ukraine. It defines the guarantees of social protection of this category of persons: "The state provides social protection to citizens of Ukraine who are serving in the Armed Forces of Ukraine and other military formations, as well as members of their families". These constitutional provisions are the legal basis for other legislative acts on social protection of ATO participants. Despite the fact that the norms of the Constitution of Ukraine are norms of direct action, they cannot regulate in detail all aspects of social protection of anti-terrorist operation participants. Therefore, the norms enshrined in the Constitution of Ukraine are further developed and specified in laws, decrees of the President of Ukraine, resolutions of the Cabinet of Ministers of Ukraine, orders of ministries and other regulations [19].

The existing array of normative legal acts, even sectoral ones, does not regulate all issues related to social protection of anti-terrorist operation participants. Among them are the following: - Lack of the Concept of medical, socio-psychological rehabilitation and professional adaptation of ATO participants; - lack of a national program aimed at social protection of ATO participants; - lack of a mechanism for social and psychological rehabilitation of anti-terrorist operation participants and members of their families and its legal regulation; - Lack of a single mechanism for accounting for anti-terrorist operation participants and related problems, in particular for identifying family members of deceased anti-terrorist operation participants from the general mass of combatants, for identifying disabled people due to participation in anti-terrorist operation from the total number of war participants, etc. In addition to the above issues, among the areas of further research should be offered the study of international experience in this area, as well as a study of the institutional structure of the process of social protection of ATO participants and their families [20].

For example, the issue of providing land plots to certain named persons is problematic. In particular, the Law of Ukraine "On the Status of War Veterans, Guarantees of Their Social Protection" establishes that combatants and persons equated to them are entitled, in particular, to such benefits as priority housing for persons in need of better living conditions and priority allotment land plots for individual housing construction, horticulture and gardening, priority repair of houses and apartments of these persons and providing them with fuel [21].

Also, a key, important point remains the protection of official rights in a pandemic. It is known that the whole world has been affected by coronavirus respiratory disease.

The right of every citizen to health care and medical assistance is established by Article 46 of the Constitution of Ukraine. In particular, health care is provided by state funding of relevant socio-economic, health and health prevention programs. The state ensures sanitary and epidemiological well-being.

Also, the state provides systematic scientifically based prevention, treatment, localization and elimination of mass infectious diseases. Legal, organizational and financial principles of executive bodies, local governments, enterprises, institutions and organizations aimed at preventing the spread and spread of infectious human diseases, localization and elimination of outbreaks and epidemics, rights, duties and responsibilities of legal entities and individuals in the field of protection of the population from infectious diseases are defined by the Law of Ukraine "On protection of the population from infectious diseases".

Thus, the protection of the population from infectious diseases is determined by one of the priority activities of the executive authorities and local governments.

In the field of protection of the population from infectious diseases, the Cabinet of Ministers of Ukraine develops and implements relevant state target programs, provides financing and logistics of health care facilities, institutions and institutions of the State Sanitary and Epidemiological Service, enterprises, institutions and organizations involved in activities. And work related to the elimination of epidemics, coordinates the implementation of these measures and works, as well as resolves other issues within the powers defined by law.

At the same time, in this area, local governments provide preventive and anti-epidemic measures in settlements, places of public recreation and recreational areas, as well as work to eliminate epidemics and outbreaks of infectious diseases and address issues of financial and logistical support of these activities and works.

In addition, local governments take comprehensive measures to eliminate epidemics, outbreaks of infectious diseases and their consequences, and ensure participation in the fight against infectious diseases of health care facilities and institutions of all forms of ownership, as well as resolve other issues within the powers defined by law.

The specially authorized central executive body for health protection in the field of protection of the population from infectious diseases develops, approves and puts into effect sanitary and anti-epidemic rules and norms, methods of examination and treatment of patients, diagnostics and prevention of infectious diseases, other normative legal acts [22].

The Regulation on the Ministry of Health of Ukraine, approved by the Resolution of the Cabinet of Ministers of Ukraine of November 2, 2006 No. 1542 stipulates that the Ministry of Health prepares proposals to ensure sanitary and epidemic well-being of the population, prevention of introduction and spread on the territory of Ukraine. Dangerous (including quarantine) and dangerous infectious diseases, as well as controls the elimination of the causes and conditions of occurrence and spread of infectious diseases, mass non-communicable diseases, poisoning and radiation damage to humans [22].

Under these conditions, the Law of Ukraine № 540-IX of 24.06.2020 "On Amendments to Certain Legislative Acts of Ukraine Aimed at Providing Additional Social and Economic Guarantees in Connection with the Spread of Coronavirus Disease (COVID-19)" was adopted (Section IX of the Final and Transitional Provisions) of the Cabinet of Ministers of Ukraine: to take measures to prevent a reduction in pension payments, as well as to index pensions, after the completion of measures to prevent the emergence and spread of coronavirus disease (COVID-19), provided for in the quarantine established by the Cabinet of Ministers of Ukraine. "Take measures to prevent reduction of state social assistance payments, as well as indexation of payments, after completion of measures to prevent the emergence and spread of coronavirus disease (COVID-19) provided by the Cabinet of Ministers of Ukraine" [23].

In addition, the Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Aimed at Providing Additional Social and Economic Guarantees in Connection with the Spread of Coronavirus Disease (COVID-19)" contains the following key provisions:

1) the Cabinet of Ministers will set a surcharge of up to 300% of salaries for medical and other workers directly involved in the elimination of coronavirus disease among people, and for social protection workers who provide services to citizens who are at home - up to 100% of salary;
2) limits have been raised for groups of single tax payers of natural persons - entrepreneurs: the first group - from UAH 300,000 to UAH 1 million, the second group - from UAH 1.5 to 5 million, the third group - from UAH 5 to 7 million;
3) operations on importation into the customs territory of Ukraine of drugs, medical devices and equipment for counteracting COVID-19 and their supply are exempt from VAT;
4) temporarily, until May 31, 2020, the excise tax is levied at the rate of 0 hryvnias per 1 L of 100% alcohol from ethyl alcohol used for the production of disinfectants;
5) payment for land and real estate tax are not paid from March 1 to March 31, 2020;
6) penalties for non-payment or late payment of the single social contribution (SSC), failure to submit (late submission) of reports on the payment of SSC are not applied from March 1 to May 31;
7) during the quarantine period, the participants in the court case may participate in the court session by videoconference outside the court premises using their own technical means;
8) the right of the court during quarantine to make a decision on restricting the access of persons who are not participants in the trial to the court hearing, if participation in the court hearing will endanger the life or health of the person;
9) for the period of quarantine, it is prohibited to increase the interest rate under the loan agreement;
10) rules of remote work of employees are introduced: the general norm of working hours is provided by the Labor Code of Ukraine, employees distribute working hours at their discretion, remote work does not entail any restrictions on labor rights, salary reduction;
11) at the request of the employer, partial unemployment benefits will be paid to employees who have not been fired, but whose salary and working hours have been reduced by the employer (only for small and medium enterprises);

12) the payment of state aid to low-income families, other types of state aid, disability pension for the period of quarantine continues;
13) for the period of quarantine, the Government will have the right to set maximum prices for anti-epidemic goods and social goods;
14) for the period of quarantine local councils, their executive committees will have the right to hold remote meetings by videoconference or audioconference, the agenda of which may include only issues of urgent changes to the local budget, other issues of urgent emergency response or liquidation as soon as possible particularly severe emergencies caused by outbreaks, epidemics and pandemics;
15) journalists are guaranteed, as before, unimpeded movement on the territory of Ukraine, including in the territories where an emergency situation has been declared [24]

4 Conclusions

Today, the importance of social rights, the development of an effective mechanism for their implementation and consolidation at the legislative level does not raise questions. Ukraine, committing itself to approximation and adaptation of national legislation to EU legislation, has made gradual convergence a priority, based on common values and close privileged ties, as well as deepening Ukraine's ties with EU policy and its participation in programs and programs agencies.

Resolving the issue of the proper provision of social rights by states is necessary for millions of people in each country. The implementation of international social standards and the recognition by states of mandatory complaint handling procedures should help to increase the level of social protection of people.

Thus, the need to reform social legislation considering its standards is one of the urgent problems of our state, the delay in carrying out reforms can not only negatively affect the economy, but also the future of the state as a whole.

References

1. Turuta, O.V.: Social human rights in Ukraine. Scientific Bulletin of Uzhhorod National University: Series: Law. Helvetica Publishing House, Uzhhorod, No. 24, vol. 1, pp. 112–115 (2014)
2. Universal Declaration of Human Rights (2008). Official Gazette of Ukraine on 15.12.2008. No 93. Art. 3103. https://zakon.rada.gov.ua/laws/show/995_015#Text
3. Fedorova, A.L.: Main tendencies and problems of development of international mechanisms of protection of social human rights. Curr. Iss. Int. Relat. **117**(1), 48–54 (2013)
4. Kovbasyuk, Y.V.: European social standards: perspectives for Ukraine (political-diplomatic context). Sci. Bull. Diplomatic Acad. Ukraine **21**(2), 13–21 (2014)
5. Association Agreement between Ukraine, of the one part, and the European Union, the European Atomic Energy Community and their Member States, of the other part 984_011 of 30.11.2015: Official Gazette of Ukraine of 26.09.2014. № 75. Volume 1. Art. 2125
6. Kovtun, V.I.: Social rights in the aspect of the human rights system. Law Soc. **3**(1), 17–21 (2016)
7. Byk, T.: Concepts and legal bases of protection of social human rights in Ukraine. Legal Ukraine, No 1, pp. 16–22 (2010)

8. Volkova, O.M.: Social rights of the person: questions of the theory: extended abstract of the thesis. Cand. Law. 12.00.01. – Kyiv, p. 20 (2011)
9. Rabinovich, P.: Limits of human rights (some issues of general theory). Ukrainian J. Hum. Rights, No 3–4, pp. 14–18 (1997)
10. Skakun, O.: Theory of State and Law. Kharkiv, p. 704 (2000)
11. Kivalov, S.V., Orzikh, M.F. (ed.): Fundamentals of jurisprudence: a textbook. Odessa: Astroprint, p. 356 (2000)
12. Busel, V.T.: Large explanatory dictionary of the modern Ukrainian language (with add.) /chief ed. V. T. Busel. Kyiv, Irpen: WTF "Perun". p. 1728 (2005)
13. Vedyakhin, V.M.: Protection measures as a legal category. Law and politics. Nota Bene, Moskow, No. 5, pp. 21–34 (2005)
14. Ozhegov, S.I.: Dictionary of the Russian language. S.I. Ozhegov; under ed. Dr. philol. Sciences, Prof. N.Yu. Swedish. Moskow: Russian Language, p. 736 (1984)
15. Fedorova, A.L.: Ukraine's obligations under the European Social Charter (revised): legal consequences in case of non-compliance. Scientific notes of NaUKMA. Legal Sciences, vol. 168, pp. 77–81 (2015)
16. The European Disability Strategy. https://ec.europa.eu/eip/ageing/standards/general/generaldocuments/european-disability-strategy-20102020_en
17. European Commission. European Pillar of Social Rights. https://ec.europa.eu/commission/priorities/deeper-and-fairer-economic-and-monetary-union/european-pillar-social-rights/european-pillar-social-rights-20-principles_en
18. The Constitution of Ukraine: The Verkhovna Rada Bulletin, No. 30. – Art. 141 (l996)
19. Chizhov, D.A.: Regulatory and legal provision of the right to social protection of anti-terrorist operation participants and members of their families. Bulletin of the National University "Lviv Polytechnic". Legal sciences, No 845, pp. 173–182 (2016)
20. Kondratenko, O.O.: General principles of regulatory and legal support of public administration in the field of social protection of the participants of the anti-terrorist heriterierist. Social and humanities policy (2016). http://visnyk.academy.gov.ua/wp-content/uploads/2016/01/2015_4_17_ukr.pdf
21. Petryshyn, O.V., Savchuk, O.O., Lyubchych, A.M.: Some problematic issues of procedures related to land disputes. Economic and legal problems of development and promotion of economic activity in modern conditions. – Kharkiv: Research Institute of NAPRN of Ukraine, 2019. pp. 6-1 (2016)
22. Legal regulation of relations in the field of protection of the population from infectious diseases. https://minjust.gov.ua/m/str_24798
23. Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Aimed at Providing Additional Social and Economic Guarantees in Connection with the Spread of Coronavirus Disease (COVID–19)" (2020). The Verkhovna Rada Bulletin. – 2020. – No 18. – Art.123
24. Press Service of the Verkhovna Rada Office. https://iportal.rada.gov.ua/news/Top-novyna/191743.html

Conducting Business Activities in Special Conditions: Problems of Legal Regulation

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Abstract. This article explores the problems of conducting business in conditions that differ from generally accepted standards and norms. Special conditions may include situations such as economic crises, natural disasters, martial law, or other circumstances that affect the normal conduct of business. The study defines the concept of "special conditions", considers the problems of legal regulation and legislative consolidation of the rules that can be applied in these situations, as well as assesses their effectiveness and possible shortcomings.

In addition, the paper improves the understanding of the impact of special conditions on various sectors of the economy, including industry, the financial sector, agriculture, and small and medium-sized businesses. Possible strategies for adaptation and survival of Ukrainian business entities in such conditions are analyzed, considering their social and economic responsibility.

The article identifies the peculiarities of economic activity in the context of the introduction of special economic regimes of a restrictive and incentive nature, during a pandemic and martial law.

The authors identify the shortcomings of the current mechanism of legal regulation of economic activity in crisis conditions and provide proposals for improving this regulation in order to ensure the stability and sustainability of the economic system in unforeseen circumstances.

Keywords: economic activity · martial law · economic crisis · special economic regime · pandemic

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1 Introduction

Business activities in special circumstances include situations when business entities operate in unusual, unpredictable, including crisis circumstances. These actions may be related to natural disasters, epidemics, military conflicts and other events that affect the normal course of business activities.

Due to the military aggression of the Russian Federation, martial law was introduced in Ukraine on February 24, 2022. That is why the Russian-Ukrainian war directly became the starting point for changes in the legislative regulation of all spheres of society, including economic activity. Today, the state's efforts are aimed at achieving the main goal of the Ukrainian people - protecting the sovereignty, territorial integrity and inviolability of Ukraine. At the same time, it is important to combine the effective work of both the physical defense of the state and the work of the "economic front", as these two components of the state's functioning are interconnected. Without the economy, there is no economic independence, and without the military, there is no physical and territorial independence of the state as the main feature of statehood in a particular country.

Therefore, the issue of the functioning of the national economy in wartime is no less important than the issue of Ukraine's defense capability. Thus, in view of the above, it is extremely important that the state provides proper legal regulation of economic activity during martial law, as this is the basis of national defense capabilities. At the same time, the spread of epidemics and other kinds of crises also pose challenges to the effective functioning of the economic system of the State.

Therefore, the purpose of this article is to analyze and develop proposals for improving the legal regulation of economic activity in special conditions, which is extremely important for providing state support and guarantees to economic entities in such specific circumstances.

2 Literature Review

A number of scientists - specialists in the field of economic law - have dealt with the issues of legal support of legal regulation of economic activity. Thus, the issues of regulation of economic activity are the subject of works by O. A. Kolesnikov, O. V. Serhiyko, O. F. Safronova and others. The following scholars have studied the problematic aspects of self-regulation of economic activity: O. O. Bakalinska, O. A. Belyanevych, V. I. Polyukhovych, O. V. Kolohoydy, V. I. Polyukhovych, V. S. Shcherbyna and others. A significant contribution to the formation of theoretical, methodological and practical aspects of ensuring the socio-economic development of the country on the basis of state regulation of economic activity was made by such leading scholars as: R. P. Boichuk, O. M. Vinnik, D. V. Zadikhailo, V. K. Mamutov, O. P. Podtserkovnyi, V. A. Ustymenko, V. S. Shcherbyna and many others.

Certain aspects of economic activity in special economic entities were dealt with by such scientists as: Prof. Zeldina O.R., whose scientific work is devoted to the problems of the special economic regime, certain elements of the special economic regime and the special regime of innovation activity were analyzed in the works of V. E. Vakim, A. V. Matvieieva, the issues of legal support of production and economic activity of state

specialized agricultural enterprises - in the work of T. V. Lyamtseva, the peculiarities of economic activity in the conditions of a pandemic - in the works of A. V. Zamryga, A. V. Matvieieva, O. O. Savchuk and others.

Some issues of regulation of economic activity during the legal regime of martial law are devoted to the work of L. A. Pankova, M. M. Prokhorenko. However, today there is no understanding either at the legislative or at the scientific and theoretical levels of the main approaches to legal support for economic activity in special conditions, what is the difference between ensuring economic activity in a pandemic and martial law, which measures are more effective in the face of certain challenges.

3 Main Content Presentation

3.1 State Influence on Business Development

Economic Today, it is important to identify potential challenges and threats to business activities, as any business activity directly affects the welfare of the population, the prosperity of the state and its economic security. First of all, it is important to pay attention to the scientific and theoretical basis of economic activity and analyze various regimes of state support for economic activity.

Economic activity is understood as the activity of business entities in the sphere of social production aimed at manufacturing and selling products, performing works or providing services of a costly nature that have price certainty [1].

As R. P. Boichuk rightly notes, the purpose of the state in the context of commodity-money relations is to improve the welfare of its citizens, and the main thing in its activities is to create conditions for effective entrepreneurial activity, organize a favorable economic environment, not to create barriers to business, not to interfere with commercial and other initiative activities [2, p. 58]. Only under such economic and legal frameworks can all socio-economic problems be successfully resolved and the economy developed. The problem of determining the place, role and importance of the state in shaping the rules of modern market mechanisms is becoming increasingly acute. The Constitution of Ukraine stipulates that Ukraine should be a social community in which the state should not oppose the interests of private individuals and structures, but create the most favorable conditions for their development. Limitation of state power in a state governed by the rule of law is one of the basic postulates. This is the basis for the regulatory regulation of the private law and public law spheres of social relations, since the state's activities in the field of public relations and in the field of economic turnover require clear, complete and even "rigid" regulation, namely, limitation by law.

The legal means for this purpose includes the following: clear regulation of the exercise by the state of its functions in cases where public authority is exercised in relations with entities pursuing their private interests, inclusion of structural elements of a private law nature in the scope of solving state-important tasks.

When it comes to the state regulatory policy in general, its important component is not only to reduce state interference in the activities of business entities, but also to remove obstacles to the development of economic activity carried out within the limits, in the manner and in the manner established by the Constitution and laws of Ukraine.

A multicomponent understanding of social justice, including respect for the dignity of all people, meeting the needs of the present generation without compromising the ability of future generations to meet their own needs, non-discrimination in the use of opportunities to improve living conditions, implementation of the principles of universal participation, promotion of decent work, raising the minimum level of social protection, and broad involvement of people who are "on the margins of these processes" is declared by the UN. Correlating justice with law and business, the UN focuses on partnerships that will ensure sustainable development goals only with the active participation of governments, parliaments, employers, workers, civil society and the private sector [3].

It should be emphasized that state regulation of economic activity is a rule-making process aimed at forming a legal regime of restrictions on free private initiative in the field of economic activity of independent entities. The tools of this policy are evidence bases (statistical studies, analysis of the effectiveness of existing regulations, results of pilot projects and analysis of foreign experience), methodological guidance (methods of drafting laws, "green" and "white" books, compilations of sustainable, best practices, etc.) and officially approved procedures for assessing the regulatory impact and rules for drafting regulations. Such procedures must necessarily include a comparison of several regulatory options, arguments in favor of the proposed options, and an analysis of existing best international practices. This policy, as A. A. Voloshynska writes, implies that "the main criterion for choosing a particular set of measures or instruments is a scientific analysis of facts, not the beliefs of legislators, considerations of an ideological or opportunistic nature."[4] It is impossible to ensure conditions for economic development, social justice, national security, etc. without analyzing "what positive law should be in terms of substantive tasks of society and the state".

The effectiveness of the state's means (economic, legal, organizational and administrative) depends on the efficiency of the use of legal instruments. For example, the Commercial Code of Ukraine (hereinafter - the CCU) provides for special business regimes at the legislative level (Chapter 8). These include: special (free) economic zones; concessions; exclusive (maritime) economic zone of Ukraine; on the state border of Ukraine; in sanitary protection and other security zones, specially protected territories and objects; economic activity in certain sectors of the national economy; economic activity in the territory of priority development; economic activity in the conditions of a state of emergency, environmental emergency; economic activity in the conditions of martial law.

A special regime exists when: 1) there is a need to introduce special business conditions; 2) the state has introduced or established a special legal regime under a special procedure; 3) special rules of law are implemented, as opposed to general rules, since the effect of general rules of law is not sufficient to achieve the purpose of introducing a special legal regime. Regulatory regulation of economic activity during a special period and further proper application and implementation of the rules of law in this area make it possible to introduce effective conditions for economic activity that allow achieving the goal of introducing such regimes [5, p. 153].

The main tasks facing the state that creates a free economic zone are usually the following: 1) solving the problem of employment by creating new jobs; 2) intensification of foreign economic relations, i.e. improvement of foreign trade; 3) creation of favorable

conditions for the development of small and medium-sized businesses in the region; 4) development of a system of benefits in the region for investors and enterprises; 5) international labor cooperation; 6) exchange of scientific and technical developments; 7) development of foreign direct investment [6]. The formation of special economic zones involves defining clear geographical boundaries, establishing a special economic regime and providing preferential conditions for residents.

Concessions are one of the key forms of cooperation between the state and enterprises in the modern economy. They are a specific type of agreement that entitles companies to exploit natural resources or infrastructure under certain conditions and for a specified period of time. In effect, the state transfers to private enterprises the right to develop and use natural resources, infrastructure or other public facilities. These may include mining, construction and management of infrastructure facilities, and provision of public services. Procedural conditions for concession activities by entities are set out in the Law of Ukraine "On Concession" [7].

The exclusive (maritime) economic zone of Ukraine is the maritime areas externally adjacent to the territorial sea of Ukraine, including the areas around the islands belonging to it, which constitute the exclusive (maritime) economic zone of Ukraine. The width of the exclusive (maritime) economic zone is up to 200 nautical miles, measured from the same baselines as the territorial sea of Ukraine [8]. It is an important component of the national economic and geopolitical strategy.

The state border of Ukraine is an integral part of the sovereignty of each country and defines its territorial boundaries. Conducting economic activity on the state border of Ukraine has its own peculiarities and requirements. This is primarily due to the need to ensure national security and prevent the illegal transportation of goods and people across the border.

Modern society faces challenges of environmental, social and economic security. Conducting business activities in sanitary protection zones around specially protected sites is a complex issue that requires a balance between economic and social needs and the preservation of natural resources and public health. Sanitary protection zones and other protection zones are a necessary element of the state policy to ensure environmental safety. Their creation and regulation is aimed at minimizing the impact of industrial and other economic facilities on the environment and human health. Economic activities in these zones are subject to strict environmental safety standards and requirements. Conducting business activities in sanitary protection and security zones is accompanied by a number of challenges and risks. These include the neglect and failure to comply with environmental regulations, insufficient control and oversight, and potential conflicts with stakeholders, including civil society organizations and government authorities.

Special economic regimes in certain sectors of the economy are an important tool for achieving specific economic, social and strategic goals. Their implementation requires careful analysis, justification and effective control in order to maximize the benefits for society as a whole.

The special regime of business in the priority territory provides for simplification of administrative and tax obligations for companies operating in the designated territory. This includes a reduction in corporate income tax, export and import privileges for raw materials, and simplified permitting procedures.

The special regime allows companies to actively introduce and develop new technologies and innovative approaches to production. This contributes to international competitiveness and ensures sustainable development of the region. The special economic regime in the territory of priority development is an important tool for stimulating economic development and increasing the competitiveness of regions. Its successful implementation requires careful planning, effective monitoring and consideration of potential risks. All this helps to build a sustainable and competitive regional economic space.

The challenges of doing business in special circumstances include those associated with volatile market conditions, unpredictable legislation, as well as restrictions on financing and access to resources. These aspects can complicate strategic planning and development of the enterprise, requiring business leaders to be flexible and manage risks effectively.

3.2 Peculiarities of Conducting Business During a Pandemic

The state is facing significant challenges in the context of the pandemic, as the process of building business relationships is changing dramatically. In particular, since the beginning of the pandemic related to the spread of the COVID-19 virus in Ukraine, a significant number of businesses have stopped operating due to the inability to conduct business as a result of quarantine, including beauty salons and cosmetic offices, gyms and group exercise facilities, shops (except for household and grocery stores), markets, cafes and restaurants (except for delivery), long-distance carriers, etc. Some businesses are moving exclusively to the online space, which has also reduced the markets for goods and services and, accordingly, the amount of income from commercial activities. At the same time, the obligations of enterprises and private entrepreneurs remain, and contracts or the law provide for liability for their failure to fulfil them. That is why force majeure in the current circumstances can become a kind of life-saving tool for Ukrainian business.

Thus, from March 2020 to March 2021, 215.3 thousand (sole proprietorships) closed in Ukraine. This is almost 50 thousand more closed businesses than in the same months of 2019–2020. Most businesses closed in the areas of warehousing and transport (almost 11 thousand), wholesale trade (5.6 thousand), and broadcasting (2.69 thousand). The number of people who decided to start a sole proprietorship during the quarantine was 240.9 thousand, which is 5 thousand less than in the same months before the quarantine. The largest number of new sole proprietorships were opened in the fields of programming (over 30 thousand), information (6.39 thousand), and other individual services (5.44 thousand). Also, sole proprietorships were actively opened in the delivery and healthcare sectors [9].

The innovations introduced by the Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Aimed at Preventing the Occurrence and Spread of Coronavirus Disease (COVID-19)" are an additional regulatory basis that business entities can refer to as a basis for non-fulfilment of obligations and simplify the procedure for recognizing such circumstances as force majeure by the CCI of Ukraine. Experts emphasize that the mere existence of quarantine as a special circumstance in the life of a country or region is not force majeure. Quarantine will become a force majeure event only if a person proves that it is impossible to fulfil the obligations under the terms of the contract due to it.

The main challenges that business entities face today in carrying out their business activities and which require immediate resolution, including at the legislative level, are: receiving visitors, in particular, to catering establishments (restaurants, cafes, etc.), shopping and entertainment centers, other entertainment establishments, as well as trade and catering activities with the use of targeted delivery of orders, provided that the relevant personnel are provided with means of individual protection. Thus, it can be concluded that if a business activity is related to direct customer service (cafes, restaurants, coffee shops, fitness centers, shopping malls, retail and consumer services, etc., except as expressly provided), it is prohibited for the period of strict quarantine.

According to the Federation of Employers of Ukraine, the situation with the operation of enterprises was extremely dire (Fig. 1 Operations of enterprises under quarantine) [10] (Fig. 1).

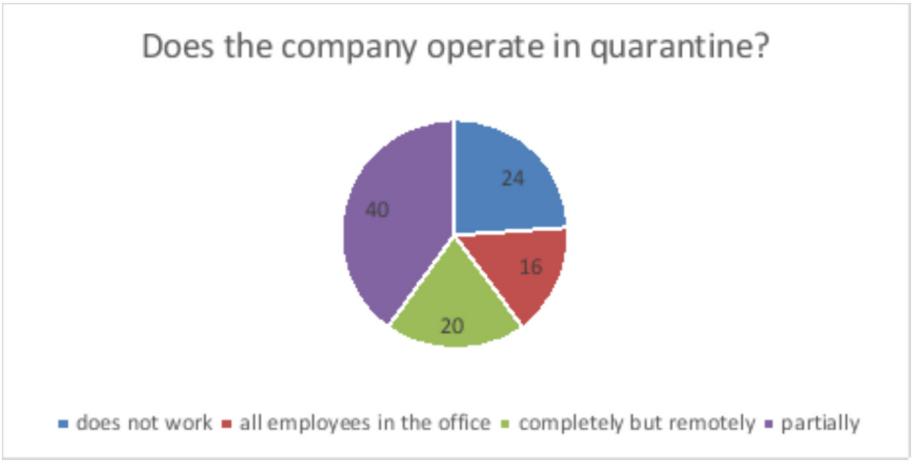

Fig. 1. Operations of enterprises under quarantine

In terms of assistance from the Ukrainian government, Ukraine has introduced five business support programs: 1) loan repayment holidays; 2) tax preferences; 3) support for small and medium-sized businesses; 4) support for agribusiness; and 5) information support for business. The essence of these programs is as follows: The NBU recommended that banks introduce a special grace period for servicing loans during the quarantine period for households and businesses, namely, full or partial exemption from paying the principal of the loan during the quarantine with a corresponding extension of the loan. This ban applies to all retail loans. It is also prohibited to impose fines and penalties for late payment during this period. Small and medium-sized business owners with employees will be provided with partial unemployment benefits. Micro, small and medium-sized enterprises have the opportunity to participate in programs financed from the state and local budgets, in particular the Affordable Loans 5–7-9% program.

Tax preferences: exemption from accrual and payment of land tax for land used in business activities, real estate tax for residential premises for March; restriction on the application of most fines for violation of tax laws; moratorium on documentary

and factual audits (except for VAT refund audits); increase in annual income limits for individual entrepreneurs of groups 1, 2 and 3; - VAT exemption on imports of goods necessary to combat the coronavirus. In addition, the Cabinet of Ministers of Ukraine has allocated UAH 4.7 billion in the 2021 state budget to support the agricultural sector. State aid is to be provided under the following programs: cheaper purchase of agricultural machinery and equipment; cheaper loans; and farm development. It is expected that about 9 thousand agricultural enterprises will receive assistance under these programs [11].

The rapid spread of the COVID-19 pandemic has proved to be a global challenge for the whole world, including the European Union.

In order to slow down and stop the spread of the coronavirus disease, the EU countries also promptly introduced strict quarantine restrictions.

For example, the speed of the spread of COVID-19 in Italy forced the government to introduce the strictest quarantine and isolation measures in the European Union, starting in February 2020 [12, p. 10]. On twelfth March of the same year, shops, restaurants and bars were completely closed, most production was suspended, except for vital ones, and only pharmacies, grocery stores and waste disposal services were allowed to operate. To support businesses, the Italian government has taken all possible measures to support credit offers to free up liquidity for businesses and households.

In Germany, the government has imposed strict bans on public events, gatherings of more than two people who are not members of the same family, non-food stores, beauty salons, fitness clubs, restaurants and hairdressers to combat the coronavirus disease. The government has also introduced a significant stimulus package to help businesses maintain economic stability. For example, six hundred billion euros were allocated to create a fund to provide loans and nationalize large enterprises that were particularly hard hit by the crisis, and one hundred and fifty-six billion euros to help small businesses and citizens [13, p. 17].

Slovakia responded to the spread of the coronavirus faster and more decisively than other EU countries, introducing a state of emergency at an early stage of the virus's spread [12, p. 24]. Only grocery stores, pharmacies, petrol stations and post offices were allowed to operate only if they complied with all hygiene standards.

The government also approved an economic program aimed at supporting entrepreneurship in the face of recession.

As for Poland, the country's policy was aimed at halting the spread of the coronavirus disease as soon as possible: on 8 March, a special law was enacted to prevent the spread of COVID-19 and to allow remote work, exempting microfirms (up to nine people) from social security contributions for the period from March to May 2020.

In Hungary, at the beginning of the pandemic, restaurants and non-food stores were not closed, but only had limited opening hours, and public events were also allowed, provided that the number of visitors did not exceed 100 people. But over time, the government tightened quarantine measures. To support entrepreneurship, the Hungarian government has introduced an economic program that includes tax exemptions for small and medium-sized businesses in certain sectors, deferred tax collection, exemption of media companies from advertising tax, and deferred interest on all loans for individuals and companies.

The Czech Republic, on the other hand, took tough measures and imposed a complete lockdown after the spread of COVID-19. It was compulsory to wear masks, walk in groups of no more than two people and keep a distance.

Most European Union countries responded quickly to the COVID-19 pandemic and imposed strict quarantine restrictions, which, unfortunately, had a negative impact on the business sector, which is now struggling to be saved by introducing a number of measures to support entrepreneurship, but still limiting the activities of enterprises to overcome the coronavirus disease. These measures are quite logical, since the shift in the focus of the state's financial plan to meet basic needs in the context of the coronavirus pandemic and the increase in social spending for budget "assistance packages" used by Austria, Italy, Spain, Germany, France and other EU countries are the most appropriate in today's conditions [14, p. 170].

It is worth noting that Ukraine lags far behind in terms of the level of state support for market participants. In order to support the economic sphere, the state should provide the participants of economic turnover with the much-needed basic elements of development: liberalization of the fiscal system based on the principles of necessity, sufficiency, reasonableness and proportionality with the conditions of competitors from other countries in taxation, technical regulation, and access to financial resources. One of the main reasons for the slow economic development is the lack of large financial institutions and the absence of adequate regulatory structures to prevent financial abuse. In this regard, the question of the nature of the limits of public law impact of the state and its legal institutions on modern economic relations is particularly relevant. The state is called upon to ensure the functioning of the economic complex as a whole, both institutionally and by replacing private capital where it is unable or uninterested to act, to eliminate market shortcomings and to act for the benefit of society. In addition, the overall economic situation in the world demonstrates the ineffectiveness of models of building market mechanisms, according to which the state is assigned only an indirect role in regulating economic processes.

We should agree with the conclusions of A. Matvieieva and O. Savchuk that economic activity in a pandemic is regulated by general legislation, considering the specifics established by special legislation. The establishment of a special economic regime makes it possible to prevent the spread of acute respiratory disease caused by the coronavirus in the country. By its legal nature, the special regime of economic activity in a pandemic is restrictive. However, it contains some legal means of incentive orientation [15, p. 463].

Thus, to summarize the above, it should be noted that due to the introduction of quarantine in Ukraine, business entities had to adapt to the conditions determined by the authorities, consider the prohibitions or recommendations on the conditions of conducting economic activities, take into account the massive spread of the coronavirus infectious disease COVID-19 and provide their employees with safe working conditions. We believe that these actions are appropriate in terms of protecting human life and health, although at the same time, the state should not forget that it is business entities that ensure the development of the national economy, pay taxes and fees, and therefore their daily activities should not be subject to unreasonable restrictions and measures of influence.

3.3 Economic Activity During Martial Law

Economic security as the ability of the national economy to maintain resilience and invulnerability to internal and external threats, to ensure high competitiveness in the global economic environment, and to ensure sustainable and balanced growth are important criteria for assessing the quality parameters of the national economy and the strategic effectiveness of the state's economic policy in the economic sphere. Therefore, the ongoing expert and analytical monitoring of the levels and threats to economic security and its components remains highly relevant, and in the context of the sharp expansion and intensification of threats caused by Russia's full-scale aggression against Ukraine, it is of particular importance.

In the first months of the full-scale war, Ukraine's economic security was largely ensured by the pre-war reserves and safety margin accumulated in the pre-war period, prompt consolidation of society's efforts at the regional and local levels, self-organization and cohesion of Ukrainian citizens in the face of the existential threat of Russian aggression, and unprecedented international support.

With the transition of Russian aggression into a protracted war of attrition, the direct impact of hostilities on the economy has intensified with targeted attacks on the country's critical infrastructure, depletion of financial reserves of the population and businesses, growing economic imbalances that emerged during the war period, and the use of various hybrid instruments of influence by the enemy [16].

Therefore, it is quite important to determine the instruments of influence on economic activity under martial law. The conditions of martial law are exceptional in the history of countries and societies, and they require the introduction of a special economic regime to ensure the functioning of the state and its economy in the face of a threat to national security. Martial law is an exceptional situation where restrictions on civil liberties and rights are usually applied to ensure the security of the country. However, this regime also has a serious impact on the economy and business activities. A special economic regime arises under martial law to coordinate and regulate economic processes in order to maintain the stability and functioning of the state.

One of the main aspects of the special economic regime is centralized management and control over economic activities. The state makes important decisions on resource allocation, price regulation, division of labor and other aspects of economic life. This ensures that resources are allocated to the most important needs, including defense, infrastructure and social programs.

The second important aspect is the mobilization of economic resources and industrial capacity for the production of military equipment and machinery. Martial law conditions often require an increase in the production of weapons, ammunition and other important goods. This can be achieved by imposing restrictions on civilian products and resources, as well as by actively using the public and private sectors to produce military goods.

A separate aspect of the special economic regime under martial law is to ensure national security and restore damaged infrastructure. The state has to restore and strengthen critical infrastructure, such as energy systems, transport networks and communications, to ensure the functioning of society in the context of a military conflict.

In accordance with the Decree of the President of Ukraine of 24 February 2022 No. 64 "On the Introduction of Martial Law in Ukraine", the Cabinet of Ministers of Ukraine decides to establish that:

1) during the period of martial law, the right to conduct economic activity may be acquired by business entities on the basis of free submission to licensing authorities, permitting authorities and public (electronic public) service providers of a declaration on conducting economic activity containing information in accordance with Annex 1, without obtaining permits (permits, licenses or other results of public services), except for the types of economic activity listed in Annex 2.
2) the declaration may be submitted at the choice of the business entity regardless of the declared (registered) location (place of residence), place of business or location of the relevant object;
3) business entities that have acquired the right to carry out economic activities on the basis of a declaration, in the absence of relevant permits (permits, licenses and/or other results of public service provision), shall immediately, but not later than three months after the termination or cancellation of martial law, apply to the relevant licensing authorities, permitting authorities and public (electronic public) service providers and obtain relevant permits in accordance with the procedure, terms and conditions prescribed by law
4) for the period of martial law, the time limits for applying for public services determined by law are suspended. From the date of termination or cancellation of martial law, the said terms shall be extended considering the time elapsed before their suspension;
5) the validity periods of existing fixed-term licenses and permits shall be automatically extended for the period of martial law and three months from the date of its termination or cancellation, and periodic payments thereunder shall be postponed for the period specified in this sub-clause (except for the validity period of licenses in the field of organizing and conducting gambling activities and payments for such licenses)
6) the validity period of valid certificates of registration of business entities as entities engaged in international transfers of goods, certificates of authority to conduct non-state expert examination of goods in the field of state export control and certificates of state certification of the internal company export control system established by the entity engaged in international transfers of goods issued by the State Export Control Service shall be automatically extended for the period of martial law and three months from the date of its termination or cancellation [17].

It should be noted that the peculiarity of economic activity in the context of the introduction of the legal regime of martial law is to grant the relevant public authorities, military command, military administrations and local self-government bodies the powers defined by the Law of Ukraine "On the Legal Regime of Martial Law" of 12 May 2015, the exercise of which may be carried out by restricting the constitutional rights and freedoms of man and citizen and the rights and legitimate interests of legal entities.

Thus, the special economic regime under martial law is a necessary tool to ensure economic stability and national security in emergency situations. It requires an integrated approach to economic management, centralized control and coordination of resources to achieve the country's strategic goals during martial law.

4 Conclusions

One of the most pressing and unresolved issues in the field of business operations under special conditions is the identification and implementation of effective management strategies in the face of uncertainty and risk. Due to the increasing complexity of modern business, business structures face complex challenges that require systemic solutions. Changes in the technological landscape and the continuous development of new innovations create gaps in the ability of businesses to adapt to rapid changes in the modern business environment. Uncertainty about the adoption and implementation of technological solutions can lead to a loss of competitiveness and failure to achieve strategic goals.

Another unresolved issue is the balance between business operations and sustainability in the face of growing social, environmental and ethical demands. Businesses face the challenge of integrating sustainability principles into their strategy while ensuring economic efficiency. At the global level, instability in the global economy, trade wars and other geopolitical factors pose additional challenges for businesses operating internationally. Risk management in the context of global instability requires new strategies and methods.

The problems of legal regulation of economic activity under special conditions are as follows: 1) regulations do not contain mechanisms for responding to emergencies, which complicates the normal functioning of enterprises; 2) in the event of emergencies, enterprises may become vulnerable to tax and other authorities, which may lead to unpredictable financial losses; 3) in crisis situations, compliance with information disclosure requirements may become problematic, which complicates the control and supervision of enterprises.

References

1. Economic Code of Ukraine: Law of Ukraine of 16.01.2003 No. 436-IV. Bulletin of the Verkhovna Rada of Ukraine, official publication of 02.05.2003. № 18. Art. 144. [in Ukrainian]
2. Boychuk R.P. Problems of legal support of state regulation of economic activity. Law and Innovation. 2018. №3(23). pp. 56–63. DOI: https://doi.org/10.31359/2311-4894-2018-23-3-56 [in Ukrainian]
3. Message of the UN Secretary-General on the occasion of the World Day of Social Justice on 20 February 2016. http://www.un.org/ru/sg/messages/2016/socialjusticeday.shtml [in English]
4. Voloshynska, A.: Problems of economic efficiency of legal regulation. Yurist. № 23. p. 21 (2015) [in Ukrainian]
5. Prokhorenko, M.M.: Legal regulation of economic activity and economic relations in a special period. Yurydychnyi vestnik **2**(39), 151–161 (2016). [in Ukrainian]
6. Chmyr, O.S.: Special (free) economic zones and territories of priority development (scientific and methodological aspects) Scientific Research Economic Institute of the Ministry of Economy of Ukraine - K.: NDEI of the Ministry of Economy of Ukraine, p. 274 (2001). [in Ukrainian]
7. On concession: Law of Ukraine of 03.10.2019 No. 155-IX. Bulletin of the Verkhovna Rada of Ukraine official publication of 29.11.2019. № 48. Art. 325 (2019). [in Ukrainian]
8. On the Exclusive (Maritime) Economic Zone of Ukraine: Law of Ukraine of 16.05.1995 No. 162/95-ВР. Bulletin of the Verkhovna Rada of Ukraine, official publication of 23.05.1995. № 21. Art. 152 (1995). [in Ukrainian]

9. Economic truth. website. https://www.epravda.com.ua/publi-cations/2021/03/24/672241/ [in Ukrainian]
10. Business and COVID-19: you can't die to survive. https://www.ilo.org/wcmsp5/groups/public/---europe/---ro-geneva/---sro-budapest/documents/publication/wcms_745558.pdf [in Ukrainian]
11. Business support programmes. Ministry of Health of Ukraine. https://covid19.gov.ua/prohramy-pidtrymky-biznesu [in Ukrainian]
12. Analytical note: The COVID-19 Pandemic in the EU: Selfishness, Solidarity or Spillover? Foreign Policy Council "Ukrainian Prism", p. 55 (2020). [in Ukrainian]
13. Treshchov, M.M.: State Fund to Combat the Pandemic: Prospects, Disadvantages, EU Experience. In: Improvement of the Financial and Credit Mechanism for Ensuring Innovative Economic Development: Materials of the All-Ukrainian Scientific and Practical Conference. Internet Conference. 20 May 2020, pp. 16–18. Dublin (2020). [in Ukrainian]
14. Pirozhkova, Y.V.: Public finance: search for an optimal model of legal regulation in the context of overcoming the COVID-19 pandemic. Bulletin of Zaporizhzhia National University. Legal Sciences, № 1. pp. 166–172 (2020). [in Ukrainian]
15. Savchuk, O., Matvieieva, A., Kritskiy, D.: Legal support of economic activity in the conditions of the pandemic. In: Nechyporuk, M., Pavlikov, V., Kritskiy, D. (eds.) Integrated Computer Technologies in Mechanical Engineering – 2022. ICTM 2022. Lecture Notes in Networks and Systems, vol. 657. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-36201-9_39 [in English]
16. Current challenges and threats to the economic security of Ukraine under martial law. https://niss.gov.ua/sites/default/files/2023-05/executive-1.pdf [in Ukrainian]
17. Some issues of ensuring the conduct of economic activity under martial law: Resolution of the Cabinet of Ministers of Ukraine of 18.03.2022 No. 314. Official Gazette of Ukraine, official publication of 05.04.2022. № 26. Art. 1399 (2022). [in Ukrainian]

Online Dispute Resolution as an Alternative Way of Dispute Settlement Involving Agribusiness Entities

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Abstract. The article analyses the conceptual approaches to the study of online dispute resolution and its role in the settlement of agro-export disputes. Agro-export relations play an important role in the development of international trade and logistics relations. The share of agricultural exports is over 40% of total national exports. This is the reason for the relevance of studying the issues of alternative dispute resolution in agro-export disputes. It is substantiated that online dispute resolution in the field of agribusiness is an independent alternative type of dispute resolution at the level of mediation, arbitration, etc., which involves the use of capabilities and tools of modern Internet technologies and is available to a wide range of persons - agribusiness entities, their contractual counterparties, consumers of products, regardless of their status and jurisdiction, and at the same time is characterized by special rules, procedures and procedural rules.

Keywords: agribusiness · alternative methods of dispute resolution · online dispute resolution · digital technologies · digitalization

1 Introduction

In contrast to the traditional judicial resolution of disputes, alternative dispute resolution (hereinafter referred to as ADR) methods have been developing in recent years, which are territorially unlimited and available to all disputes, regardless of industry affiliation. In accordance with the norms of international and national legislation, the parties to commercial contracts in case of non-fulfillment or improper fulfillment of the terms of such contracts can go to court or use alternative methods of conflict resolution. The attractiveness of alternative methods of resolving agricultural export disputes directly depends on the possibility of actual implementation and realization of the agreements reached, taking into account the presence of the so-called international (foreign) element in such a dispute, the subjection of the subjects of the dispute to different jurisdictions,

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which determines the difference in the legislative regulation of the order and methods of dispute resolution in different countries of the world, which in turn leads to difficulties during the execution of the agreement and the resolution of disputes. The use of alternative methods of dispute settlement has a positive effect, since it is such methods that allow shortening the time for consideration of cases, reducing court costs, reducing the workload of courts, and achieving a balance of interests of conflicting parties [1, p. 312]. Alternative methods of dispute resolution include: mediation, arbitration, intermediation, negotiations, conciliation, arbitration court, online dispute resolution, etc. (Fig. 1).

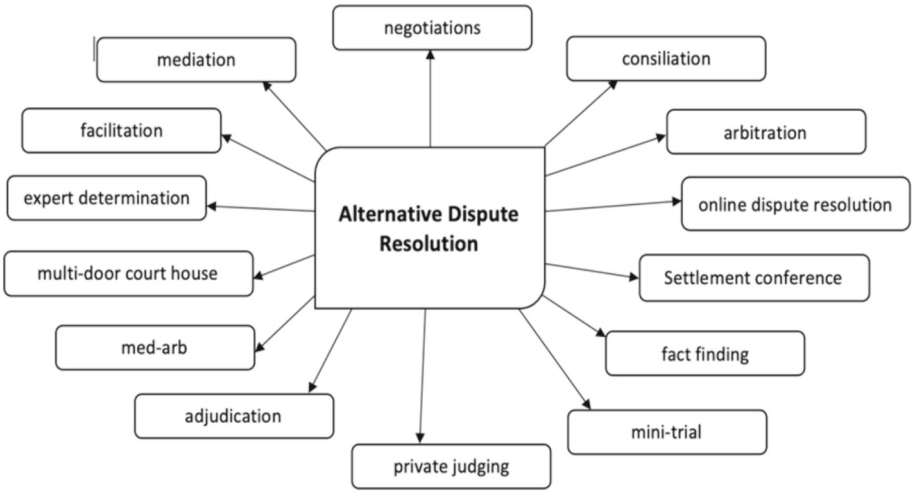

Fig. 1. Types of alternative dispute resolution methods

2 Literature Review

Many domestic and foreign scholars have paid attention to the study of online dispute resolution as a type of alternative dispute resolution, including Y.Y. Bakai, N.V. Vasylyna, O.A. Telychko, V.A. Rekun, A. Lodder, E. Heuvel, M.V. Mykytyn, I. Manevy, V.Y. Polatai, F. Petrauskas, T.A. Tsuvina, V. Tan, C. Rule and others.

Researchers have studied the possibility of introducing online dispute resolution as an alternative dispute resolution method, as well as certain issues of the online dispute resolution procedure and its advantages over litigation.

At the same time, despite a sufficiently in-depth study of this issue in general, the issue of the prospects for introducing online dispute resolution procedures in the field of agribusiness in the context of its digital transformation and, in particular, in relation to the resolution of agro-export disputes has remained unaddressed by lawyers, which is why this study is relevant.

3 Main Content Presentation

3.1 Online Dispute Resolution as a Type of Alternative Dispute Resolution

The trend of introducing IT technologies into the daily life of society leads to the inevitability of using their capabilities in the justice system by the courts and in the field of out-of-court settlement of disputes. In this regard, we should agree that it is IT technologies that can become the basis for a quick and less expensive dispute resolution, provide a communication and information platform for establishing partnerships, resolving and settling disagreements, fixing agreements, including in a non-documentary form [2, p. 117].

It is worth noting that the use of the Internet and the latest information and communication technologies for the consideration of disputes between agribusiness entities has significantly intensified in recent years. The primary cause of this was the spread of the global COVID-19 pandemic, restrictions on free movement, the ban on international air travel, the introduction of a self-isolation regime upon arrival in other countries, and later military actions on the territory of Ukraine. In this regard, GAFTA Rules No. 125 were amended to introduce the possibility of conducting hearings of this specialized international commercial arbitration remotely, online.

The opinion of scientists is reasonable, pointing out that the development of information technologies, the digitalization of the economy, the intensification of trade relations in the cross-border space, the increase of financial and trade transactions carried out using computer networks, as well as the need to find adequate and effective ways to settle disputes in the era of combining the traditional and digital economy create prerequisites for the development of an electronic system of alternative dispute resolution mechanisms [3, p. 29]. Nowadays, this trend is extremely relevant for resolving disputes in the field of agricultural exports.

In the scientific space there are such concepts as online dispute resolution, electronic dispute resolution, electronic online dispute resolution, Internet dispute resolution, online alternative dispute resolution, which are essentially the same and are used as synonyms.

At the same time, today there is no single scientific thought regarding the legal nature of this concept. Thus, A. Lodder defines online dispute resolution (hereinafter referred to as ODR) exclusively as a way of using alternative methods of dispute resolution with the help of information and communication technology tools, although they include online court proceedings and other special forms of dispute resolution [4, p. 144]. At the same time, E. Heuvel noted that online dispute resolution is the use of communication networks to resolve disputes using alternative dispute resolution methods [5, p. 14].

Other representatives of the legal doctrine believe that ODR includes technical means and mechanisms that are not dispute resolution methods and are aimed solely at creating the necessary conditions under which alternative dispute resolution methods become more accessible to users of relevant networks, systems, platforms, etc. calling ODR electronic ADR enforcement mechanisms [6, p. 15]. It is difficult to agree with this point of view, since ODR cannot be reduced only to technical means and mechanisms aimed exclusively at creating the necessary conditions for dispute resolution, because this would lead to an unjustified narrowing of this concept.

I. Manevy notes that ODR is the use of Internet capabilities to implement alternative dispute resolution procedures in virtual space [7, p. 23].

At the same time, V.Yu. Polatai considers electronic dispute resolution as one of the varieties of alternative dispute resolution, which is a set of methods for settling disputes (conflicts) with the use of Internet technologies, and at the same time as the development of programs and computer networks for resolving disputes using methods of alternative dispute resolution [8].

According to F. Petrauskas, ODR arose as a result of the synergy between ADR and information and communication technologies and is currently developing and functioning independently as a method of resolving disputes that have arisen on the Internet and for which traditional means of resolution have proved insufficiently effective or unavailable at all [9].

Thus, the analysis of scientific opinions makes it possible to conclude that foreign and domestic scientists consider ODR as a form of ADR, namely, as an external expression of actions and decisions that have legal significance, aimed at resolving a dispute using ADR, and as one of the types of ADR (Fig. 2).

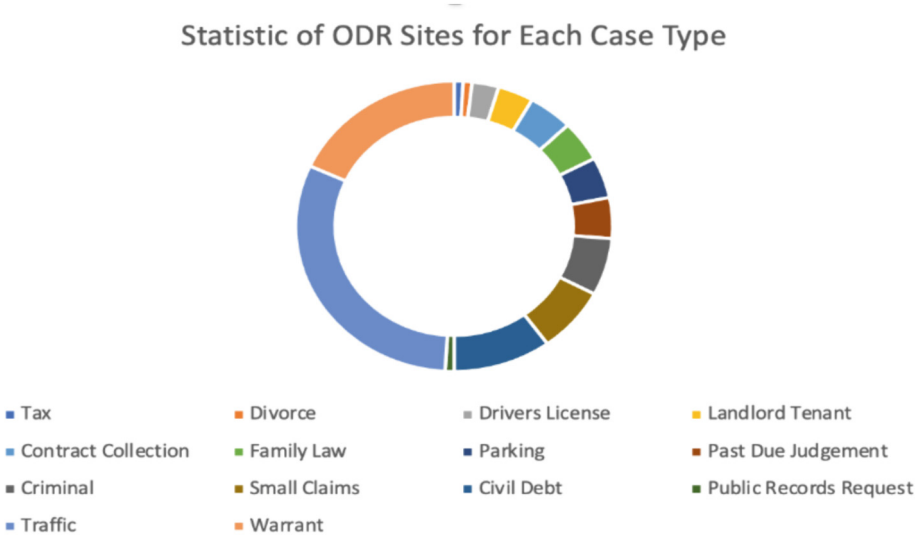

Fig. 2. Statistic of ODR Sites for Each Case Type

3.2 Peculiarities of Using Online Dispute Resolution with the Participation of Agribusiness Entities

In our opinion, ODR in the field of agribusiness is an independent alternative type of dispute resolution along with mediation, arbitration, etc., using the capabilities and tools of modern Internet technologies available to a wide range of people – agribusiness entities, their counterparties under contracts, consumers of products, regardless of their

status and jurisdiction, and is characterized by special rules, procedures and procedural norms.

At the legislative level, ODR has found its way into Directive 2013/11/EU and Regulation No. 524/2013 of the European Parliament and of the Council of 21 May 2013 on online dispute resolution and consumer disputes and amending Regulation (EU) No. 2006/20 of the Directive 2009/22/EU. The main goal of the mentioned normative legal act is to achieve a high level of consumer protection by providing them with the opportunity to submit complaints on a voluntary basis to institutions that use independent, transparent, efficient, fast and fair alternative dispute resolution methods to resolve disputes. In addition, consumers can carry out alternative settlement of all types of contractual disputes that arise with sellers (traders), both on the territory of one state and outside its borders. EU Regulation No. 524/2013 defines an online dispute resolution procedure, which is a centralized, multilingual, interactive website that allows consumers to resolve their disputes online. According to Art. 1 of the Regulation, the main goal is to create a European ODR platform to achieve a high level of consumer rights protection, a transparent and effective system of alternative dispute resolution between consumers and online sellers.

Therefore, EU legislation defines a model of ODR dispute settlement using the services of ADR entities, in particular, arbitrators, mediators, etc., using ODR platforms, in the form of an interactive website, which, in turn, will allow to resolve domestic and cross-border disputes simply, effectively, quickly, inexpensively without going to court.

The existence of online dispute resolution platforms creates the prerequisites for a technical revolution in this area. Such systems work according to the principle of a one-stop shop, namely, they make it possible to submit an application for consideration of the dispute and evidence, inform the participants of the process about their rights and obligations, conduct negotiations, etc.

For example, the Modria platform provides online dispute resolution services to any parties by conducting online negotiations and reaching a compromise solution that will suit both sides of the negotiations. More than 60 million cases are resolved each year through this platform, 90% of which are done automatically.

The French platform Demander Justice contains instructions for the preparation of claims and online dispute resolution, provides online dispute resolution services, is designed to facilitate access to justice for all citizens and receive quality legal assistance. The Canadian resource Civil Resolution Tribunal – Canada's primary online arbitration court – deals with small disputes with an amount of no more than $5,000. The Dutch Rechtwijzer platform, developed by the Dutch Legal Aid Board as part of a public-private partnership, allows the parties to jointly draw up a dispute settlement agreement and, if necessary, involve a third party – a mediator.

Ukraine is no exception, where the Pinky Solutions ODR platform has been created today, the purpose of which is online dispute resolution using Internet technologies, which allows you to avoid lengthy court processes and save time and money. Such procedures can be applied to a wide range of problems: from e-commerce to labor disputes and domestic disputes.

As T.A. Tsuvina rightly notes, online ADR is beginning to integrate into the online platforms of formal justice, becoming part of them, which is an indicator of the hybridization of the processes of formal and informal justice. The above indicates the creation of a new architectonics of the dispute resolution system. Firstly, consensual principles prevail in it, which makes it possible to settle the dispute at the earliest stages due to the fact that negotiations, mediation and other conciliation procedures are built into the dispute resolution process. Secondly, at the center of such a system are the users of the platform – the parties to the dispute, their interests and convenience, in particular, some systems provide for the possibility of leaving feedback from the parties, which are later used by developers for their improvement. Thirdly, the creation of online courts increases the efficiency of the judiciary and saves state resources due to the automation of processes. Fourthly, the use of such systems is less expensive for the parties due to lower court fee rates and the opportunity to represent their interests independently, without a professional representative, because the system is understandable and designed for a user who is not a specialist in the field of law. Fifthly, such a system is able to provide equal access to justice, because the simplicity and high degree of its algorithmization can balance the positions of the parties and eliminate, or at least mitigate the so-called procedural advantages of one of the parties, associated, for example, with its large financial resources, the frequency of going to court, awareness in the field of law, etc. [10, p. 71].

In addition, ODR is a system that allows parties to resolve their dispute from start to finish, i.e., from the filing of a claim or claim to the resolution of the dispute, in an online forum. Therefore, ODR should be distinguished from: 1) systems that allow electronic submission of documents to the court (e-filing) or online case management and electronic evidence disclosure system (e-discovery); 2) online information platforms; 3) platforms for online storage and search of documents on the Internet [11, p. 104].

Among the main advantages of using ODR, there are such things as confidentiality, which is ensured by the possibility not to raise the issue of the quality of goods and services provided for public discussion, and therefore to ensure the preservation of business reputation, because agreed decisions and agreements, unlike court decisions, are not subject to public publication; trust formed between the consumer and the supplier of goods and services thanks to the positive experience of dispute settlement; neutrality, which is ensured thanks to appropriate algorithms of IT technologies with minimal intervention of the human factor; availability due to fixed payment, without additional payments and fees; efficiency, which is manifested in shortened terms of dispute settlement, namely from a few hours to 60 days [2, pp. 115–116].

C. Rule's opinion is appropriate that online dispute resolution is currently defined as one of the main trends in the reform of both private and public dispute resolution systems, because information and communication technologies are currently so firmly embedded in our lives that they have become recognized as the "new normal" [12, p. 8].

The foregoing makes it possible to highlight the features inherent in ODR in the field of agribusiness:

– online dispute resolution is an out-of-court method of resolving disputes that does not deprive the parties of the right to go to court;

– transboundary nature of the procedure – since the Internet is a global system, any entities can enter into such legal relations, regardless of their legal status and jurisdiction, without the territorial limitation of a certain state;
– promptness of dispute resolution compared to other alternative dispute resolution methods;
– is used to resolve disputes that have arisen both online and offline;
– cost-effectiveness – saving time and money;
– algorithmization and the presence of such stages as:

  - filing a complaint by the applicant through the online platform;
  - attraction of the defendant by e-mail;
  - conducting online negotiations;
  - possible involvement of a mediator, arbitrator, intermediator, other disinterested person, etc.;
  - the achievement of a legally formalized agreement.

4 Conclusions

Thus, access to justice is the cornerstone of any democratic state based on the rule of law, and a necessary condition for the effective use and protection of their rights by citizens and business entities. At the same time, the use of information and communication technologies can improve access to justice, because they not only have the potential to simplify and speed up procedures, but also to increase the consistency and predictability of results, their flexibility [13]. The use of modern technologies will make it possible to shorten the time for consideration of cases, expand access to justice, speed up the receipt and execution of court decisions, reduce the workload of courts, simplify mechanisms for resolving disputes, reduce court costs, submit online applications to the court about rights violations, and ensure easy access to justice. The development of modern technologies and the expansion of Internet capabilities directly led to the use of online tools to create a new institution that has most advantages over existing legal institutions. One of the areas where the introduction of ODR in modern conditions is particularly relevant is agribusiness. Nowadays, Ukraine is at the stage of forming the fundamental foundations of the concept of online dispute resolution, including with the participation of agribusiness entities, with the aim of establishing this type of alternative dispute resolution as an effective instrument for resolving disputes both within the state and in relations with foreign counterparties.

References

1. Bakai, Y.Y.: Legal principles of alternative methods of settlement of agro-export disputes. In: Hetman, A.P., Kurman, T.V. (eds.) Agrarian and Land Law of Ukraine: Modern Paradigm and Development Prospects: Collective Monograph, Kharkiv, p. 576 (2022). (in Ukrainian)
2. Vasylyna, N.V.: Prospects for the introduction of online dispute resolution in Ukraine. Sci. Herald Uzhhorod Nat. Univ. **1**(55), 114–117 (2019). (in Ukrainian)

3. Telychko, O.A., Rekun, V.A.: Online dispute resolution in the field of e-commerce as an alternative method of pre-trial conflict resolution. Subcarpathian Law Herald **4**(39), 29–32 (2021). (in Ukrainian)
4. Lodder, A.: The third party and beyond. An analysis of the different parties, in particular the fifth, involved in online dispute resolution. Inf. Commun. Technol. Law **15**(2), 144 (2006). (in English)
5. Heuvel, E.: Online Dispute Resolution as a Solution to Cross – Border – E-Disputes: an introduction to ODR, p. 31 (2000). (in English). https://www.oecd.org/digital/consumer/1878940.pdf
6. Mykytyn, M.V.: Prospects for the functioning of ODR platforms in Ukraine as the newest concept of dispute resolution, Odesa, p. 36 (2018). (in Ukrainian)
7. Manevy, I.: Online dispute resolution: what future? p. 81 (2001). (in English). http://lthoumyre.chez.com/uni/mem/17/odr01.pdf
8. Polatai, V.Yu.: Resolution of disputes on the Internet. An alternative method. Archive of the National University "Odesa Law Academy" (2015). (in Ukrainian). http://dspace.nlu.edu.ua/bitstream/123456789/9803/2/Polatay.pdf
9. Petrauskas, F.: Online Dispute Resolution in Consumer Disputes (2011). (in English). https://ojs.mruni.eu/ojs/jurisprudence/article/view/584
10. Tsuvina, T.A.: Online courts and online dispute resolution in the context of the international standard of access to justice: international experience. Prob. Legality (149), 62–79 (2020). (in Ukrainian). file:///C:/Users/%D0%90%D0%BB%D0%B5%D0%BA%D1%81%D0%B0%D0%BD%D0%B4%D1%80/Downloads/Pz_2020_149_7.pdf
11. Tan, V. Online dispute resolution for small civil claims in Victoria: a new paradigm in civil justice. Deakin Law Rev. **24**, 101–138 (2019). (in English)
12. Rule, C.: Is ODR ADR: a response to Carrie Menkel-Meadow. Int. J. Online Dispute Resolut. **3**(1), 8–11 (2016). (in English)
13. Parliamentary Assembly. Access to justice and the Internet: potential and challenges. Committee on Legal Affairs and Human Rights, Resolution 2031 (2015) of the Council of Europe (2015). (in English). https://pace.coe.int/en/files/22283/html

Forecasting Innovative Changes in Managing Socio-Economic Systems

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Abstract. The planning of innovative changes in socio-economic systems should focus on the effective utilization of the existing potential for innovative development. This research proposes a method for strategic planning of innovative changes, which enables the determination of development goals, approaches to problem-solving, and a system of indicators to optimize plans for innovative change. The stages of organizing innovative activities, aligned with the mechanism of project development and implementation, are identified. The technique is improved through a system of analytical indicators that assess the state of innovative activity and the scientific and technical level of innovations. The establishment of admissible sets of elementary processes and their combinations leading to innovative changes is also discussed. The planning algorithm is adapted to the type of innovative behavior and the state of the innovation potential within the socio-economic system. The potential for innovation in socio-economic systems is exemplified by the case of Ukraine, with the determination of the strategy for its innovative development in relation to the potentially optimal state.

Keywords: innovation · innovation changes · planning · indicators of planning · innovative behavior · innovation activity

1 Introduction

Innovation planning plays a crucial role in enabling organizations and individuals to identify and prioritize new ideas, technologies, and processes that drive growth and enhance competitiveness. This research paper aims to provide a comprehensive overview of innovation planning in the field of computer science, including its definitions, benefits, and best practices.

Objectives include determination of the foundations of innovative activity in the conditions of functional digitalization of production, based on the activation of the implementation of information and communication technologies of the digital economy to ensure the development of economic systems.

While there are various models concerning innovation changes, they all share a common understanding that innovation activities can be broadly described and visualized through process models. Although innovation studies are not a new topic, an increasing number of studies are being conducted in response to evolving innovation forms and

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changing global situations. Some models describe the life cycle of innovation as a function consisting of three distinct phases: emergence, growth, and maturity (Howard and Guile, Mitrova and Perani and Sirilli [1]). Other studies emphasize the characteristics of innovation defined by different stages of development. Linear models of innovation typically distinguish the discovery (invention), definition of possible application spheres, development, design, and use as phases of the innovation process (Schomberg, L. V. and Blok V. [2]; Ahn J., Duval R.A. and Sever C [3]; Robert A., [4]; Carayannis et al. [5]).

In the context of computer science, it is essential to establish a clear definition of innovation planning. Innovation planning refers to the process of identifying, evaluating, and prioritizing potential technological, organizational, or business innovations that drive growth and success. This process involves a range of activities such as brainstorming sessions, idea generation workshops, market research, and the development of plans and strategies for implementing and scaling new innovations. This paper presents a discussion on the necessity and constant refinement of the development strategy, including innovative design, based on planning and environmental forecasting.

Organizations may encounter several key challenges when implementing innovation planning. One challenge is the difficulty of identifying and prioritizing the most promising ideas and technologies, particularly in fast-moving industries where trends and technologies rapidly change. Organizations should adopt a proactive approach to innovation planning by continuously monitoring market trends and actively seeking out new ideas and technologies to drive growth and success. Another challenge is the inherent risk associated with innovation. While innovation can bring significant benefits, it also carries a level of risk as new ideas and technologies may not always succeed. Organizations should carefully assess the potential risks and rewards of each innovation before allocating resources for implementation. Additionally, the allocation of resources for innovation poses another challenge, especially for organizations with limited resources. Implementing new ideas and technologies often requires significant investments in terms of time and money.

To overcome these challenges, organizations need to prioritize their innovation efforts and allocate resources to initiatives that offer the highest potential for success. Adopting a structured and systematic approach to innovation planning is crucial. This approach can involve the use of tools and techniques such as roadmapping, which visualizes an organization's innovation goals and plans. Roadmapping helps identify key milestones, resources, dependencies, track progress, and adjust plans as necessary. In summary, innovation planning is a critical aspect of computer science that helps organizations and individuals identify and prioritize new ideas, technologies, and processes to drive growth and enhance competitiveness. While innovation planning brings significant benefits, it also presents challenges, including the difficulty of identifying and prioritizing promising ideas and technologies, the risks associated with innovation, and the need to allocate resources effectively. To address these challenges, organizations should adopt a structured and systematic approach to innovation planning, such as roadmapping, to track progress and adjust plans accordingly [6, 7].

2 Materials and Methods

In the process of planning innovations, the main focus is on making a reasonable choice of the main directions of innovation [8]. Strategy, in the context of innovation management, refers to a conscious and thoughtful set of norms and rules that underlie the development and adoption of strategic decisions affecting the future state of an enterprise. It serves as a means of connecting an enterprise with the external environment. The development of measures and plans, such as programs and projects, is an essential aspect of strategy to achieve the intended goals. These plans should consider the scientific, technical, and production potential of an enterprise, as well as its market and sales opportunities. The management of the innovation process entails the crucial task of developing and implementing the innovation strategy of the economic entity, which is subordinate to the general strategy. The innovation strategy establishes the goals of innovation, determines the means to achieve them, and identifies the sources of funds for innovation (Fig. 1) [9].

Primary innovation structures, attack strategies, defense strategies

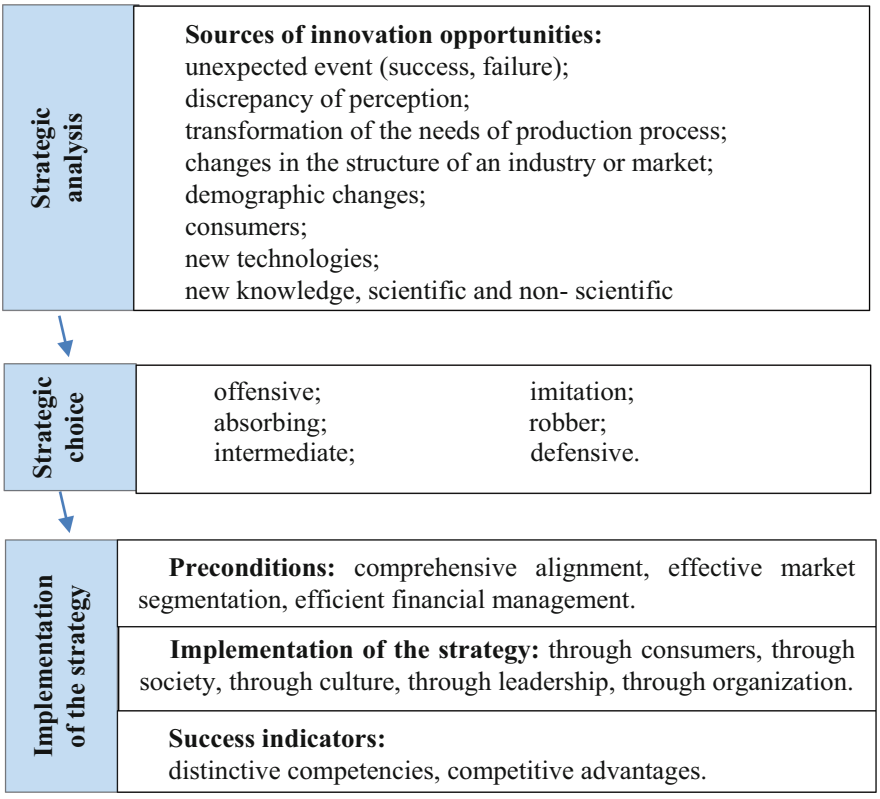

Fig. 1. Aspects of strategic innovative planning [10]

Projects involving innovative changes are characterized by significant information complexity and a high degree of uncertainty in the initial stages. Efficient managing of such projects requires well-structured information about the upcoming work stages [11].

At this stage, it becomes necessary to establish permissible sets of elementary processes and their combinations that lead to the emergence of innovative products of appropriate quality. From these permissible sets, a realized set of innovations is selected, forming an innovative change [12]. When considering an individual enterprise as the object at the first level, it becomes part of a higher-level set with specific characteristics at the subsequent level.

The innovative behavior of socio-economic systems (CES) is diverse, and various classification features can be used to analyze it. According to L. G. Ramenskiy, there are four types of innovative behavior for enterprises based on their goals: violets, commutants, patents, and explorative.

Socio-economic systems are classified as complex systems. Planning complex systems in the economy requires considering several properties to ensure the adequacy of the constructed plans. Table 1 presents the most important properties and characteristics of complex systems in the economy.

Each stage of the planning process corresponds to specific features of the state of the socio-economic system, which in turn characterize the type and strategy of the innovation system.

Patent Stage: Patent systems, also referred to as "sly foxes," can vary in size. The strategy at this stage is to differentiate products and focus maximum effort on a narrow market segment. Patents leverage differences in product quality, services, and advertising. The primary focus is to determine and deliver consumer value. Development in this stage can take two directions: stagnation or moderate growth within the occupied market segment. If the market segment's volume stagnates, the system's growth stops; otherwise, it expands in size; change of strategy and transformation into a larger violet system.

Violet Stage: Systems exhibiting innovative violet behavior are characterized by a large number of employees, multiple branches and subsidiaries, and a wide range of products. These systems make significant investments in R&D and maintain extensive marketing networks. Violet products are known for their excellent quality, standardization, unification, and manufacturability, resulting in lower prices due to mass production. Typical representatives of this type are multinational companies that create oligopolistic markets. Violets can further evolve into "proud lions," "mighty elephants," and "hulking hippos" based on their evolutionary development stages.

Proud lions focus on a narrow but massive range of highly demanded goods, displaying the most dynamic pace of development, large-scale production, and R&D expenditures.

Mighty elephants exhibit average dynamic development and extended diversification to compensate for a potential loss of a leader's position in the region, aiming for stability [11]. This type prefers implementing successful innovations rather than creating them from scratch.

Hulking hippos comprise small systems oriented towards meeting local and national needs, characterized by wide diversification. They transit smoothly to the commutative behavioral type, actively participating in the routinization of new products through imitative activity, as imitation is cheaper than independent innovation.

Table 1. System object properties [13–17]

Properties	Characteristics of Complex Systems in the Economy:
Integrity	A change in any component of the system affects the other components and the system as a whole. The system exhibits unity among its elements, self-preservation in content, and self-reproduction in form. A system with signs of self-organization becomes more stable and gains the ability to develop
Hierarchy	The components of the system are strictly subordinated, forming a systemic structure with levels of constituent parts. Each system can be considered as an element of a higher-level system (supersystem) and as a subsystem. Elements can belong to multiple subsystems through interconnections
Integrity or synergy (emergence)	The system possesses properties that are absent in its individual elements. Synergistic relationships between the elements result in an overall effect greater than the sum of the effects of the individual elements
Openness	The system functions through the exchange of energy and information flows with other systems and its environment
Dynamism	The system undergoes changes in parameters and structure under the influence of external factors. It has a purpose and functions that involve interactions with other systems and the environment, as well as overcoming internal contradictions
Resilience and adaptability	The system can maintain its structure, functionality, and purposeful existence in the presence of internal contradictions and external influences. However, the equilibrium of a system is relatively stable, and the significant influence of the external environment can lead to the emergence of multiple centers of disequilibrium

(*continued*)

Table 1. (*continued*)

Properties	Characteristics of Complex Systems in the Economy:
Fractality	The functioning and development of the system are independent of the scale of observation. Changes in higher-level systems result in similar changes in the subsystems. The functioning of the components is interconnected, and the violation of functional complementarity disrupts the integrity of the system
Self-organization and self-development	The system has the ability to change its internal structure under the influence of internal or external factors. This process involves the formation of dissipative structures and the pursuit of dynamic equilibrium
Non-linearity (randomness and uncertainty)	Complex systems exhibit a probabilistic nature due to the interaction of numerous external and internal factors. Economic and mathematical models based on probability theory are often used to study them. The development of a system is characterized by cyclical periods of progress and degradation. As the complexity of the system increases, cross-cyclic phenomena may occur, where the phases of development of some components overlap with the regression of others. It is challenging to isolate and study phenomena in such systems in their purest form due to their interaction with the environment

Commutative Stage: This stage involves the ability to search for strategic partners through engagement with switching systems. Small firms, which cater to local, narrow-group, or even individual demands, play a unifying and connecting role in the economy. These firms undertake tasks that are not of interest to violets, patents, or exporters, hence the term "commutants." They facilitate the diffusion of innovations while also routinizing them. Small firms actively promote new products, technologies, and services based on innovations, accelerating the diffusion process. The commutative stage also encompasses a venture type of behavior observed in systems with flexible and mobile structures. These systems excel in the speed of new product development, surpassing the capabilities of large enterprises. These ventures often engage in product production and transfer their developments to other systems. Due to their small scale, these systems have a limited number of employees.

Each system type (violent, commutators, patents, ventures, and explorative) possesses unique characteristics and varying degrees of strategy implementation to achieve product competitiveness (refer to Table 2 for details).

To remain competitive in a specific market segment, when technology advancements or production organization improvements are not possible, enterprises often have to reduce the price of their goods and decrease profit margins. Switching enterprises and

Table 2. Analysis of innovative strategies [18, 19]

Type of innovative behavior	Characteristic	Features
Venture	Systems with flexible and mobile structures operate at the stages of growth of inventive activity	They do not organize the production of products, but transfer their developments to other systems. The number of employees is small
Explorative	Medium or small systems that enter the market with a fundamentally new product, subsequently forming a new industry	They are distinguished by their dedication, high professional level of employees and leaders, high expenditures on R&D, the results of which are qualitatively new products and new technologies
Violent	Large systems that carry out mass production, operating in the market with their own or acquired new products, are ahead of the competition thanks to mass production and the effect of scale. They are characterized by forceful competitive and innovative behavior	The systems are large in size, have a large number of employees, many branches and subsidiaries, and a full range of products. They are distinguished by high costs from R&D, production, marketing and distribution networks. High quality products thanks to the high level of standardization and unification. Many violets are TNCs, create an oligopolistic market
Patent	Large, medium, small systems produce new or modernized products with unique characteristics and adapted to narrow segments of a wide market	In specialized production, the stock of competitiveness of a product is ensured by the consumer value of the product and full compliance with consumer expectations
Commute	Small systems carry out the diffusion of innovations created by other innovative organizations, adapting them to the requirements of the local market	Satisfying the local needs of local markets or even individual demand, “bind the economy across the entire space”

patents, while maintaining production costs, can enhance the quality of manufactured goods by introducing innovations [20–23]. Violent strategies involve implementing innovative approaches to enhance technology, production organization, labor, and management. Those who fail to innovate in a timely manner in terms of products and processes are eventually ousted from the market according to the objective law of competition.

The variety of corporate strategies and organizational forms of business entities offers numerous strategic positions and options for selecting competitive strategies with an innovative focus. To navigate this decision space effectively, it is crucial to adequately assess the firm's position in the market and identify its strategic competitive behavior.

3 Results

The effectiveness of managing the organization of innovative activities within business entities is evident through the synergistic interaction of various stages associated with the process of developing, implementing, and promoting innovations. Additionally, these stages are closely connected with changing the mental resource of employees, including the formation of corporate culture, business image, labor motivation system for innovation development and implementation, and corporate social responsibility.

Six stages of organizing innovative activity have been identified, aligned with the mechanism of developing and implementing investment projects:

1) planning of idea carriers;
2) determination of basic and functional strategies, as well as establishing a system of goals for their implementation;
3) assessment of innovative potential;
4) formation of the structure, regulations, and criteria for implementing and controlling innovations;
5) development and examination of innovative projects;
6) preparation of an innovation program and an innovation budget, including an assessment of innovation effectiveness.

The success of an innovation project is reflected in the interdependence between technology, operating costs, sales volume, and the price of a new product or service being offered. This is manifested through growth rates of economic value added and financial efficiency. From a societal perspective, the resource intensity of the innovation program decreases.

Table 3 presents a general grouping of the developed system of analytical indicators that enable the assessment of an economic entity's innovation activity. These indicators cover the scientific and technical level of innovation, the specific manifestation of the innovation process, and different aspects of evaluating innovation effectiveness.

The socio-economic system (SES) has been chosen as the subject of research, and it is important to consider multiple levels within the SES: macro-level: this represents the country as a whole (concept); meso-level: this refers to regions (plan); micro-level: this pertains to individual enterprises (program).

Table 3. The system of analytical indicators for assessing innovative activities [21]

Complex criterions (K_i)	Number of indicators	Of these, by stages of innovation		
		I	II	III
1. Scientific and technical level of innovation (K_1)	19	5	9	5
1.1. Progressiveness	7	2	4	1
1.2. Technicality	5	2	3	–
1.3. Competitiveness	1	–	–	–
1.4. Legal security	4	1	1	2
1.5. Manufacturability	2	–	1	1
2. Innovative process (K_2)	25	9	11	5
2.1. Innovative activity	2	–	–	2
2.2. Intensity	4	1	3	–
2.3. Saturation	7	2	4	1
2.4. Complexity	5	3	–	2
2.5. Duration	3	1	2	–
2.6. Completeness of coverage	4	2	2	–
3. Effectiveness of innovatioň activity (K_3)	16	1	1	14
3.1. Commercialization	1	–	–	1
3.2. Wide range and versatility of application	1	–	–	1
3.3. Financial	6	–	–	6
3.4. Investment	4	–	–	4
3.5. Incentives	3	–	–	3
All groups	60	15	21	24

Creating a computer-mathematical model for innovation planning in computer science can involve the use of optimization techniques. Optimization techniques are mathematical approaches that aim to find the best solution to a given problem by maximizing or minimizing a specific objective function.

One approach to developing a computer-mathematical model for innovation planning is utilizing linear programming. Linear programming involves optimizing a linear objective function while adhering to a set of linear constraints. In the context of innovation planning, the objective function could represent the expected value or impact of a specific innovation, while the constraints could reflect the available resources and limitations of the organization.

The integral indicator R, which represents the quality index of the evaluated program, can be defined as the sum of the products of the values of complex criteria (K_i) and their corresponding weight characteristics (v_i), as shown in formula (1):

$$R = \sum_{i=1}^{n} v_i \cdot K_i \tag{1}$$

Here:

v_i - weight characteristics of the importance of complex criteria K_i;

i - number of the complex criterion;

K_i - values of complex criteria.

Complex criteria K_i are typically derived from mathematical operations performed on a group of p initial indicators b_{ij}, where $j = 1, 2, \ldots, p$, which describe the object being evaluated. The formulation for complex criteria is given as:

$$K_i = \sum_{j=1}^{p} w_{ij} \cdot b_{ij}$$

To assess the compliance of programs (plans), a set of complex criteria can be selected based on a system of analytical indicators for assessing innovative activities (Table 4). Weight characteristics of importance are then assigned to each complex criterion, considering the number of indicators included in each group. The obtained data is as follows:

K_1 - scientific and technical level of innovation, $v_1 = 0.317$;

K_2 - innovation process, $v_2 = 0.417$;

K_3 - efficiency of innovation activity, $v_3 = 0.266$;

To normalize the real assessment according to the b_ij criterion, the formula (2) is used:

$$b_{ij} = \frac{a'_{ij} - a_{(min)}}{a_{ij(max)} - a_{ij(min)}} \tag{2}$$

Here:

a' - is an expert assessment set for the ij particular criterion for assessing b_{ij} on a point scale;

$a_{ij(max)}$ - is the maximum possible value of the expert assessment for a particular criterion for assessing b_{ij} on a point scale;

$a_{ij(min)}$ - is the minimum possible value of the expert assessment for a particular criterion for assessing b_{ij} on a point scale.

Weighting coefficients w_{ij} are then established for specific assessment criteria, considering their partial contribution to the overall assessment (Tables 4, 5 and 6).

Table 4. Scoring system for a complex criterion K1

Weight coefficient w_{ij}	Private criterion b_{ij}	Essence of a particular criterion	The value of a particular criterion
$w_{11} = 0{,}368$	b_{11} Progressiveness	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{12} = 0{,}263$	b_{12} Technicality	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{13} = 0{,}053$	b_{13} Competitiveness	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{14} = 0{,}211$	b_{14} Legal security	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{15} = 0{,}105$	b_{15} Manufacturability	average performance	10
		dynamic reproduction	5
		steadiness	0

Table 5. Scoring system for a complex criterion K2

Weight coefficient w_{ij}	Private criterion bij	Essence of a particular criterion	The value of a particular criterion
$w_{21} = 0{,}08$	b_{21} Innovative activity	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{22} = 0{,}16$	b_{22} Intensity	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{23} = 0{,}25$	b_{23} Saturation	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{24} = 0{,}2$	b_{24} Complexity	average performance	10
		dynamic reproduction	5
		steadiness	0

(*continued*)

Table 5. (*continued*)

Weight coefficient w_{ij}	Private criterion bij	Essence of a particular criterion	The value of a particular criterion
$w_{25} = 0{,}12$	b_{25} Duration	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{26} = 0{,}16$	b_{26} Completeness of coverage	average performance	10
		dynamic reproduction	5
		steadiness	0

Table 6. Scoring system for a complex criterion K3

Weight coefficient wij	Private criterion bij	Essence of a particular criterion	The value of a particular criterion
$w_{31} = 0{,}0625$	b_{31} Commercialization	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{32} = 0{,}0625$	b_{32} Wide range and versatility of application	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{33} = 0{,}375$	b_{33} Wide range and versatility of application	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{34} = 0{,}25$	b_{34} Investment	average performance	10
		dynamic reproduction	5
		steadiness	0
$w_{34} = 0{,}1875$	b_{35} Incentives	average performance	10
		dynamic reproduction	5
		steadiness	0

The normalization of the obtained assessments was carried out by an expert assessment method. The values of complex criteria for various types of innovative behavior are provided in Table 7.

To assess the complex coefficients of the criteria, the classification of the system of indicators is used, given in Table 8.

The values of the complex coefficients show that venture capitalists, violets, and exporters have a significant scientific and technical level of innovation (K_1), violets are far superior to all in the innovation process (K_2), switches have the lowest indicator of the innovation process, and the efficiency of innovation (K_3) has a spread the least significant by types of behavior.

The calculated integral indicators for various types of innovative behavior are given in Table 9.

Table 7. Complex criteria values

K_i	Venture	Violent	Patent	Explorative	Commute
K_1	0,7895	0,7370	0,4475	0,7365	0,2635
K_2	0,4650	0,8500	0,5450	0,4800	0,1800
K_3	0,7500	0,6250	0,5938	0,7813	0,5313

Table 8. Criteria significance level classification

Significance level of the criterion	Complex criterion value
Absolutely significant	1–0,99
Significant in the long run	0,85–0,98
Significant in the medium term	0,75–0,84
Relatively significant	0,65–0,74
Insignificantly	<0,65

Table 9. Integral indicator

Venture	Violent	Patent	Explorative	Commute
0,643677	0,754329	0,527060	0,641443	0,299902

The integral indicator, which serves as a comprehensive measure for assessing the level of innovativeness, holds significant importance for violets but is least relevant for commutants (see Fig. 2).

In the field of computer science, there exist several key metrics that organizations can utilize to gauge the effectiveness of their innovation planning endeavors. One such metric is the quantity of new ideas or technologies generated. This metric aids organizations in tracking the output of their innovation planning efforts and evaluating whether they are generating a sufficient volume of ideas. Another metric is the success rate of new

ideas or technologies, which enables organizations to assess the quality of their ideas and identify areas for improvement. Additionally, the impact of new ideas or technologies on the organization is a vital metric that involves measuring their financial impact, operational efficiency, and customer satisfaction. Furthermore, the level of employee engagement in the innovation process serves as a fourth metric, which helps organizations evaluate the level of buy-in and support for innovation among employees while identifying potential barriers to innovation. To summarize, organizations can employ several key metrics, including the quantity of new ideas or technologies generated, the success rate of these ideas or technologies, their impact on the organization, and the level of employee engagement, to effectively measure the effectiveness of their innovation planning efforts in computer science. By tracking these metrics, organizations can gain valuable insights and identify areas for improvement.

Through our analysis, we have discovered that the choice of an innovative behavior model for a firm's planning depends on environmental factors. Once a certain level is reached, welfare no longer plays a primary role in determining the model of innovative behavior within the socio-economic system. On the contrary, the endowment of scientific research potential becomes the determining factor for the type of innovative behavior in systems with a sufficient level of welfare. Even against the backdrop of relatively high welfare, a relatively low level of research resources prevents the acquisition of a specific role function. For further calculations, we present an innovative model based on generalized average data, which incorporates all the criteria of the considered socio-economic systems.

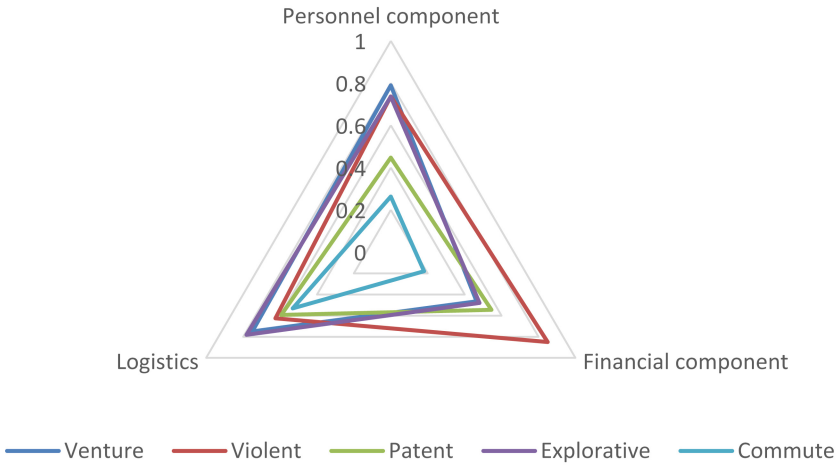

Fig. 2. The results of strategies for various states of the socio-economic system

Now, let us proceed with calculating the potential of socio-economic systems for innovation using Ukraine as an example. The innovative potential of socio-economic systems comprises three main components: financial, material and technical, and personnel.

For the calculation of Ukraine's innovative potential in socio-economic systems, we propose the use of two indicators for each component

1. Personnel Component. The following indicators characterize the proportion of individuals engaged in innovative activities within the total population:

1.1. Number of individuals employed in science and scientific services as a percentage of the total labor force (P).

1.2. Employment in medium and high-tech production as a percentage of the total labor force (F).

2. Financial Component. Indicators within this group characterize the physical volumes of financing in the innovation sphere, such as the share of investments relative to GDP and the share of investments in the total volume:

2.1. Total expenditures on research and development (R&D) as a percentage of GDP (E).

2.2. Share of the volume of sold innovative products (goods and services) in the total volume of sold products (goods and services) of industrial enterprises, expressed as a percentage (I).

3. Material and Technical Component. Indicators within this group characterize the number of organizations involved in scientific activities and possessing a material and technical basis for innovation:

3.1. Share of industrial enterprises that have introduced innovations (products and/or technological processes) in the total number of industrial enterprises, expressed as a percentage (T).

3.2. Number of registered patent applications for inventions and utility models per year, per total workforce (Y).

All data are given for the period 2013–2022 in Table 10.

The constructed innovative profile of Ukraine was analyzed using an optimal strategy, which was derived from all considered socio-economic systems based on the highest integral indicator of viability and overall performance, visually resembling the optimal strategy (see Fig. 3).

This approach enables the determination of the type of innovative behavior by considering a set of criteria. It also aids in identifying the diffusion process, which results from the increased production of innovative products consumed by the market.

The strategy for the innovative development of Ukraine, in relation to the potentially optimal state, is characterized by a lag in terms of the financial component and well-being level. In conditions of a low financial component, the innovation process is formally restricted. The absence of a deficit in research resources encourages the active utilization of closed innovations aimed at improving and modernizing already existing products within the domestic market. As prosperity grows, it becomes possible to independently create new innovations not only for the domestic market but also for the international market.

Understanding the growth rate of costs in the R&D cycle and their share in the total investment in technological development for new product production and commercialization is crucial for effective innovation management and planning.

Table 10. Innovative parameters for calculating the socio-economic system of Ukraine

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1. Personnel component										
The number of people employed in science and scientific services (thousands of people) – x1	19261,4	19314,2	18073,3	16443,2	16276,9	16156,4	16360,9	16578,3	16590,2	16602
Employment in high-tech production (thousands of people) – x2	504,1	493,6	456,0	422,9	428,1	415,8	437,9	421,6	418,7	415,7
2. Financial component										
Total expenditures on R&D (mln.UAH) – x3	9419,9	10248,5	9487,5	11003,6	11530,7	13379,3	16773,7	16773,7	16891,1	17009,4
Costs for innovations, (mln.UAH) – x4	11480,6	9562,6	7695,9	13813,7	23229,5	9117,5	12180,1	14220,9	14320,5	14420,7
3. Logistics										
Share of industrial enterprises that introduced innovations – x5	2181	2002	1729	1655	1503	1376	1491	1503	1493	1482
Number of registered patent applications for inventions and utility models per year – x6	44876	45910	50234	63266	73690	73411	83654	82914	83495	84079

The assessment of the scientific and technical factors pertaining to Ukraine's national security should be conducted with the aim of achieving conditions that would allow the country to secure a prominent position in the global economy.

In order to address this optimization problem, the model can identify a set of innovations that maximize the expected value or impact, taking into account the available resources and limitations. Alternatively, decision analysis techniques like decision trees

Fig. 3. Presents a comparative analysis of the strategies for Ukraine.

or expected value analysis can be employed. These techniques involve evaluating potential outcomes associated with different decisions and their corresponding probabilities, ultimately selecting the decision with the highest expected value [24]. Within the context of innovation planning, decision analysis techniques can be used to assess potential outcomes of various innovations and identify those that offer the greatest expected value or impact.

To summarize, a computer-mathematical model for innovation planning in computer science can be created using optimization techniques such as linear programming or decision analysis. By defining an objective function and constraints, and solving the optimization problem, the model can identify a set of innovations that maximize the expected value or impact considering the available resources and limitations.

4 Conclusions

Planning for innovative changes is an integral part of competitive strategy development. The planning process for innovative changes should encompass multiple stages. The organization of innovative activities should be aligned with the mechanisms for developing and implementing investment projects. Projects involving innovative changes are characterized by significant information complexity and a high degree of uncertainty. To effectively manage such innovative projects, well-structured information regarding the upcoming tasks is essential. The choice of an innovative behavior model depends on environmental factors. The evaluation of program (plan) compliance is based on a system of analytical indicators designed for assessing innovative activities comprehensively. The conducted studies provide a basis for developing fundamental models of innovative systems and modeling methods to address planning problems. Consequently, the research formulates the problem of planning innovation activity as an optimization problem for the allocation of limited resources. Additionally, a search method for

solving the optimization problem of planning innovation activity is proposed. In future studies, it is planned to develop algorithms for analyzing incentive mechanisms for innovative development of both large companies and enterprise personnel, as well as develop proposals for improving the methods for determining priorities for the development of innovations.

References

1. Giulio, P., Giorgio, S.: Benchmarking innovation in Europe, vol. 2(1), pp. 4–15 (2008)
2. Schomberg, L.V., Blok, V.: The turbulent age of innovation. Questioning the nature of innovation in responsible research & innovation (2021). https://doi.org/10.1007/s11229-018-01950-8
3. Ahn, J., Duval, R., Sever, C.: Macroeconomic Policy, Product Market Competition, and Growth: The Intangible Investment Channel, IMF Working Paper, No. 20/25, International Monetary Fund, February 2020. https://www.ecb.europa.eu/pub/economic-bulletin/artcles/2021/html/ecb.ebart202008_03~da0f5f792a.en.html
4. Robert, A., Valerie, J., Vincent, L., Filippos, P., Ieva, R., Lara, V.: The digital economy and the euro area. Economic Bulletin Articles, European Central Bank, vol. 8 (2021). https://ideas.repec.org/a/ecb/ecbart/202100083.html
5. Carayannis, E., Grigoroudis, E.: Quadruple innovation helix and smart specialization: knowledge production and national competitiveness. J. Nat. Res. Univ. High. Sch. Econ. **10**, 31–42 (2016). https://doi.org/10.17323/1995-459x.2016.1.31.42
6. Ghezzi, A., Cavallo, A.: Agile business model innovation in digital entrepreneurship: lean startup approaches. J. Bus. Res. **110**, 519–537 (2020). https://doi.org/10.1016/j.jbusres.2018.06.013
7. Artomova, A.V., Kuznetsova, Y.V.: The impact of the COVID-19 pandemic on migration flows from Ukraine to the countries of the European union. Problemy i perspektyvy rozvytku pidpryiemnytstva: zb. nauk. prats **25**, 4–16 (2020). https://doi.org/10.30977/PPB.2226-8820.2020.25.0.4
8. Ferreira, J., Coelho, A., Moutinho L.: Dynamic capabilities, creativity and innovation capability and their impact on competitive advantage and firm performance: The moderating role of entrepreneurial orientation. Technovation **92–93**, 102061 (2018). https://doi.org/10.1016/j.technovation.2018.11.004
9. Iarmosh, O., Prokhorova, V., Shcherbyna, I., Kashaba, O., Slastianykova, K.: Innovativeness of the creative economy as a component of the Ukrainian and the world sustainable development strategy. IOP Conf. Ser. Earth Environ. Sci. **628**, 012035 (2020). Ivano-Frankivsk, Ukraine. https://iopscience.iop.org/article/10.1088/1755-1315/628/1/012035/pdf
10. Kotytko, T., Bryl, I., Piletska, S., Arefieva, O., Arifiev, S.: Strategy of innovative development of an enterprise on the basis of evaluation of its intellectual capital. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu **3**, 134–141 (2021). http://nvngu.in.ua/jdownloads/pdf/2021/3/03_2021_Korytko.pdf
11. Baloch, M.A., Ozturk, I., Bekun, F.V., Khan, D.: Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: does globalization matter? Bus. Strategy Environ. **30**(1), 176–184 (2020). https://doi.org/10.1002/bse.2615
12. Chirumalla, K.: Building digitally-enabled process innovation in the process industries: a dynamic capabilities approach. Technovation **105**, 102256 (2021). https://doi.org/10.1016/j.technovation.2021.102256
13. De Loecker, J., Eeckhout, J., Unger, G.: The rise of market power and the macroeconomic implications. Q. J. Econ. **135**(2), 561–644 (2020). Oxford University Press, Oxford. https://academic.oup.com/qje/article/135/2/561/5714769?login=true

14. Boroda, G., Gorbunov, A., Gorbunova, M.: Intellectual potential as a foundation of innovative development of socio-economic systems. In: Popkova, E.G., Sergi, B.S. (eds.) Modern Global Economic System: Evolutional Development vs. Revolutionary Leap, ISC 2019. LNNS, vol. 198, pp. 1419–1426. Springer, Cham (2021). https://link.springer.com/chapter/10.1007%2F978-3-030-69415-9_157
15. Khanin, S., Arefieva, O., Dergaliuk, M., Popelo, O., Tulchynska, S.: Concept of the activation of intellectual and innovative determinants for the development intensification of reginal economic system. Laplage em Revista (International) **7**(Extra E), 234–244 (2021). https://ela.kpi.ua/bitstream/123456789/55128/1/P234-244.pdf
16. Popelo, O., Butko, M., Revko, A., Garafonova, O., Rasskazov, O.: Strategy of the formation and development of an innovative agroindustrial cluster of the region in a context of decentralization of the authoritative powers. Financ. Credit Activity Probl. Theory Pract. **2**(37), 219–230 (2021). http://fkd1.ubs.edu.ua/article/view/230180
17. Chernyakovska, L., Nizamutdinov, M.: Development of knowledge base for intellectual decision support in the process of innovative project management. In: 2019 XXI International Conference Complex Systems: Control and Modeling Problems (CSCMP), 3–6 September 2019, 19318924, pp. 384–387 (2019). https://ieeexplore.ieee.org/document/8976758
18. Khanin, S., Tulchynska, S., Popelo, O.: Systematization of functional features of intellectual and innovative determinants of the intensification of the regional economic development. Laplage em Revista (International) **7**(2), 710–720 (2021). https://laplageemrevista.editorialaar.com/index.php/lpg1/article/view/1118/1018
19. Thomas, J.: Case study: the value of intellectual property in innovative product development. In: Di Bucchianico, G., Shin, C., Shim, S., Fukuda, S., Montagna, G., Carvalho, C. (eds.) Advances in Industrial Design, AHFE 2020. AISC, vol. 1202, pp. 240–247 (2020). https://link.springer.com/chapter/10.1007%2F978-3-030-51194-4_32
20. Artomova, A., Malkina, M.: The trade balance of Germany in the skilled crisis and post-crisis development of world economy. J. Econ. Reforms **1**(33), 13 (2019). http://nbuv.gov.ua/UJRN/Cher_2019_1_5
21. Rusina, A.N., Bogdasarian, I.S., Filimonenk, I.V.: Assessing the impact of intellectual potential on the innovative development of resource-based region. In: Popkova, E.G., Sergi, B.S. (eds.) LNNS, vol. 129, pp. 740–754. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-47945-9_79
22. Gabriela, B., Christmann, O., Ibert, J.: Innovations in spatial planning as a social process – phases, actors, conflicts. Eur. Plann. Stud. **28**(3), 496–520 (2020). https://doi.org/10.1080/09654313.2019.1639399
23. Davydova, I., Artyomova, A., Uvarova, I.: Methodology for sustainable development management of the power supply industry in the global market. Adapt. Manag. Theory Pract. Ser. Econ. **15**(30) (2023). https://doi.org/10.33296/2707-0654-15(30)-19
24. Fornell, C., Larcker, D.: Evaluating structural equation models with unobservable variables and measurement error. J. Mark. Res. **18**(1), 39–50 (2021). https://doi.org/10.2307/3151312

Combined Anaerobic and Aerobic Technology for Wastewater Treatment

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Abstract. Issues of wastewater treatment, biotechnologies of food industry enterprises are considered. It was determined that the problems of wastewater treatment of food enterprises, which have a multicomponent and polydisperse composition, are highly concentrated, which can have a negative impact on the environment. The qualitative and quantitative composition of wastewater from food industry enterprises is given, the existing technologies of wastewater treatment are given, the biochemical processes of purification are described, and the ways of improving the technology of biological wastewater treatment by using their further treatment on a bioplateau are substantiated. Biological technologies for further purification of wastewater in a bioplateau from organic pollutants, nitrates, phosphates with artificial and natural aeration are described. Permanent control of wastewater treatment is offered, as well as initial control of the quality of treated water, environmental protection measures are described.

Keywords: wastewater · biotechnology · innovative technologies · sustainable development

1 Introduction

1.1 The Relevance of the Topic

Enterprise wastewater belongs to the category of highly concentrated and has unstable indicators in terms of quality and quantity. Such wastewater is a complex polydisperse systems and contains impurities of different natures: fat, milk, scales, wool, blood, pieces of tissue, salts, insoluble mineral impurities, etc. The analysis of literary sources showed that in Ukraine and leading European countries intensive search for the most rational and highly effective methods and technologies of wastewater treatment and retreatment is underway. The most common solutions in this area are a combination of classical cleaning methods (mechanical, physical-chemical, biological, etc.) with ecologically innovative methods of additional cleaning on a bioplateau.

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1.2 Goal

On the basis of the study of existing methods, to propose the improvement of the technology of biological purification of wastewater of food industry enterprises from nitrogen and phosphorus compounds with the help of nitrifying bacteria of the Nitrosomonas and Nitrospira groups and higher aquatic plants to increase the efficiency of wastewater treatment.

To achieve the goal, the following tasks must be solved:

- describe the qualitative and quantitative composition of wastewater;
- describe the qualitative and quantitative composition of wastewater and the existing technology of its biological treatment;
- describe the technological process of biological wastewater treatment;
- characterize raw materials and materials used in wastewater treatment;
- propose changes in wastewater treatment technology;
- consider the biochemical processes that take place in the process of wastewater treatment;
- carry out economic calculations of the wastewater treatment efficiency;
- consider environmental protection measures.

1.3 Research Methodology

The methodological basis of the work is the dialectical method, the use of which allows studying the object and subject of research in their epistemological unity, interrelationship, and differences. The method of writing an article consists of the use of several basic methods of scientific knowledge. Using the historical method, the historical and general theoretical questions of the essence of scientific approaches and the practice of applying wastewater treatment methods were clarified. The use of methods of analysis and synthesis made it possible to separate the most effective and environmentally friendly methods of wastewater treatment. The logical-semantic method determined the relationships and mutual influences of the method of using the bioplateau with other environmentally friendly methods of wastewater treatment. Scientific abstraction and generalization of scientific-theoretical information as a process of establishing general properties and features made it possible to reach and formulate final conclusions regarding the subject of research. The research also used methods of analysis of statistical and environmental information with open access and the results of a survey of entrepreneurs and enterprise managers according to the methodology developed to assess the situation from the “basic level” - the judgments and expectations of the main economic agents: entrepreneurs and enterprise managers (the field stage of the third monthly survey held July 4–14, 2022 for the entire territory of Ukraine) [1].

1.4 Literature Review

The analysis of literary sources showed that in Ukraine and leading European countries intensive search for the most rational and highly effective cleaning methods and technologies is conducted. The most common solutions in this area are a combination

of classical cleaning methods (mechanical, physical-chemical, biological, etc.) with ecologically innovative methods of additional cleaning on a bioplateau.

Thus, investigating the problem of environmental deterioration due to the presence of highly concentrated wastewater contaminated with organic compounds at enterprises processing livestock products [2], the authors determine that the problem of wastewater treatment has not only an ecological basis, but is also caused by the inefficient operation of the treatment facilities themselves, because outdated technologies are used and the equipment is worn out. The researchers found out that traditional methods using aeration tanks cannot meet the required indicators of wastewater treatment, so this study considered the advantages of the biological method of wastewater treatment, the conditions and requirements for its use. The research identified a number of problems that are solved by involving associations of microorganisms and characterized the known effective associations of microorganisms that are immobilized on a carrier in order to increase the biomass that directly participates in the cleaning process. With high levels of pollution, the researchers suggested intensifying the processes of biological purification by switching the treatment plant to biosorption mode, which increases the efficiency of purification by increasing the concentration of activated sludge when introducing carriers with immobilized microorganisms. Examples of technology modifications, in which the parameters of immobilization of microorganisms, the mode of air supply, are changed, the expediency of using certain selected genera of microorganisms and their combination with other types of biological agents are indicated. The authors found that the advantages of this method are cheapness and environmental friendliness, since disposal technologies do not require significant structural changes to already existing wastewater treatment lines, and various wastes of natural and artificial origin can be used as carriers. It should be noted that the technologically proposed method of purification can be implemented only with a preliminary selection of the most effective composition of microorganisms, by growing (immobilizing) their biomass on a carrier separately from the bioreactor, in which the purification process directly takes place. Correct work in the aeration tank also involves periodic replacement or cleaning of carriers from spent microflora. Another group of scientists [3] investigated modern trends and prospects of wastewater treatment technology of wineries. The water footprint of wineries usually exceeds 1 L of water/liter of wine. In a European context, this equates to over one hundred million hectoliters of water annually, most of which eventually becomes wastewater. Winery wastewater is known to contain high organic loads, which are most often quantified by chemical oxygen consumption (COC). Especially during the grape harvest season, the discharge of wastewater from a winery with extreme COC values can paralyze municipal wastewater treatment plants. As a result, treatment facilities set strict limits on wastewater parameters. This forces wineries to either transport wastewater to specialized facilities capable of treating the wastewater end, or invest in their own treatment facilities. Because wine has historically been produced by small wineries, either option is an economic challenge for these often family-owned businesses. This work reflects the need for reliable wastewater treatment technologies that can handle the fluctuations in winery wastewater parameters throughout the year and the aforementioned peaks. Technologies are classified into physico-chemical, biological, membrane, progressive oxidation and combined processes. There are a number of cleaning methods

that have shown an COC removal rate of over 90%. However, they vary significantly in size, process flexibility, and maintenance complexity. Some alternative processes are also critically evaluated in the context of the circular economy and water reuse, which can further improve the economic process for small and medium-sized wineries.

Presenting the results of the study of wastewater treatment conditions on the example of a meat processing enterprise [4], the researchers indicated that for local wastewater treatment of food industry enterprises, physico-chemical cleaning methods are widely used, which, with correctly selected reagents and their doses, allow to achieve high cleaning efficiency. At the same time, the doses of reagents and the conditions of their use can differ dramatically at enterprises, so the regularities of the cleaning process must be studied on a specific drain. The work investigates the regularities of the process of coagulation of wastewater using coagulants and flocculants of different chemical composition using the example of wastewater from a turkey meat processing enterprise. The regularities of the wastewater coagulation process in a wide range of medium pH values were studied. It was experimentally established that the optimal pH of the environment for the use of polyaluminum chloride is within 5.9 ÷ 6.4, iron chloride 6.2 ÷ 6.7, iron sulfate 5.1 ÷ 5.7. The regularities of the effect of the coagulant dose on the efficiency of removing suspended substances from wastewater and the reduction of color were established. Based on the obtained data, the authors determine the most optimal doses of coagulants. The rational dose of polyaluminum chloride was 140 mg/l, iron sulfate – 110 mg/l, and iron chloride – 80 mg/l. The regularities of the wastewater flocculation process using flocculants of different charge and molecular weight were studied. The most effective types of flocculants were determined and the optimal doses of reagents were determined. Rational conditions for physical and chemical treatment of wastewater using coagulants and flocculants have been determined. The obtained data make it possible to optimize the operation of local treatment facilities of the processing enterprise: to increase productivity, as well as to reduce operating costs. Selected binary combinations of reagents make it possible to achieve an efficiency of 99.4% removal of suspended substances and 82.4% color reduction.

When considering the possibility of improving the technology of wastewater treatment of food industry enterprises, researchers [5] investigated the feasibility of replacing conventional membranes for FPW treatment with low-cost dynamic membranes (DM) as an alternative. The DM Anaerobic Bioreactor (DAnMBR) was operated for 90 days to evaluate the treatment efficiency with real FPW at different organic load levels (OLR) of 3.5, 5.0, 6.5 and 7.0 g COD (Chemical Oxygen Demand)/l day After the reactor reached a steady state of 90% COC removal, the reactor feed was gradually supplemented with FPW from 10% to 90% as COC to allow the methanogenic bacteria to adapt to any potential inhibitory effects from its persistent content. The bioreactor demonstrated stable performance at an OLR of 5.0 g COC/L per day with 97.5% COC removal and achieved 20 mg/L Total Suspended Solids (TSS). A significant correlation was found between the fractions of COCs removed through acidogenesis and methanogenesis with different OLRs, indicating that increased scavenging efficiency is beneficial for the activity of methanogenic archaea. Methane gas yield reached a maximum of 0.40 L methane/g COC added at OLR 3.5 and 5.0 g COC/L day. The average permeate flow in these studies is about 60 l/m2 h. DM became contaminated after 57 days (at a flow rate of 27.16 l/m2 h,

an immediate drop to 2.16 l/m2 h) when operating at 3.5 g HSC/l day. After fouling, the membrane was physically cleaned, backwashed on the place for 5 min, and reused without any chemical cleaning. Improved filtration resistance is facilitated by the appearance of DM fouling caused by the release of soluble microbial products (SMP) and extracellular polymeric substances (EPS), as well as an increase in the protein/carbohydrate (P/C) ratio of the mixed solution. Determination of the economic efficiency of the proposed dynamic anaerobic membrane bioreactor (DAnMBR) remains unresolved.

The review of the literature on the topic also gives reasons to claim that a cost-effective and environmentally acceptable solution to the modern existing problem of cleaning highly concentrated wastewater of food industry enterprises can be a combined anaerobic-aerobic cleaning technology. The use of anaerobic-aerobic methods of wastewater treatment is effective, since using only the anaerobic stage of treatment, it is impossible to achieve strict standards, both when discharging treated wastewater into treatment facilities and into surface reservoirs. In this case, the anaerobic method of purification is used as the first biological stage, while one or two stages of the bioplateau are used as platforms for further purification [6, 7, 10].

2 Main Content Presentation

Protection of the natural environment and rational use of nature are the basis of sustainable development and ensuring environmental safety. The introduction of environmental measures and technologies, innovative solutions in environmental protection is a conscious direction of European development both at the state and regional levels, including the local level and the level of specific enterprises. Food industry enterprises are those that have a certain negative impact on the environment and require the development and implementation of a number of environmental protection measures.

Considering the negative impact of food industry enterprises, it is necessary to develop new and improve existing technological solutions and approaches, based on leading European practices, to preserve and improve the environment safe for human life and health on the basis of sustainable development and environmental safety.

Of the physico-chemical methods of wastewater treatment, the most effective for food industry enterprises is the pressure flotation method. This method allows for a high degree of purification from undissolved impurities, suspended substances, fats and surfactants, which are contained in high concentrations and are characteristic of food industry enterprises. The difference of this method lies in the high efficiency of capturing pollution particles with small air bubbles, as a result of which float complexes are formed that are easily removed.

To intensify the speed of flotation extraction of particles due to their thickening, it is advisable to use coagulation and flotation. The type and doses of reagents are selected based on the results of previous experimental work. This method makes it possible to increase the efficiency of sewage treatment by 15–20%. Its advantage lies in the high degree of purification and continuity of the process. In turn, the simplicity and compactness of the installation allows you to significantly reduce construction and installation work and place it near the enterprise.

The main drawback of this solution is an insufficiently high degree of purification according to COC and BOC, since most of the biogenic elements in wastewater are in dissolved form. In addition, during the cleaning process, a large amount of floating sludge is formed, which requires subsequent stabilization and dehydration, which consumes expensive reagents. The use of the flotation method does not allow to fully ensure the given degree of purification; therefore, it is necessary to use biological aerobic and anaerobic methods.

Aerobic treatment, used for food enterprises, provides a high degree of wastewater treatment, characterized by a low (up to 2000 mg/l) MPC (Maximum permissible concentrations) value. These can be confectionery factories, cheese factories, dairies, ice cream factories, sausage factories, plants for the production of vegetable oils and products based on them, soybean processing plants, etc. During biological purification, proteins, fats, carbohydrates, surface-active substances, tartaric acid and other compounds are destroyed by bacteria, which are both immobilized and free-floating in aerobic conditions, but optimal conditions must be created for the development of microbial cultures. In this direction, the most promising are aeration tanks working with high doses of activated sludge and pure oxygen.

A feature of aerobic cleaning methods is the provision of water biocenoses with oxygen for the oxidation of pollutants contained in water with the emission of carbon dioxide, mineral compounds and biomass. Thanks to the latest developments and the technology of supplying the oxidant in aerobic reactors, oxygen-poor zones and oxygen-enriched zones are created. Thanks to this, an oxidation reactions necessary for the selection and accumulation of polyphosphate-forming microflora, decomposition of nitrates (with repeated return of activated sludge), and oxidation processes, which allow reducing MPC and BOC, occur at the same time.

Despite all the positive qualities of this method, aerobic biological treatment has a number of significant disadvantages associated with higher costs for aeration and disposal of excess activated sludge. In addition to the extreme economic inefficiency of this method, the variable composition of wastewater and the high concentration of pollutants more than 2000 mg/l of MPC often lead to overloading of aerobic biological treatment facilities, as a result of which pollution enters the environment without hindrance.

The advantages of the aerobic method include: the possibility of working at low concentrations of COC, BOC pollutants in wastewater, reducing the content of nitrogen and phosphorus compounds, the possibility of using several stages of purification to achieve the required MPC values, relatively small investment costs.

The advantages of the combined technology in comparison with traditional aerobic treatment are as follows: a high degree of purification of wastewater with high concentrations of organic pollutants COC $>$ 2000 mg/l, a small increase in excess biomass is 5–10 times less during aerobic treatment (biomass is stable, does not rot at storage), resistance to long interruptions in the supply of wastewater, low operating costs. The main disadvantage of this technology is high capital investment.

Microorganisms are the main objects of wastewater treatment biotechnologies. In purification systems, a biological method is used to purify water from organic substances using a system of mixed microflora (aerobic bacteria, algae, protozoa, bacteriophages, fungi), activated sludge, and biofilms that oxidize incoming substances. Representatives

of the microbial mixture contribute to the intensification of natural water purification processes. But at the same time, it should be remembered that the condition for sustainable work of the microbial community is the stability of the composition of the environment.

At the heart of aerobic methods is the use of groups of microorganisms, for the vital activity of which a constant supply of oxygen and maintenance of the temperature of the environment at the level of 20–40 °C are mandatory. Violation of oxygen and temperature conditions leads to changes in the composition and number of microorganisms. Purification of wastewater under aerobic conditions is carried out using biofilters or by cultivating microorganisms in activated sludge, the biocenosis of which consists of various groups of living organisms (bacteria, worms, fungi, algae, crustaceans). Activated sludge is an amphoteric colloid with a pH value of 4–9, and its dry matter includes 70–90% organic and 10–30% inorganic substances. The main purpose of aerobic cleaning methods is the oxidative mineralization of carbon-containing organic compounds and the transformation of reduced forms of nitrogen into oxidized ones (nitrification of nitrogen with the formation of nitrite and nitrate ions).

Under the action of exoenzymes, amino acid chains are split and transferred to a state convenient for absorption by cells. As a result of intracellular processes, amino acids with the participation of endoenzymes are further destroyed with the release of free ammonia (ammonification process), namely:

$$NH2\,R{-}CH + 0,5O2\,RCOCOOH + NH3.COOH$$

Ammonifying bacteria (mainly of the genus Bacillus: B. subtilis, B. megaterium) and non-spore forms - representatives of the genera Pseudomonas, Micrococcus, Mycobacterium, Proteus, Arthrobacter are characterized by the consumption of many organic compounds. Despite the fact that these microbial organisms mainly utilize proteins, they are also able to biochemically convert organic acids and carbohydrates.

Aerobic methods are also usually divided by the type of tank in which the oxidation of pollutants takes place. Reservoirs can be bioengineering structures in the form of biological ponds (so-called bioplateaus, filtration fields), and special devices are also used - biofilters and aeration tanks. In biological ponds (bioplateau), aerobic oxidation (mineralization process) of organic compounds takes place with the participation of microorganisms, algae, and higher aquatic plants (reed, cattail, rush, duckweed, water spinach, water hyacinth, etc.). Favorable conditions for the effective course of oxidizing reactions in artificially created hydrobiocenoses are the insignificant depth of the reservoir, the absence of current, a large number of microalgae that saturate the water with oxygen, a sufficient number of protozoa that feed on bacteria, etc.

Filtration fields are specialized plots of land set aside for discharge of polluted wastewater and inhabited by soil aerobic microorganisms that biochemically convert harmful organic substances into water and carbon dioxide. Large-scale use of biological ponds and filtration fields is limited by the seasonal nature of their work, low throughput, as well as the need to set aside significant land areas and constantly control the level of groundwater. In this regard, in practice artificial structures such as reservoirs (biofilters, aerotanks) have become widespread. Biological filters (biofilters) are special types of bioreactors with volumetric loading of the filter element, on which the immobilized (fixed on a stationary carrier) biomass has the form of a film.

Aerotanks belong to homogeneous bioreactors. Their typical design is a deep reinforced concrete hermetic rectangular tank with a height of 3–6 m, equipped with aeration devices and connected to a sump. The air tank is divided by partitions into 3–4 corridors. The types of aeration tanks are determined mainly by the method of oxygen supply, the design of the reactor itself, and the volume of loaded material. Water purification in the aeration tank occurs in the process of flowing through it an aerated mixture of wastewater and activated sludge.

Thus, filamentous bacteria present in the flocculating mixture of activated sludge destroy organic substances and ensure their rapid deposition in sedimentation tanks, where compacted sludge is formed. The role of nitrifying bacteria (Nitrosomonas, Nitrobacter) is reduced to the oxidative transformation of reduced forms of nitrogen according to the following reactions:

$$Nitrosomonas\, NH3 + O2\, NO2- Nitrobacter\, NO2- + O2\, NO3-$$

Therefore, when there are nitrite and nitrate ions in the water at the exit from the aeration tank, this indicates a deep level of its purification.

In anaerobic methods, it is provided that wastewater treatment takes place without access of oxygen and for this purpose, as a rule, methane fermentation is used. The advantage of this method is a high level of conversion of pollutants with the formation of an additional product - biogas. The fermentation process is carried out in closed tanks - methane tanks (septic tanks). Methane tanks are hermetic mixing reactors filled with immobilized activated sludge, sludge ponds or other structures. Methane tanks are designed both for sewage treatment and for the generation of methane - a valuable gas with a high heat-generating capacity.

The characteristics of microorganisms participating in wastewater treatment and the biochemical scheme are important for understanding the processes of wastewater treatment. At the same time, we must take into account that many agents participate in these processes, including heterotrophic bacteria, cyanobacteria, fungi and protozoa (flagellates, ciliates, sarcoids, and amoebae), as well as multicellular organisms (nematodes, worms, and rotifers) [6, 7]. The most active fat mineralizers are Pseudomonas fluorescens. PS pyacyanea., Bacillus fluorescens, Ps. liquefaciens, Achromobacter lipolyticum, which have the ability to split them [8–10].

Biochemical processes in the application of aerobic wastewater treatment methods consist of two stages: 1) adsorption of easily oxidizable substances with intensive use of oxygen; 2) post-oxidation of slowly oxidizing organic substances, regeneration of activated sludge.

An important role in these processes is played by the cycle of tricarboxylic acids (the Krebs cycle, or the citric acid cycle), consisting of a series of consecutive reactions catalyzed by ten different enzymes. It is a central part of the general path of catabolism, a biochemical cyclic process of aerobic organisms, during which the transformation of two- and three-carbon compounds, which are formed as intermediate products in living organisms during the breakdown of carbohydrates, fats and proteins, takes place, to CO2. At the same time, the released hydrogen goes into the chain of tissue respiration, where it is further oxidized to water, taking part in the direct synthesis of the universal source of energy - ATP. The well-known sequence of reactions of the cycle of tricarboxylic acids is as Fig. 1.

During water purification, denitrification processes occur under the action of nitrifying nitrifying bacteria. The first stage - ammonium nitritation - is carried out by oxidizing bacteria and oxidizing archaea - the genus Nitrosomonas and Nitrosococcus. The second stage of nitrification is nitrite nitration by oxidizing bacteria belonging to the genus Nitrobacter and Nitrospira. Nitrification is the final stage of nitrogen-containing mineralization of organic substances. Decomposition of organic compounds can occur due to the formation of amino acids, which further release ammonia. Acetyl-CoA is also subjected to oxidative decarboxylation, which condenses with oxalic-acetic acid to form citric acid, which isomerizes into cis-aconic acid, and then into isolicimonic acid. This process proceeds in two stages: first, the dehydrogenation of isolitric acid from oxalosuccinic acid takes place, which then decarboxylates, turning into ketoglutaric acid. Next, oxidative decarboxylation of ketoglutaric acid occurs and succinyl-CoA is formed, which turns into free succinic acid. This is followed by the dehydrogenation of succinic acid with the formation of fumaric acid, which turns into malic acid. After dehydrogenation, oxalic-acetic acid is produced, and it can condense again with acetyl-CoA (CH3-CO-S-KoA) [8, 10].

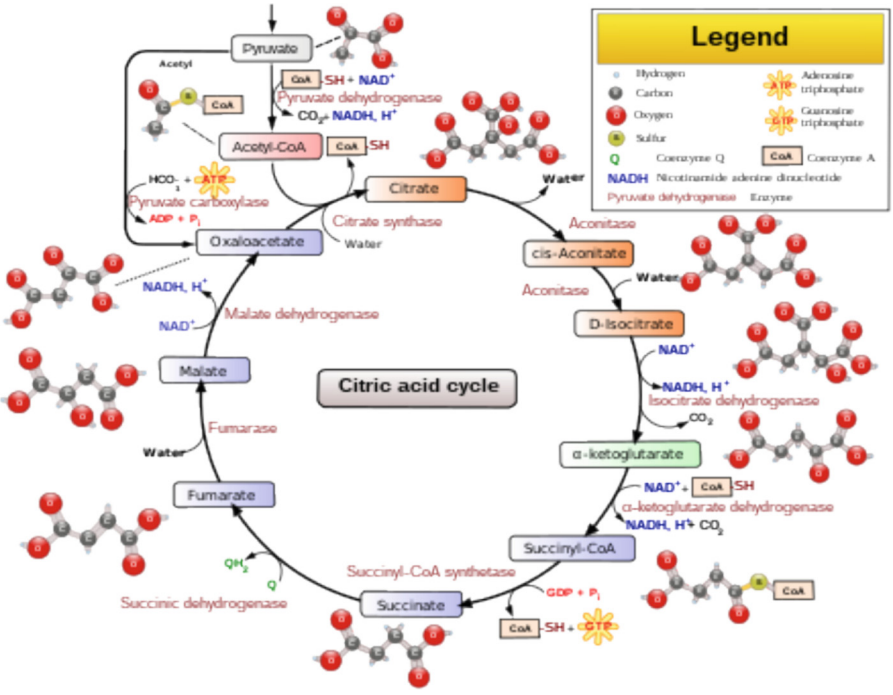

Fig. 1. Sequence of reactions of the cycle of tricarboxylic acids

3 Conclusions

The proposed method of wastewater treatment is a combined biotechnological process based on the ability of microorganisms to assimilate organic substances, which are components of polluted wastewater, as sources of nutrition. At the end of the biological treatment, the organic pollution of the wastewater becomes harmless and oxidation products - H2O, CO2, NO3-, SO42-, etc. Microorganisms in the course of this receive everything necessary for their vital activities - solar energy and substances for constructive metabolism, cell regeneration and biomass growth. As a result, they remove debris from the water, which are then removed with gaseous metabolic products and their own biomass in the form of activated sludge [11]. It should also be borne in mind that the treatment scheme must be selected taking into account the features and capabilities of urban water treatment facilities, as the discharge of insufficiently treated sewage of this category can have a significant negative impact on the operation of urban water treatment facilities [12]. Thus, the ecological problems of wastewater treatment of food industries can be partially solved with the simultaneous step-by-step application of physico-chemical and biological methods. A combination of physico-chemical (pressure flotation, treatment with reagents) and biological (oxidation of microflora in anaerobic and aerobic conditions) methods is necessary for a complex and energy-efficient solution to this problem. Such a combination eliminates the shortcomings of each of the methods and allows the most effective solution to the task.

References

1. Anghel, J., Ghulik, A.: Jak ukrajinsjka promyslovistj dolaje vojenni vyklyky. Instytut ekonomichnykh doslidzhenj ta politychnykh konsuljtacij (2022). (in Ukrainian). https://rpr.org.ua/news/yak-ukrainska-promyslovist-dolaie-voienni-vyklyky/
2. Rebrykova, P.A., Shydlovsjka, O.A., Zholobak, N.M., Mokrousova, O.R.: Biotekhnologhichni aspekty ochyshhennja stichnykh vod pidpryjemstv, shho pererobljajutj produkty tvarynnyctva. Naukovi praci NUKhT **24**(6), 42–49 (2018). (in Ukrainian). https://nuft.edu.ua/doi/doc/swnuft/2018/6/7.pdf
3. Miklas, V., Touš, M., Miklasová, M., Máša, V., Hornák, D.: Winery wastewater treatment technologies: current trends and future perspective. Chem. Eng. Trans. **94**, 847–852 (2022). (in English)
4. Makhlay, K., Tseitlin, M., Raiko, V.: A study of wastewater treatment conditions for the poultry meat processing enterprise. East. Eur. J. Enterp. Technol. **3**(10(93)), 15–20 (2018). (in English). https://doi.org/10.15587/1729-4061.2018.131122
5. Siti Baizurah Mahata, R., Omara, H., Abdullaha, C.: Performance of dynamic anaerobic membrane bioreactor (DAnMBR) with phase separation in treating high strength food processing wastewater. J. Environ. Chem. Eng. **9**(3), 105245 (2021). (in English). https://doi.org/10.1016/j.jece.2021.105245
6. Henze, M., Harremoës, P., la Cour Jansen, J., Arvin, E.: Wastewater Treatment: Biological and Chemical Processes, p. 430. Springer, New York (2002). (in English)
7. Zhmur, N.S.: Technological and biochemical processes of wastewater treatment at facilities with aerotanks (AQUAROS, Moscow), p. 512 (2003). (in English)
8. Ostapchenko, L.I., Kompanecj, I.V., Skopenko, O.V.K., et al.: Biokhimija. Praktykum. Vydavnycho-polighrafichnyj centr “Kyjivsjkyj universytet”, p. 296 (2018). (in Ukrainian)

9. Ghubsjkyj, Ju.I.: Gh93 Biologhichna khimija: Pidruchnyk, p. 508. Ukrmedknygha, Kyjiv-Ternopilj (2000). (in Ukrainian)
10. Ghuljajev, V.M., Voloshyn, M.D.: Ekologhichna biotekhnologhija. Navchaljnyj posibnyk dlja studentiv specialjnosti Biotekhnologhija. Dnipropetrovsjk, p. 126 (2002). (in Ukrainian)
11. Stoljbergh, F.V.: Ekologhyja ghoroda. Uchebnyk, p. 464. Lybra, Kyev (2000). (in Ukrainian)
12. Zapoljsjkyj, A.K.: Vodopostachannja, vodovidvedennja ta jakistj vody, p. 670. Vyshha shkola, Kyjiv (2005). (in Ukrainian)

Criminal Law Aspects of Wartime Collaboration in the Criminal Code of Ukraine

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Abstract. The article states that war is perhaps the most potent catalyst for bringing societal issues to the front and revealing gaps in legislation that require not only prompt but also efficient responses from legislators. Thus, the majority of criminal law issues related to investigating and countering collaborationist activities remain unresolved and demand thorough investigation and coverage. It is pointed out that criminalizing collaborationist activities amidst the Russian-Ukrainian war is a necessary criminal law measure to punish a person (citizens of Ukraine) for unlawful actions in favor of the enemy (aggressor) state and to the detriment of our country. Criminalized actions which by their content are manifested in collaborationist activities (a new Article 111^1 of the CC of Ukraine) are akin to actions that, according to Article 111 of the CC of Ukraine, should be considered high treason. However, it should be taken into account that one of the differentiating features of the elements of these crimes is the period of an act: before occupation of territory: it is regarded as high treason; after occupation: it is collaborationism. It is noted that the new legal constructs of the elements of crimes against national security in Articles 111 (High Treason), 111^1 (Collaborationist Activities), 111^2 (Aiding the Aggressor state) of the Criminal Code of Ukraine raise many questions regarding their differentiation. The paper outlines the expediency of differentiating such collaborationist activities as transferring material resources and aiding the aggressor state. The latter encompasses voluntary collection, preparation, and transfer of material resources or other assets to representatives of the aggressor state, its armed formations, or the occupation administration of the aggressor state based on whether material resources are in possession of a person or not. It has been determined that in cases where any crime envisaged in Parts 1–8 of Article 111^1 of the Criminal Code of Ukraine was interrupted at the stage of preparation or attempt, and there was voluntary renunciation, the person is not subject to criminal liability (except in situations where actions actually committed by this person contain elements of another criminal offense). It has been proven that collaboration with the invader must receive appropriate legal assessment, and persons who have committed such crimes should be held criminally liable for collaborationist activities.

Keywords: collaborationist activities · cooperation · aggressor state · invader · occupied territories · criminalization of activities · crime elements · punishment

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1 Introduction

1.1 Research Problem Formulation

The Ukrainian Criminal Code (hereinafter referred to as the CC of Ukraine) comprises crimes against the fundamentals of Ukrainian national security, such as: actions aimed at forceful change or overthrow of the constitutional order or take-over of government (Article 109 of the CC Ukraine); trespass against territorial integrity and inviolability of Ukraine (Article 110 of the CC Ukraine); financing of actions committed for the purpose of forcible change or overthrow of the constitutional order or take-over of government, change of boundaries of the territory or state border of Ukraine (Article 110^2 of the CC Ukraine); high treason (Article 111 of the CC Ukraine); sabotage (Article 113 of the CC Ukraine); espionage (Article 114 of the CC Ukraine). The indicated crimes are generally perceived as high treason. Along with this, the general understanding of the *high treason* concept should encompass crimes like collaborationist activities (Art. 111^1 of the CC Ukraine) and aiding the aggressor state (Art. 111^2 of the CC Ukraine). The emergence of such a socially-dangerous phenomenon as wartime collaboration in Ukrainian society was triggered by the full-scale Russian-Ukrainian war on February 24, 2022. It is important to emphasize that war may be the most potent catalyst for bringing societal issues to the forefront and revealing gaps in legislation that necessitate not only prompt but also efficient responses from legislators.

Against the backdrop of the war, the state was forced to introduce amendments and additions to the CC of Ukraine regarding the criminal behavior of Ukrainian citizens who knowingly and voluntarily began collaborating with the enemy. During detention, collaborators exhibited overtly aggressive and violent behavior towards the Ukrainian population, exposing their preference for a "Russian world" and harboring hatred towards everything national. Due to the prevalence of collaborationist activities among authorities, law enforcement agencies, educators, and citizens who remained on the territories occupied by the Russian Federation, there arose a need to strengthen criminal liability for treason and collaborations.

Accordingly, the aforementioned permits placing on the agenda the necessity to conduct research into the criminal law aspects of wartime collaboration in the Criminal Code of Ukraine.

1.2 Analysis of Essential Research and Publications

Criminalization of collaborations in Ukraine is viewed as a relatively new legal phenomenon that has nevertheless attracted the attention of legal scholars. For instance, I. Bohatyriov has considered the criminal law and criminological scale of wartime collaboration in Ukraine under martial law and demonstrated that both internal and external factors of the Russian-Ukrainian war can influence the activities of collaborationists [1].

V. Krishhak notes that crimes against the fundamentals of national security have always been and remain the most dangerous for social relations. He argues that during martial law there is a necessity to increase accountability for crimes falling under this category. In addition, he outlines the results of analyzing peculiarities of criminal law innovations concerning liability for collaborationist activities [2].

O. V. Kuzmenko has analyzed forensic characteristics of criminal offenses envisaged in the recently introduced Article 111[1] *Collaborationist Activities* of the Criminal Code of Ukraine and determined that specific forensic investigation methodologies for crimes falling within this category rely on their forensic characteristics. He emphasized that having knowledge of specific elements (such as the method of committing a criminal offense and the perpetrator's identity) would assist investigators in formulating relevant investigative hypotheses, determining the course of investigation, and delineating the circle of individuals involved in this crime [3].

I. A. Skichko has conducted research on the interaction within collaborationist activities in the context of pre-trial investigation. She addressed the subject as both a general legal and a purely forensic category. The researcher provided a definition of interaction, characterized its types, and determined that the scope and number of forces and means involved in investigative (search) actions depend on the degree of social danger or the specifics of the offense. I. A. Skichko justified that interaction is a form of communication during the pre-trial investigation of a criminal offense. Interaction is implemented by legitimately involving a broad range of authorized individuals to solve tasks of a criminal proceeding, among which the primary one is efficient and prompt prosecution of guilty parties [4].

The article by K. Yanishevska and A. Krysko studies the general-theoretical concept of wartime collaboration and its genesis: its emergence and development during the Second World War and transformation in the context of the realities of the modern Ukrainian state. The researchers have analyzed the main features of this phenomenon, namely: the presence of subjects engaged in collaborationist activities and a clearly defined nature of the intent to harm not only the state's sovereignty but also the territorial integrity of Ukraine through various forms of collaborationism. Individual types of collaborationist activities have been also systematized and outlined.

However, most of the criminal law-related issues concerning the investigation and counteraction of collaborationist activities remain unresolved and require in-depth research and coverage.

The **Article Purpose** is to outline the criminal law aspect of wartime collaboration in the Criminal Code of Ukraine and to identify possible ways to improve the legal constructs regulating it.

2 Main Content Presentation

The increase in the number of crimes involving collaborationist activities registered and investigated by law enforcement agencies is associated with the armed aggression of the Russian Federation, which resulted in the occupation of part of Ukraine. The beginning of the full-scale Russian-Ukrainian war specifically has emphasized the issue of proving crimes within this category. During identification and investigation of crimes related to collaborationist activities, it was determined that not only Russian agents but also our citizens were involved in their commission on Ukrainian territory. The current situation has demanded not only an improvement in the process of proving such crimes but also comprehensive coverage of the criminal law aspect concerning wartime collaboration in criminal legislation.

The assertion that the most harmful crimes to modern society are crimes against the fundamentals of national security stems from the fact that they pose a real threat to state security, defense capability, independence, and constitutional order.

A collaborator is a person who knowingly collaborates with an occupying civil administration or military authority, thus causing harm to his/her own state. General national law defines collaborationist activities as betrayal of citizens and betrayal of the interests of his/her own state.

All crimes involving collaborationist activities exist on the same plane as high treason and aiding the aggressor state, and only in specific cases they are dully qualified: in the absence of high treason. They logically may form numerous ideal and real aggregates. The practical understanding of collaborative activity is complicated by the fact that the legislator has not explained the wartime collaboration concept, but only outlined certain areas of manifestation of this process.

As defined in Encyclopedia of Modern Ukraine: "*Wartime collaboration* (from French "collaboration" is cooperation, collaboration) is a conscious, voluntary, and deliberate cooperation with the enemy in his/her interests and to the detriment of one's own state and its allies. In the legislation of most countries, wartime collaboration is classified as a crime against one's own state, treason, and certain legal rules stipulate long-term imprisonment or death penalty depending on the extent of harm inflicted by the collaborator" [6].

Wartime collaboration is also defined as "a specific form of high treason that occurs in the territories occupied by the enemy during an international armed conflict and involves cooperation of population with the invader" [7].

Let's note that the *collaboration* term refers to actions carried out:

- under occupation. However, this does not mean that a crime of this category cannot be perpetrated outside the occupied territory. An example could be conducting economic activities in cooperation with the aggressor state (Part 4 of Article 111^1 of the CC of Ukraine) while being outside Ukraine;
- in the form of cooperation with the aggressor state, such cooperation is characterized by voluntariness, although this attribute is addressed in Article 111^1 of the Criminal Code of Ukraine only in relation to five specific forms of this offence. Cooperation may be aimed at supporting armed aggression and temporary occupation, avoiding individual responsibility for the commission of armed aggression and occupation, etc.;
- by representatives of Ukrainian population: both its citizens and stateless persons or foreigners;
- with an intention to cause harm to the state of Ukraine, its patriots, or allies.

The mentioned features do not provide a full capability to differentiate these actions from those specified in Articles 111 and 436^2 of the CC of Ukraine. Despite the fact that cooperation with the aggressor state and/or its occupation administration is outlined only in Parts 4 and 6 of Article 111^1 of the CC of Ukraine, overt or covert cooperation with the aggressor state (including through the establishment of bodies and organizations in the occupied territories) is defined as a mandatory feature of the offense in all other parts of this article.

Part 1 of Article 111^1 of the CC of Ukraine delineates various forms utilized to carry out these actions, such as:

- public denial by a citizen of Ukraine of carrying out armed aggression against Ukraine, establishing and confirming temporary occupation of part of the territory of Ukraine;
- public calls by a citizen of Ukraine to support decisions and/or actions of the aggressor state, armed groups, and/or occupation administration of the aggressor state, to cooperate with the aggressor state, armed formations, and/or occupation administration of the aggressor state, not to recognise the extension of the state sovereignty of Ukraine over the temporarily occupied territories of Ukraine [8].

Currently, scholars define the *wartime collaboration* concept as: "a substantive socio-psychological and ethical phenomenon that encompasses certain forms of treasonous collaboration of individual population members with occupation authorities, their representatives, or the aggressor country through various actions in all areas of human life (economic, social, educational, political, military, etc.). The overall purpose of collaborationist activities is to inflict the greatest possible harm upon the country by undermining its state sovereignty, territorial integrity and security» [9].

Having analyzed the above, it is reasonable to agree with Ye. Pysmenskyi who has identified the main features and common features of collaborationist activities, namely:

- the presence of subjects in this activity: collaborators, who can be individual citizens or groups collaborating with the aggressor state or its representatives to cause harm to the state sovereignty of their own country;
- direct collaboration involving the agressor state or its representatives;
- distinct intention to cause harm to the territorial integrity and state sovereignty through various forms of collaborationist activities.

It is worth pointing out that the international legal definition of collaborationist activities can be set out as follows: collaborationist activity is a conscious, voluntary cooperation of a person or a group of people with the occupation authorities to carry out hostile actions against their own country, its people, and interests. Such activities may include:

- aiding occupation authorities;
- undergoing military service in the units of the invaders;
- collecting and transferring information;
- disclosing military and state secrets;
- collaborating with occupation authorities in all areas of human activity;
- conducting educational activities according to the syllabus of the occupying country;
- propagating occupation ideology, etc.

It should not be forgotten that collaborationism falls under the jurisdiction of international law and national legislation of countries that observe the principles of human rights and democracy, as it was and remains a crime against humanity, peace, security and well-being of mankind.

Given that collaboration poses a direct threat to Ukraine's national security, including its state sovereignty, territorial integrity, constitutional order, and other vital national interests, the proposed amendment to Article 111^1 of the Criminal Code of Ukraine is

both timely and justified. It is crucial to emphasize that criminalizing collaborationist activities amid the Russian-Ukrainian war serves as a necessary criminal law measure to prosecute persons (Ukrainian citizens) for illegal actions benefiting the enemy (aggressor) state at the expense of our own country.

Article 111^1 of the CC of Ukraine comprises 8 parts, each encompassing multiple elements of crimes, punishments for their commission, and a comment. Criminalized actions which by their content are manifested in collaborationist activities are akin to actions that, according to Article 111 of the CC of Ukraine, should be considered high treason. However, it is essential to remember that one of the key features of these crimes is the time of their commission:

– it is regarded as an act of high treason before territory occupation;
– it is considered collaboration after occupation.

It is important to emphasize that this feature cannot be universally considered or applied to all cases.

The analysis of Article 1111 of the Criminal Code of Ukraine demonstrates that the legislator does not provide a definition for the *collaborator* term; instead, he/she introduces an article titled *On Collaborationist Activities*. Based on the content of this article, collaborationist activities of Ukrainian citizens during martial law are only possible within the territories occupied by the aggressor state. Explaining the content of the amended article and several provisions of the Criminal Code of Ukraine, it is worth pointing out that according to the legislation, collaborationist activity is recognized as follows:

– "public denial by a Ukrainian citizen of the armed aggression against Ukraine, establishment and approval of the temporary occupation of part of Ukraine's territory, or public appeals by a Ukrainian citizen to support decisions and/or actions of the aggressor state, armed formations, or occupation administration of the aggressor state, to collaborate with the aggressor state, armed formations, or the occupation administration of the aggressor state, or to deny the extension of Ukraine's state sovereignty over temporarily occupied territories of Ukraine…" (Part 1 of Article 111^1 of the CC of Ukraine);
– "voluntary occupation by a Ukrainian citizen of a position unrelated to fulfillment of organizational or administrative and economic functions within illegal authorities established in the temporarily occupied territory, including within the occupation administration of the aggressor state…" (Part 2 of Article 111^1 of the CC of Ukraine);
– "participation of a Ukrainian citizen in propagandistic activities within educational institutions, irrespective of ownership type or form, with the aim of promoting armed aggression against Ukraine, establishing and endorsing the temporary occupation of part of Ukraine's territory, evading responsibility for the armed aggression by the aggressor state against Ukraine, as well as any actions by Ukrainian citizens aimed at implementing the educational standards of the aggressor state within educational institutions…" (Part 3 of Article 111^1 of the CC of Ukraine);
– "transfer of material resources to illegal armed or military formations established in the temporarily occupied territory, and/or to armed or military formations of the

aggressor state, and/or conducting economic activities in cooperation with the aggressor state, illegal authorities established in the temporarily occupied territory, including the occupation administration of the aggressor state…" (Part 4 of Article 111^1 of the CC of Ukraine);

- "voluntary occupation by a Ukrainian citizen of a position related to performing organizational-managerial or administrative-economic functions within illegal authorities established in the temporarily occupied territory, including within the occupation administration of the aggressor state, or voluntary election to such authorities, as well as involvement in organizing and conducting illegal elections and/or referendums in the temporarily occupied territory or public calls for holding such illegal elections and/or referendums in the temporarily occupied territory…" (Part 5 of Article 111^1 of the CC of Ukraine);
- "organizing and conducting events of a political nature, engaging in awareness-raising activities in collaboration with the aggressor state and/or its occupation administration to support the aggressor state, its occupation administration, or armed formations, and/or avoiding responsibility for their armed aggression against Ukraine. Active involvement in such activities without showing signs of high treason…" (Part 6 of Article 111^1 of the CC of Ukraine);
- "voluntary occupation by a Ukrainian citizen of positions within illegal judicial or law enforcement agencies established in the temporarily occupied territory, as well as voluntary participation of a Ukrainian citizen in illegal armed or military formations created in the temporarily occupied territory, and/or in armed formations of the aggressor state, or aiding such formations in conducting hostilities against the Armed Forces of Ukraine and other military formations created in accordance with the laws of Ukraine or against volunteer formations formed or self-organized to protect the independence, sovereignty, and territorial integrity of Ukraine…" (Part 7 of Article 111^1 of the CC of Ukraine);
- "the actions or decisions of persons specified in Parts 5–7 of this Article that have led to the death of people or caused other grave consequences…" (Part 8 of Article 111^1 of the Ukrainian Criminal Code) [8].

Let's note that the new legal constructs of crime elements against national security in Articles 111 (High Treason), 111^1 (Collaborationist Activities), 111^2 (Aiding the Aggressor state) of the Criminal Code of Ukraine raise many questions regarding their differentiation. When analyzing the eight parts of Article 111^1 of the Criminal Code of Ukraine, we can identify at least 24 distinct crime elements within them, without explicitly delineating subjects involved in criminal interaction (aggressor state, occupation administration, illegal armed formations, etc.).

In order to fully understand the reasoning behind the punishment of these crimes outlined by the legislator, wartime collaboration should also be interpreted as high treason due to the confluence of grave circumstances committed in the occupied territory. In terms of the scope of manifestation, it is essential to emphasize that the legislator identifies specific activities as well as occupation of positions as forms of collaborationism. However, the legislator does not classify positions as collaborationist activities; instead, the emphasis is placed on the purpose, motives behind these actions, and, in certain instances, their resulting consequences [7].

Notably, to address specific existing issues in the Verkhovna Rada of Ukraine, around eight draft laws have been registered on:

- strengthening responsibility for actions stipulated in Parts 1 and 2 of Article 111^1 of the CC of Ukraine;
- clarifying the intent in Part 4 of Article 111^1 of the CC of Ukraine;
- defining a list of economic activity areas that should not be viewed as a crime within the meaning of Part 4 of Article 111^1 of the CC of Ukraine;
- criminalizing specific areas of activity for officials in institutions not directly associated with government authorities, such as notaries, registrars, and lawyers, who provide public services.

The work of the legislators continues; however, progress, in our opinion, is quite slow, and time passes. It should also be taken into account that changes require caution regarding the retroactive effect of the law and considering the absence of a consistent judicial practice of the Supreme Court on these matters. Recent practical developments suggest that judges of the Supreme Court of Ukraine acknowledge the potential occurrence of crimes which involve both collaboration and high treason. Specifically, such a combined crime may occur when an individual, following his/her appointment to a position, exploits his/her power to undermine Ukraine's security.

What is more, there is a possibility of a perfect combination of high treason and collaboration when a person is appointed to a position in the occupation authorities or law enforcement, and this position involves a professional oath of allegiance to the Ukrainian people. Furthermore, transfer of material resources (Part 4 of Article 111^1 of the CC of Ukraine) and collection, preparation, and transfer of material resources (Part 1 of Article 111^2 of the CC of Ukraine) raise numerous questions concerning various sanctions. In the first case, it may be interpreted as the transfer of one's resources that a person may use or possess. In the second case, it relates to resources that a person does not directly own. In other words, this can be interpreted as active actions aimed at collecting and transferring material resources not only to illegal military formations in temporarily occupied territories but also to armed or military formations of the aggressor country [10].

It is expedient to differentiate between such collaborationist activities as transferring material resources and aiding the aggressor state. The latter involves voluntary collection, preparation, and transfer of material resources or other assets to representatives of the aggressor state, its armed formations, or the occupation administration of the aggressor state based on whether a person owns the material resources or not.

As we see, the questions exist but currently do not provide a final answer regarding qualification correctness. It is worth agreeing with practices [7] demonstrating that elements of crimes of this category can be differentiated based on the intent of a person. In the first case (Part 4 of Article 111^1 of the CC of Ukraine), such transfer occurs due to coincidental circumstances and adherence to the rules set by the invader in order to preserve one's or others' livelihoods. In the other case (Part 1 of Article 111^1 of the CC of Ukraine), the transfer of material resources is aimed at aiding the aggressor state and inflicting harm to Ukraine.

Let us stress that the definition of economic activity types in interaction with the occupation state requires clarification, as well as whether criminal liability for tax payments is envisaged in Part 4 of Article 111^1 of the CC of Ukraine. For instance, Article 48 IV of the Hague Convention (IV) respecting the Laws and Customs of War on Land and its annex: Regulations concerning the Laws and Customs of War on Land defines: "If, in the territory occupied, the occupant collects the taxes, dues, and tolls imposed for the benefit of the State, he shall do so, as far as is possible, in accordance with the rules of assessment and incidence in force, and shall in consequence be bound to defray the expenses of the administration of the occupied territory to the same extent as the legitimate Government was so bound" [11].

Let us point out that criminal liability under Parts 1, 2 of Article 111^1 of the CC of Ukraine occurs for collaboration as a misdemeanor, while under Parts 3–8 of this Article, criminal liability arises for committing a grave and particularly grave crime. Let's specify punishments for crimes envisaged in Article 111^1 of the CC of Ukraine:

– if, at the time of committing a criminal offense outlined in Parts 1–8 of Article 111^1 of the CC of Ukraine, a person does not hold any specific position or engage in certain types of activities, the court may establish a corresponding prohibition "for the future" regarding holding a specific position or engaging in certain activities for a period determined by the court;
– the deprivation of the right to hold certain positions or engage in certain activities applies to minors only as an additional punishment. Consequently, there might be situations where the court cannot impose any punishment on a minor (aged 16 to 18) for a criminal offense outlined in Parts 1 and 2 of Article 111^1 of the Criminal Code of Ukraine. In such cases, the court is left with one option: to discharge a person from punishment based on Part 4 of Article 74 of the CC of Ukraine;
– the punishment system set out in Parts 1–8 of Article 111^1 of the Criminal Code of Ukraine is generally ambiguous and lacks clarity. It is unclear why collaborationist activities result in different punishments, with some offenders facing up to 3 years imprisonment and others receiving sentences of 12–15 years.

Let's note that Article 111^1 of the CC of Ukraine lacks a provision similar to Part 3 of Article 111, which states: "a citizen of Ukraine shall be discharged from criminal liability if he/she:

– has not taken any action upon receiving an assignment;
– has voluntarily notified the authorities of his/her connection with the enemy and the received assignment" or to Part 6 of Article 260 of the CC of Ukraine: "A person who was a member of groups specified in this Article shall be discharged from criminal liability under this Article for any actions provided for by part 1 or 2 of this Article, if he/she:

  - has voluntarily abandoned any such group;
  - has reported its existence to government authorities or local governments" [8].

However, Art. 17 of the CC of Ukraine stipulates voluntary renunciation in an unconsummated criminal offence and lists its features:

– the voluntary renunciation shall mean discontinuation of the preparation for crime or a criminal attempt by a person of his/her own will;
– final discontinuation of his/her own will;
– a person has realised that the criminal offence may be consummated.

Therefore, in cases where any crime envisaged in Parts 1–8 of Article 111^1 of the Criminal Code of Ukraine was interrupted at the stage of preparation or attempt, and there was voluntary renunciation, the person is not subject to criminal liability (except in situations where the actions actually committed by this person contain elements of another criminal offense).

In addition, criminal liability for collaborationist activities is excluded by legislation if such actions have been taken by a person in response to or in connection with illegal actions:

– resulting from physical coercion inflicted upon a person or his/her family members, supported by relevant evidence;
– stemming from threats of murder or violence where there were justifiable grounds for fearing such threats, and if there is substantial evidence;
– aimed at averting imminent danger that could not be prevented by alternative means in the given circumstances, and if the resulting harm is equal to or less than the harm prevented (e.g., in cases of emergency), which is substantiated by appropriate evidence, etc.
– arising from other overt and covert actions directed towards the individual and his/her close ones, etc.

We firmly believe it is crucial to precisely define the subjects involved in this category of crime, the unlawfulness of their actions, and other circumstances that might lead to the manipulation of specific provisions within the legal regulation due to gaps, fostering conditions for courts to abuse their authority when delivering judgments. Thus, cooperation with the invader must receive the appropriate legal assessment, while persons who have committed such crimes should bear criminal responsibility for collaborationist activities.

Let's note that as of March 2023, a total of 1804 persons faced prosecution under Article 111^1 of the Criminal Code of Ukraine. Among them, proceedings involving 605 persons were in the stage of special pre-trial investigation, while 453 proceedings were suspended due to wanted status. Additionally, 1081 criminal cases were sent to the court, with 515 cases undergoing special pre-trial investigation. Since the enforcement of Article 111^2 of the Criminal Code of Ukraine on April 23, 2022, there have been 465 criminal proceedings, with 31 cases referred to court. Out of 82 persons prosecuted under special pre-trial investigation, proceedings involving 29 individuals were investigated, while proceedings concerning 17 persons were suspended due to their wanted status [7].

As we can see from the provided statistics, the number of investigated proceedings could have been significantly higher. On this matter, it is important to support A. Kovalenko, who rightly points out: "Due to the occupation of parts of Ukraine's regions, investigative authorities may lack the physical ability to conduct searches at the residences of certain individuals" [12, pp. 63–64]. Consequently, the utilization of an extensive array of procedural tools may not always be feasible in criminal proceedings

linked to the specified category of crimes due to their commission in the temporarily occupied territories of Ukraine and the presence of witnesses, evidence, documents, physical evidence, as well as the suspects themselves involved in such crimes on these territories.

3 Conclusions

The provisions outlined in this article and characterizing the criminal-legal scope of collaborationist activities in Ukraine during martial law stress the urgent need for further scientific research in order to improve legislation in this area as well as for the development of measures to prevent and counteract collaborationism within Ukrainian society. In view of the fact that collaborationist activities undermine the national security of Ukraine, pose a direct threat to its state sovereignty, territorial integrity, constitutional order and other national interests, the amendment of Article 111^1 of the Criminal Code of Ukraine is appropriate, timely and justified.

References

1. Bohatyrov, I.: Kryminalno-pravovi ta kryminolohichni vymiry kolaboratsiinoi diialnosti v Ukraini v umovakh voiennoho stanu. Publichne pravo. **1**(49), 57–64 (2023)
2. Krishchak, B.I.: Osoblyvosti dokazuvannia zlochyniv, pov'iazanykh z kolaboratsiinoiu diialnistiu. Naukovi zapysky Lvivskoho universytetu biznesu ta prava. Seriia ekonomichna. Seriia yurydychna. Vyp. **37**, 56–61 (2023). https://doi.org/10.5281/zenodo.7934032
3. Kuzmenko, O.V.: Osoblyvosti kryminalistychnoi kharakterystyky kolaboratsiinoi diialnosti. Analitychno-porivnialne pravoznavstvo (Elektronnyi resurs) **1**, 336–339 (2022). https://doi.org/10.24144/2788-6018.2022.01.60
4. Sichko, I.A.: Vzaiemodiia v dosudovomu rozsliduvanni kolaboratsiinoi diialnosti: teoretyko-pravovyi aspekt. Pravo ta derzhavne upravlinnia **4**, 158–162 (2022)
5. Yanishevska, K.D., Krysko, A.S.: Zahalno-teoretychni aspekty ta klasyfikatsiia kolaboratsiinoi diialnosti yak kryminalno-pravovoho yavyshcha. Visnyk NTUU «KPI». Politolohiia. Sotsiolohiia. Pravo. Vyp. **4**(56), 71–76 (2022)
6. Hrabovskyi, S.I.: Kolaboratsionizm/Entsyklopediia Suchasnoi Ukrainy (Elektronnyi resurs)/redkol. In: Dziuba, I.M., Zhukovskyi, A.I., Zhelezniak, M.H.T., et al. (eds.), vol. 14, Kyiv (2014). https://esu.com.ua/search_articles.php?id=4446
7. Zhydkov, V.L., Zhyla, O.B.: Dokazuvannia zlochyniv pro kolaboratsiinu diialnist: problemni pytannia zakonu/Ukrainska Helsinska spilka z prav liudyny: ofits. sait, 5 May 2023. https://www.helsinki.org.ua/articles/dokazuvannia-zlochyniv-pro-kolaboratsiynu-diialnist-problemni-pytannia-zakonu/
8. Kryminalnyi kodeks Ukrainy vid 5 April 2001 r, vol. 2341-III (zi zmin. ta dopov) (2001). https://zakon.rada.gov.ua/laws/show/2341-14#Text
9. Pysmenskyi, Y.: Kolaboratsionizm u suchasnii Ukraini yak kryminalno-pravova problema. Pravo Ukrainy **12**, 116–128 (2020). https://doi.org/10.33498/louu-2020-12-116
10. Yanovska, O.: Kolaboratsiina diialnist ta posobnytstvo derzhavi-ahresoru: rozmezhuvannia kryminalnykh pravoporushen i dokazova baza/Verkhovnyi Sud: ofits. sait, 21 July 2022. https://supreme.court.gov.ua/supreme/pres-centr/news/1298517/

11. IV Konventsiia pro zakony i zvychai viiny na sukhodoli ta dodatok do nei: Polozhennia pro zakony i zvychai viiny na sukhodoli. Haaha, 18 zhovtnia 1907 roku. Data pidpys: 18 October 1907. Data nabr. chyn. dlia Ukrainy, 24 August 1991. https://zakon.rada.gov.ua/laws/show/995_222#Text
12. Kovalenko, A.: Protsesualni problemy rozsliduvannia kolaboratsiinoi diialnosti v umovakh pravovoho rezhymu voiennoho stanu/Kryminalno-pravovi, kryminolohichni, kryminalni protsesualni ta kryminalistychni problemy protydii zlochynnosti v umovakh voiennoho stanu: mat-ly Vseukr. nauk.-prakt. konf. (Elektronnyi resurs). (Kyiv—Lviv—Dnipro, 20 April 2022), pp. 68–69 (2022)

Digital Platforms' Practices on Content Moderation: Substantive and Procedural Issues Proposed by DSA

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Abstract. Digital Services Act (DSA) is one of the first and one of the most comprehensive legal acts in the world regulating relationships between digital platforms and their users. It sets fundamental principles on how platforms should act to combat illegal content while respecting human rights standards. However, it is disputable whether DSA can minimize all risks posed by various types of content usually shared by users on various platforms. These concerns become extremely apparent in times of sharp social conflicts and wars when disinformation, fakes and hate speech are used as a powerful weapon of information war. In this research these concerns are analyzed from substantive and procedural perspectives. For this purpose, both substantive and procedural provisions of the DSA are critically analyzed. Concerning substantive provisions, the authors discuss what types of content the DSA aims to combat and what instruments are used for this purpose. Procedural provisions are those which establish mechanisms for platform users to appeal against platform's decisions. The authors analyze these provisions from access to justice and fair trial perspectives.

Keywords: Digital Services Act · online platforms · illegal content · disinformation · contract law · harmful content · contracts of adhesion · internal complaint-handling system · out-of-court dispute settlement · access to court · access to justice · fair trial

1 Introduction

The role of online platforms in the modern world is extremely important. Not only do they allow people from various parts of the globe to communicate with each other, share their thoughts and opinions, and offer their goods and services beyond the borders, they also determine what sort of content placed by their users is good or bad, permissible or not. The activity conducted by platforms for these purposes is called content moderation: by virtue of algorithms and human analysis platforms detect content which is illegal, harmful or which does not comply with the platforms' terms and conditions and make decisions regarding this content (hide the content for a wide audience, block or delete the content or even the user's account).

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Considering the scale of lots of modern online platforms in terms of the number of their users (like Facebook, TikTok or YouTube) content moderation provided by platforms is very important since it can stop socially dangerous and illegal content from spreading. However, social events which happened during the recent 4–5 years show that efforts made by platforms are not enough to moderate content of this kind and to prevent sharp social conflicts and crisis on the vine. The wars in Ukraine and in Israel have shown how rapidly fakes, disinformation, hate speech and anti-Semitic narratives can share around the globe and to which dramatic consequences they may lead in offline world.

Although most of the countries currently do not provide any regulation concerning content moderation conducted by platforms, some jurisdictions have already made significant efforts to find optimal regulatory solutions. One of the most prominent examples is Regulation (EU) 2022/2065 of the European Parliament and of the Council of 19 October 2022 on a Single Market for Digital Services and amending Directive 2000/31/EC (Digital Services Act) [1]. Not only is this legal act the most comprehensive in the world, it is also the broadest in terms of scope of its application: it encompasses all 27 Member States of the European Union (EU) and is also applied to providers of intermediary services residing in other countries all over the world if they target their services on European market and European consumers (article 2). However, the DSA has already gained some criticism from both academics and practical lawyers in Europe even before it was adopted. There are both substantive and procedural provisions in the DSA which have been criticized: substantive ones – for the lack of mechanisms capable of combating fakes and harmful content, procedural – for the possible lack of effectiveness of the mechanisms of out-of-court dispute resolution which is a basic model chosen in DSA to resolve disputes between platforms and users.

1.1 Literature Review

Content moderation is one of the most widely discussed issues in modern academic literature. Researchers provide the analysis of these issues from various perspectives. Kyle Langvardt provides general analysis on content moderation suggesting a general framework on these issues [2]. Evelyn Douek regards content moderation from international law perspective focusing on problems of application of international law approaches [3]. Stephen Macedo looks at content moderation issues through the lens of constitutional law coming to the conclusion that classical constitutional law approaches are hardly applicable to these issues since platforms are private, not public entities [4]. Barrie Sander regards content moderation issues from human rights perspective (right to freedom of expression, right to human dignity etc.) suggesting possible ways to apply human rights standards to these issues [5]. Meanwhile, *Niva Elkin-Korenand et al.* [6] *and* Mark MacCarthy [7] analyse content moderation practices from private law perspectives focusing on contract law and consumer law approaches to these issues respectively.

In light of the recent adoption of the Digital Services Act (DSA) more and more research publications focusing on the analysis of this Regulation have begun to appear. Some of these papers provide a comprehensive analysis on the DSA [8–10], while others focus on particular aspects of this Regulation [11, 12]. However, considering the scope

and the complexity of DSA there are still a lot of issues which have to be raised and discussed.

This paper aims to provide a comprehensive critical analysis of substantive and procedural provisions laid down in DSA and to evaluate whether these provisions are capable to combat content which does not qualify as illegal, but still is socially dangerous (disinformation and content harmful for certain social groups) in the modern world. The authors will focus on the problems raised in the article in light of the challenges brought about by the military conflicts and wars which recently emerged or escalated in various parts of the world, in particular, in Ukraine and Israel.

2 Main Content Presentation

2.1 Digital Fight with Harmful Content and DSA: *Substantive Provisions*

The Web 2.0 architecture made it possible for people around the world not only to get information in digital environment, but also to freely share information online with others (both publicly and privately). This made various digital platforms, especially social media ones, extremely popular and attracting millions of users around the world. The main side effect of this tendency is the spreading of terabytes of illegal, harmful or false information all over the world, which becomes especially dangerous in times of social conflicts and crises.

Informational dangers become the most evident during wars and armed conflicts, and although modern wars mostly have a local character, these dangers concern lots of societies and jurisdictions influencing international and domestical policies around the globe. The most prominent example in this regard is the full-scale invasion of Ukraine starting in February 2022, which has been associated with massive Russian information campaign deployed on various online platforms purporting to spread fakes, hateful expressions and dangerous incitements concerning Ukraine and Ukrainians online. The study prepared by Directorate General for Communications Networks, Content and Technology in the EU considers this Russian campaign as a significant risk for European public safety, fundamental rights and civic discourse. It also finds that the Kremlin's campaign is an integral part of Russia's military agenda and causes risks to the electoral processes inside the European Union [14, p. 10]. The other example in this regard is the armed conflict in Israel starting in October 2023. It has been accompanied with lots of fakes gaining millions of reviews on various platforms all over the world (there is even a special page on Wikipedia named "Disinformation in the 2023 Israel–Hamas war" which contains information on dozens of online posts which were detected to be fakes). Meanwhile, the spreading of anti-Semitic expressions and incitements to violence online has given rise to various anti-Semitic incidents all over the world (the one in Dagestan (Russian Federation) [15], attack on Jewish cemetery in Vienna [16] etc.).

In light of these facts the role of regulatory mechanisms to combat information risks becomes extremely important. As mentioned, in the EU this role was mostly assigned to the Digital Services Act (DSA). DSA focuses on combating primarily illegal content on various online platforms. The notion of 'illegal content' first of all encompasses any information which is not in compliance with the EU law or the law of any Member State in itself (Article 3 (h) of DSA). For example, this is illegal hate speech, terrorist content

or unlawful discriminatory content. Second, 'illegal content' also involves information that is not in compliance with the EU law or the law of any Member State in relation to an activity (Article 3 (h) of DSA). This includes sharing of images depicting child sexual abuse, unlawful non-consensual sharing of private images, the sale of non-compliant or counterfeit products etc. (paragraph 12 of the preamble to DSA).

However, the notion of illegal content does not involve various kinds of content which does not qualify as illegal one, but which is dangerous for certain social groups or the whole societies and states, like disinformation and content that is harmful for some people or social groups. Spreading disinformation generally is not considered as a violation since usually it is regarded as a manifestation of the right to freedom of expression constituting one of the fundamental human rights in democratic societies. Besides, illegal content does not encompass lots of manifestations of antipathy to some people or social groups expressed in a way which does not qualify as illegal hate speech, but which still may give rise to dangers for these people (especially when posted by famous influencers or politicians) (for further mentioning – 'harmful content'). Graphically the correlation between these notions can be depicted in the following way (Fig. 1):

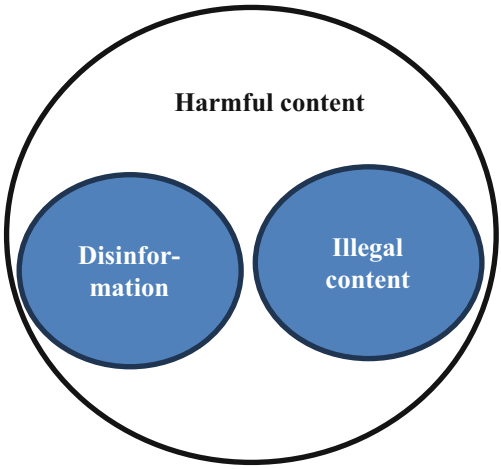

Fig. 1. .

Thus, mechanisms introduced by the DSA to combat illegal content are not applicable to disinformation and harmful content which does not qualify as illegal content. In particular, platforms are not obliged to take any actions considering these kinds of content or accounts which share it if they receive notices from other users (article 16 of the DSA). Besides, national competent authorities may not order platforms to act against such content: DSA gives national judicial and administrative authorities of Member States a power to order to act against illegal content (article 9), but this provision does not allow these authorities to interpret the term "illegal content" broader than it is defined in the DSA.

On the other hand, it cannot be said that DSA leaves disinformation and harmful content without any attention. It introduces some mechanisms concerning these

issues attempting to mitigate them carefully. However, these mechanisms relate only to so-called very large online platforms (VLOPs) and very large online search engines (VLOSEs), i.e. platforms which have more than 45 millions of users in the EU (article 33).

First, there are mechanisms which come down to the obligation of VLOPs and VLOSEs to put in place risk assessment (article 34) and risk mitigation (article 35) measures. Disinformation and harmful content constitute a so-called 'fourth category of risks' under DSA. VLOPs and VLOSEs are obliged to carry out risk assessment concerning these kinds of content once a year and put in place adequate measures to mitigate them.

Second, DSA provides a framework for combatting disinformation by virtue of self- and co-regulation. In particular, article 45 says that the Commission and the Board shall encourage and facilitate the drawing up of voluntary codes of conduct at Union level. Where significant systemic risk emerge and concern several VLOPs and VLOSEs, the Commission may invite the providers of such platforms and other stakeholders to participate in the drawing up of codes of conduct as well as a regular reporting framework on any measures taken and their outcomes. Some Codes of this kind have already been adopted: these are Code of Conduct on Countering Illegal Hate Speech Online 2016 [17] and Code of Practice on Online Disinformation 2018 (and the renewed Code of 2021 [18]). The Codes were developed by the leading tech companies on the European Commission's initiative. The monitoring and assessment of compliance by the signatories of these Codes are given to the signatories themselves, however, the Commission retains the right to prepare its own assessments.

Third, DSA also introduces special crisis response mechanisms. The notion of "crisis" is defined rather broadly: a crisis shall be deemed to have occurred where extraordinary circumstances lead to a serious threat to public security or public health in the Union or in significant parts of it (article 36 (2) of DSA). If a crisis occurs, the European Commission upon the Board's recommendation may adopt a decision, requiring one or more providers of VLOPs or VLOSEs to take one or more of the actions, like: assessment of how the use of their services contribute to a serious threat, application of effective measures to prevent or to limit such contribution, reporting to the Commission on the impact of the specific measures taken. If the Commission considers that the implemented measures are not effective or proportionate it may adopt a decision requiring the provider to review the identification or application of those specific measures.

However, neither of these mechanisms introduced by DSA are effective enough to combat disinformation and harmful content. VLOPs' and VLOSEs' obligations on risk assessment and risk mitigation (articles 34, 35) are more about self-monitoring of these risks and their mitigation by platforms. However, state or European authorities are neither empowered nor able to detect underassessment or undermitigation of risks by platforms and sanction them for this. Self- and co-regulatory mechanisms, although being flexible and market-based, are not obligatory for the platforms. First, platforms may avoid adhering to the Codes of conduct or withdraw from them (like Twitter withdrew from Code on disinformation recently). Second, neither Member States' bodies, nor European authorities may oblige platforms to adhere to the Codes: it is only said in the preamble to DSA that refusal without proper explanations by an online platform to

participate in the application of a code of conduct could be taken into account when determining whether the online platform has infringed the obligations laid down by the Regulation (recital 104). However, it does not mean that the platform may be sanctioned for not adhering to the Code of conduct. Finally, crisis response mechanisms also leave a room for platforms to choose their own approach to combatting disinformation and harmful content even in times of the hardest crises. Basically, platforms may choose remedies to mitigate risks in times of crises on their own, and even if the Commission identifies that these remedies are not sufficient, it may only oblige platforms to review the remedies, but not to apply an exact remedy identified by the Commission.

In the end, the policy to combat disinformation and harmful content depend mostly on terms and conditions developed by this or that platform and applicable only within a particular platform to the relationships with its users. As the war in Ukraine has shown, various platforms have chosen different strategies to combat dangerous disinformation campaigns coordinated by Russia and harmful content: some of them have been making rather radical steps suspending the Russia-affiliated accounts (like Meta and Alphabet), while others have been applying *laissez-faire* approach giving content moderation issues away mostly to the users themselves (like Telegram and recently Twitter ("X"). The study prepared by Directorate-General for Communications Networks, Content and Technology in the EU also stresses on the lack of uniformity between platforms in terms of combating disinformation campaigns concerning the war in Ukraine [14, p. 10].

Regarding terms and conditions developed by platforms, it can be said that they are contracts by their nature (between platforms and their users) and thus they are products of freedom of contract and of party autonomy. DSA does not regulate what can and what cannot be included into terms and conditions. Instead, DSA provides formal requirements to terms and conditions: they shall be set out in clear, plain, intelligible, user-friendly and unambiguous language, and shall be publicly available in an easily accessible and machine-readable format (article 14 (1). Besides DSA imposes obligations concerning the way terms and conditions shall be disclosed for users, amended and notified of to users. This approach lying in the basis of DSA is explainable: any regulatory act cannot interfere into the substance of contract relationship or dictate what shall and shall not be included in a contract. However, terms and conditions developed by platforms (especially VLOPs and VLOSEs) go beyond a classical concept of contract and start being onerous regulators of relationships between millions of users. First, they are drafted by entities which are very powerful from social, political and economical perspectives. Second, their content may not be suggested by users: users may only agree with them (and then join a platform) or disagree (and then remain aside the platform). Third, compliance with the terms is monitored and assessed only by one party – by a platform, while users are those under monitoring and assessment.

In this context what could help combatting dangerous content falling out of the concept of "illegal" is some kind of liability regime. Undoubtedly, the issue of liability is very ambiguous issue for platforms which shall be treated very carefully by platforms. Generally, platforms are shielded from liability under the so-called 'safe harbor' regime. Although there are some nuanced amendments into provisions setting this regime in DSA, generally this regime remains the same. On the one hand, platforms do not bear liability for not reacting to the content placed by third parties (users), unless they have

actual or constructive knowledge of the illegality of the content and act not expeditiously to remove or to disable access to the illegal content (article 6). On the other hand, platforms are not liable if they in good faith and in a diligent manner carry out voluntary own-initiative investigations into, or take other measures aimed at detecting, identifying and removing, or disabling access to, illegal content (so-called 'Good Samaritan principle', article 7). However, both provisions use the term 'illegal content' as a basic one. Thus, platforms cannot be held liable for combatting or not combatting disinformation and other harmful content at all.

Undoubtedly, DSA's substantive provisions reflex democratic and human rights based approach to combatting various types of content which may harm some persons or the whole society. More radical approaches could lead to imbalance and authoritarian policy concerning platforms, which is inappropriate. However, as is seen from this analysis, DSA does not have effective mechanisms to mitigate risks concerning disinformation and harmful content, which can be very high. The main problem is that platforms remain 'sovereigns' in digital space [20, p. 203] and there are no effective mechanisms to make them collaborate with each other and develop joint policies on combatting various types of content, which may do harm.

2.2 Digital Fight with Harmful Content and DSA: *Procedural Provisions*

Numerous questions also arise regarding the procedural aspects of the issue, particularly concerning the effort to offer effective remedies in relevant disputes. The DSA outlines three types of dispute resolution methods: an internal complaint-handling system (Article 20 of the DSA), out-of-court dispute settlement (Article 21 of the DSA) and court protection (Paragraph 1, Article 21 of the DSA).

First of all platforms should offer users the opportunity to file a complaint regarding specific types of decisions made by the platform based on the illegality of content or its non-compliance with terms and conditions, in particular: "(a) decisions whether or not to remove or disable access to or restrict visibility of the information; (b) decisions whether or not to suspend or terminate the provision of the service, in whole or in part, to the recipients; (c) decisions whether or not to suspend or terminate the recipients' account; (d) decisions whether or not to suspend, terminate or otherwise restrict the ability to monetize information provided by the recipients" (Article 20 of the DSA).

Such internal complaint-handling system give the platforms the opportunity to change their own decisions, providing a review mechanism without usage of other ADR methods and court litigation [21, p. 12]. There should be the possibility to lodge a complaint electronically and free of charge for a period of at least six months from the date when the recipient of the service was informed about such a decision of the platform. The internal complained-handling system should meet some minimum requirements, such as: a) accessibility; b) user-friendliness; c) effectiveness, i.e. it should enable and facilitate the submission of complaints. The complaint should be handled by the online platforms "in a timely, non-discriminatory, diligent and non-arbitrary manner". If a decision is deemed groundless, the platform should satisfy the complaint. Such a decision should be reasoned, made under human control rather than just automatically, and the person who made a complaint should be informed about the decision without unduly delay.

Taking into account that internal complaint-handling systems are under the platforms control and may lack independence and impartiality, the DSA strengthens the system by incorporating an external review of decisions via out-of-court dispute settlement. The latter is facilitated by a certified out-of-court dispute settlement body, serving as the third neutral party, whose task is to address and resolve disputes arising between the platforms and users in regard of the decisions made by the platforms. Users have the option to choose whether they prefer to utilize the internal complaint-handling system or out-of-court dispute settlement. This safeguard does not mandate the prior exhaustion of internal complaint-handling mechanisms, though it also does not preclude their utilization. The platforms are obliged to provide an access to such mechanisms.

While in the initial draft of the DSA these bodies were granted the authority to issue binding decisions, thereby excluding court jurisdiction [22, pp. 438–440], the final text of the DSA clarifies that out-of-court dispute settlement bodies do not preclude court jurisdiction and cannot render binding decisions for the parties involved in the dispute. In fact, out-of-court dispute settlement bodies are not considered even '*de facto*' courts [23, 24, p. 25]. Such solution seems to be more reasonable in view of the provisions of the Council of Europe and EU standards on access to justice and fair trial (para 1 Article 6 of the European Convention on Human Rights (the ECHR), Article 47 of the EU Charter of Fundamental Rights) taking into account following considerations.

First of all, para 1 Article 6 of the ECHR enshrines the right to a fair trial, and access to court is one of its parts. The European Court on Human Rights (the ECtHR) stated that a right to access to court is not absolute and can be restricted taking into account that the right of access to court is not absolute and should be regulated by the state, which is permitted indirectly and this regulation may vary in time and place according to the needs and resources of society and individuals [25]. It means that in practice some disputes may be excluded from the court's jurisdiction but for such restrictions, a proportionality principle should be met. In this regard, the ECtHR evaluates: a) whether the aim of the restriction of the right to access to court was legitimate; b) what particular measures were used to restrict the right to access to court, and whether they were minimally burdensome and necessary in a democratic society; c) whether there was a reasonable and proportionate relationship between the measures taken and the aim set; d) determining whether the restriction in question does not contradict the very essence of the right to a fair trial, since a person cannot be deprived of the right to access to court as a result of a restriction, but there must always be alternative ways to protect violated rights, freedoms, and interests if certain cases are excluded from the jurisdiction of ordinary courts [26–28]. At the same time in cases when some disputes are excluded from the court jurisdiction and refer to some other quasi-judicial organs the ECtHR points out that such organs become "a court" in the sense of the ECHR and should meet all minimal standards of a fair trial in terms of para 1 article 6 of the ECHR [29]. It means that in case of the binding nature of the out-of-court settlement and its decisions the body which provides such a settlement should also provide the participants with such guarantees as a reasonable time of a trial, publicity, independence, and impartiality of the court, established by law, fair hearing (equality of arms, adversarial principle, due notification, right to be heard, etc.). Taking into account the current development of technologies, the nature of disputes covered by the DSA and their number the creation of a new set of courts for DSA purposes seems

to be expensive, time-consuming, and unrealistic. Therefore, DSA has chosen the way of redress mechanisms diversification to provide different "paths to justice" [30, p. 48]. This decision reflects the recent trends of the expansion of alternative dispute resolution (ADR) methods and the so-called privatization of the civil justice sector in terms of the international standard of access to justice [31].

The DSA incorporates quality control measures for alternative dispute resolution in this area, requiring out-of-court dispute settlement bodies to obtain certification from the Digital Service Coordinator (the DSC) of the Member State in which they are situated. This certification is time-limited and can be granted for a maximum period of five years. According to Article 21 of the DSA, to obtain a certificate, such a body must fulfill the following criteria:

- impartiality and independence, including financial independence from providers of online platforms and recipients of the services provided for these platforms;
- expertise, i.e. the body should have necessary expertise in specific areas of illegal content or in the application and enforcement of terms and conditions of one or more types of online platforms as well as skills for resolution of the disputes;
- non-linked remuneration, which means that the members of the body involved in the out-of-court settlement procedure should obtain its remuneration for the procedure but not for the results of the case;
- accessibility through electronic means of communication, including the initiation of the procedure and the submitting of the necessary documents online;
- efficiency, which means that the body should provide the service of settling disputes in a swift, efficient and cost-effective manner;
- compliance with rules, which are clear, fair, accessible, and in strict accordance with the law provisions.

All these requirements seem to be justified, but at the same time, they are not strict enough to be brought to life without further detailing. For example, what does the clear and fair procedure mean in terms of Article 21 of the DSA? It seems that clear procedure refers to the principle of legal certainty and mean predictability of the procedure rules, which should be given to the DSC for certification. The notion of fair procedure is more complicated, because usually right to a fair trial is connected with the judicial guarantees in terms of para 1 Article 6 of the ECHR, but they can be hardly applicable in this case because the out-of-court dispute settlement bodies are neither courts nor even quasi-judicial organs. There are some requirements for particular ADR methods in other EU instruments. In particular, the Directive 2013/11/EU of the European Parliament and of the Council of 21 May 2013 on alternative dispute resolution for consumer disputes and amending Regulation (EC) № 2006/2004 and Directive 2009/22/EC (Directive on Consumer ADR), which in Article 9 contains some parameters of the fairness of ADR methods in consumer disputes. Some provisions also included in the Regulation (EU) 2019/1150 of the European Parliament and of the Council of 20 June 2019 on promoting fairness and transparency for business users of online intermediation services pays a lot of attention to the effective dispute resolution system between providers of online intermediation services and business users. In particular, the Regulation (EU) 2019/1150 prescribes three-level dispute resolution system, which consists of internal

complaint-handling system (Article 11), mediation (Article 12–13) and judicial proceedings by representative organizations or associations and by public bodies (Article 14). Some requirements to mediators we can see in Article 12 of the Regulation (EU) 2019/1150 – the mediators must be independent and impartial, affordable for business users, capable of providing services in the relevant language, easily accessible either physically or remotely, able to offer services promptly, and possess a sufficient understanding of general business-to-business commercial relations for effective contribution to dispute resolution. On the one hand abovementioned criteria can indeed serve as certain guidelines for the out-of-court dispute settlement procedures, on the other hand they oriented to the specific types of cases which are different from the disputes, covered by the DSA. It seems that there should be own set of rules for quality and fairness standards for out-of-court dispute settlement to unify the criteria for the standardization process in all EU Member States. This is especially important given that these bodies will settle the disputes not only on the private content policies connected with the terms and conditions of the platforms, but also disputes concerning the illegal content which also could affect public interests and interests of third persons. Otherwise the redress mechanisms would be ineffective or all these disputes will migrate to the courts.

3 Conclusion

DSA is an important step towards the creation of a comprehensive regulatory framework for online platforms in democratic societies. It sets fundamental principles on how online platforms should act to combat illegal content while respecting human rights standards.

However, approaches chosen in the DSA have some vulnerabilities, which become especially conspicuous in times of sharp social crises, conflicts, and wars. Considering substantial provisions of the DSA, their main vulnerability is a lack of instruments to combat disinformation and other types of harmful content. Although these types of content are not illegal, they may be not less dangerous for the societies and states. DSA does not directly oblige platforms to combat these types of content, neither does it put any liability on platforms for not combatting disinformation and harmful content placed by their users. The only instrument which DSA suggests is self- and co-regulation meaning that platforms are highly recommended to adhere to the codes of conduct and implement their provisions in their practices. However, this instrument relies on voluntary decisions of platform operators, and cannot be said to be effective enough.

Procedural perspective of content moderation under DSA looks like a beautiful showcase, which however hides a number of challenges. On the one hand the DSA opens the door for the three-level dispute-resolution system, which covers an internal complaint-handling system, out-of-court dispute settlement and court litigation, and let the users choose the best option in his or her particular case following the best traditions of access to justice standards. But on the other hand, such regulation has so framework character that we hardly could put together puzzles of the out-of-court dispute settlement mosaic. A great discretion powers given to the DSC looks more like shifting responsibility from the EU level to the Member States concerning the organization of dispute settlement area for such disputes with the lack of useful mechanisms for implementation. It seems that in this regard, standardized criteria for certification of

the out-of-court dispute settlement bodies should be developed as well as the criteria for fairness of the procedure should be clarified more precisely taking into account the specifics of the disputes.

References

1. Regulation (EU) 2022/2065 of the European Parliament and of the Council of 19 October 2022 on a Single Market for Digital Services and amending Directive 2000/31/EC (Digital Services Act) (Text with EEA relevance) OJ L 277, pp. 1–102, 27 October 2022
2. Langvardt, K.: Regulating online content moderation. Georgetown Law J. **106**, 1353–1388 (2018)
3. Douek, E.: The limits of international law in content moderation. UC Irvine J. Int. Transnational Comp. Law (6), 37–76 (2021)
4. Macedo, St.: Lost in the marketplace of ideas: toward a new constitution for free speech after Trump and Twitter?' Philos. Soc. Criticism **48**(4), 496–514 (2022)
5. Sander, B.: Freedom of expression in the age of online platforms: the promise and pitfalls of a human rights-based approach to content moderation. Fordham Int. Law J. **43**(4), 939–1006 (2020)
6. Elkin-Korenand, N., de Gregorio, G., Perel, M.: Social media as contractual networks: a bottom-up check on content moderation. Iowa Law Rev. **107**, 987–1049 (2022)
7. MacCarthy, M.: A consumer protection approach to platform content moderation. In: Petkova, B., Ojanen, T. (eds.) Fundamental Rights Protection Online: The Future Regulation of Intermediaries (Edward Elgar Publishing) (2020)
8. Savin, A.: The EU Digital Services Act: towards a more responsible Internet. Copenhagen Business School, CBS LAW Research Paper No. 21-04. J. Internet Law 17 (2021)
9. Turillazzi, A., Taddeo, M., Floridi, L., Casolari, F.: The digital services act: an analysis of its ethical, legal, and social implications. Law Innov. Technol. **15**(1), 83–106 (2023)
10. Kalėda, S.L.: New European Union's Regulatory framework of the digital space: the digital markets act and the digital services act. Teisė **127**, 25–42 (2023)
11. Busch, Ch., Mak, V.: Putting the digital services act into context: bridging the gap between EU Consumer Law and Platform Regulation. J. Eur. Consum. Mark. Law (EuCML) **10**, 109 (2021)
12. Frosio, G.: Platform responsibility in the digital services act: constitutionalising, regulating and governing private ordering. In: Savin, A., Trzaskowski, J. (eds.) Research Handbook on EU Internet Law. Edward Elgar, Queen's University Belfast Law Research Paper (2023, forthcoming). Available at SSRN. https://ssrn.com/abstract=4236510
13. Pakutinskas, P., Šepetys, T.L.: Algorithmic parody protection in the European Union: CDSM Directive and DSA Regulation Perspective. Baltic J. Law Politics **16**(1), 79–104 (2023)
14. Digital Services Act: Application of the Risk Management Framework to Russian disinformation campaigns. Publications Office of the European Union, Luxembourg (2023). https://op.europa.eu/en/publication-detail/-/publication/c1d645d0-42f5-11ee-a8b8-01aa75ed71a1
15. Провокации легли на благодатную почву». Антисемитские беспорядки в Махачкале (Provokatsii Legli na Blagodatnuyu Pochvu. Antisemitskie Besporiadki v Makhachkale) (Meduza), 30 October 2023. (in Russian). https://meduza.io/feature/2023/10/30/provokatsii-legli-na-blagodatnuyu-pochvu-antisemitskie-besporyadki-v-mahachkale-kto-v-nih-uchastvoval-chto-eto-voobsche-bylo-i-chem-mozhet-zakonchitsya
16. Pleitgen, F., Krebs, K., Picheta, R.: An existential threat: antisemitic attacks soar across Europe amid Israel-Hamas war. CNN, 4 November 2023. https://edition.cnn.com/2023/11/04/world/an-existential-threat-antisemitic-attacks-soar-across-europe-amid-israel-hamas-war/index.html

17. Code of conduct on countering illegal hate speech online of 30 June 2016. https://ec.europa.eu/info/policies/justice-and-fundamental-rights/combatting-discrimination/racism-and-xenophobia/eu-code-conduct-countering-illegal-hate-speech-online_en
18. The 2022 Code of Practice on Disinformation. https://digital-strategy.ec.europa.eu/en/policies/code-practice-disinformation
19. Filatova-Bilous, N.: Content moderation in times of war: testing state and self-regulation, contract and human rights law in search of optimal solutions. Int. J. Law Inf. Technol. **31**(1), 46–64 (2023)
20. Pretelli, I.: A humanist approach to private international law and the internet a focus on platform users as weaker parties. Yearb. Private Int. Law 2020–2021 **22**, 201–243 (2021)
21. Ortolani, P.: The resolution of content moderation disputes under the Digital Services Act. Giustizia Consensuale **2**, 533–573 (2022). https://deliverypdf.ssrn.com/delivery.php?ID=418083072021025010121016007022089069023068051019054037097074091071120088089000018007062038051121060056046122030103006116065108028023001062001068079082119108016084084077039079105124119116029007107112081099068126080107079118013121103078116066095079078002&EXT=pdf&INDEX=TRUE
22. Wimmers, J.: The out-of-court dispute settlement mechanism in the Digital Services Act – a disservice to its own goals. JIPITEC **12**, 421–441 (2021)
23. Holznagel, D.: The Digital Services Act wants you to "sue" Facebook over content decisions in private de facto courts. Verfassungsblog **6**, 24 (2021). https://verfassungsblog.de/dsa-art-21/
24. Husovec, M.: Will the DSA work? On money and effort. In: van Hoboken, J., Quintais, J.P., Appelman, N., Fahy, R., Buri, I., Straub, M. (eds.) Putting the Digital Services Act into Practice: Enforcement, Access to Justice, and Global Implications (Verfassungsbook on Matters Constitutional, 2023), pp. 19–34 (2023). https://www.ivir.nl/publicaties/download/vHoboken-et-al_Putting-the-DSA-into-Practice.pdf
25. Ashingdane v. the United Kingdom, no. 8225/78, 28 May 1985. http://hudoc.echr.coe.int/eng?i=001-57425
26. Golder v. United Kingdom, no. 4451/70, 21 February 1975. http://hudoc.echr.coe.int/eng?i=001-57496
27. Nataliya Mikhaylenko v. Ukraine, no. 49069/11, 30 May 2013. http://hudoc.echr.coe.int/eng?i=001-119975
28. Tserkva Sela Sosulivka v. Ukraine, no. 37878/02, 28 February 2008. http://hudoc.echr.coe.int/eng?i=001-85246
29. Lithgow and others v. the United Kingdom, no. 9006/80, 8 July 1986. https://hudoc.echr.coe.int/eng?i=001-57526
30. Handbook on European law relating to access to justice. Publications Office of the European Union, Luxembourg (European Union Agency for Fundamental Rights) (2016)
31. Komarov, V., Tsuvina, T.: International standard of access to justice and subject of civil procedural law. J. Nat. Acad. Legal Sci. Ukraine **28**(3), 197–208 (2021)

Directions of the Formation of the Model of Sustainability of the Aerospace Complex of Ukraine

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Abstract. The article is intended to research on issues of content of national sustainability and theoretical and legal, managerial foundations for formation of sustainability model of objects of aerospace complex of Ukraine and definition of its components.

It is determined that one of the gaps in building a system of national stability in general and the stability of aerospace facilities in particular is implementation of reactive managerial, administrative and crime detection and investigation measures by law enforcement agencies in order to minimize risks and threats to aerospace facilities.

It is proved that ensuring implementation of the tasks of forming model of stability of objects of the aerospace complex should be associated with the concept of information security. This is impossible without introduction of innovative space technologies based on artificial intelligence.

There are a number of risks regarding the use of artificial intelligence at aerospace complex objects: lack of research on legal phenomenon of artificial intelligence and its status in the implementation of tasks at different levels; there is no single categorical apparatus; general legal and scientific approaches to defining concept of artificial intelligence and its place in the modern system of social relations are not formed.

It is stated that sustainability model of any object of the aerospace complex of Ukraine should consist of: a system of regulatory support; system of bodies: subjects of security; a system of risk assessment and identification of threats to various types of security of objects; system of algorithms of actions in regular and emergency circumstances.

Keywords: national sustainability · aerospace facilities · sustainability model · information security · artificial intelligence · security threat monitoring · concept · legal regulation

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1 Introduction

National sustainability, according to the Concept for Ensuring the National Sustainability System, is defined as "a set of purposeful actions, methods and mechanisms of interaction between public authorities, local self-government bodies, enterprises, institutions, organizations, civil society institutions guaranteeing safety and continuity of the functioning of main fields of life of society and the state before, during and after crisis situation onset [1]".

Concept adoption has set a number of theoretical and applied tasks for scientific society:

- formation of mechanisms for organizing and coordinating actions to form innovative approaches to technical, engineering, institutional level, safety and security of critical infrastructure facilities.
- formation of a methodological level of national security risk assessment, the state of relevant capabilities in order to prepare, adopt and implement strategic decisions aimed at building sustainability of aerospace complex objects of Ukraine;
- at coordination level of the activities of the subjects of system of national sustainability, formation of effective system of communication between public authorities, local self-government bodies and population.

This became the lever for formation of theoretical and legal basis of national stability system in the period remaining before the attack of armed forces of the Russian Federation.

One of sustainability system components of aerospace complex of Ukraine is creation of its information security system. Taking into account the opinions of EU founders, it is possible to determine that space technologies contribute to:

- development of space cartography;
- space communications;
- development of key sectors of critical infrastructure, including transport, IT, telecommunications;
- ensure development of security and defense sector with advanced weapons, communication services and current information.

In all these technologies, information terabytes circulate, that requires the use of fuses to destroy it, twisting something. As can be seen, the main component of effectiveness and stability of these complexes in a changing situation of the war period is the level of information security of each object and business entity, as well as resistance to various terrorist threats [2, pp. 166–174]. What has been identified in current conditions has a number of gaps.

The next component is system formation of measures for monitoring environment of aerospace complex objects and the axis that can create a security threat to these objects. Analysis of practice of using profiling indicates that as a rule it is used at air transport facilities and insufficiently developed methods of its use in ensuring detection of threats to the ground infrastructure of space activities.

Taking all this into account, it can be argued that currently there are issues of conducting research on current state and prospects in the following areas:

1. Theoretical and legal basis for formation of a model of stability of the aerospace complex with allocation of its place in the system of national stability of Ukraine.
2. Legal and managerial issues of ensuring information security of business entities in the field of space activities.
3. Formation of a system of coordination and interaction of national and international security entities of aerospace industry entities within the framework of system formation of national sustainability.
4. Legal issues of system formation of normative regulation of the system of stability of objects of the aerospace complex.
5. Legal and organizational problems of monitoring security threats to objects of aerospace complex of Ukraine using the profiling method.

2 Literature Review

Solution of these tasks is not possible without the implementation of scientific research in general humanitarian, legal and managerial and applied formation fields of a system of critical infrastructure stability of Ukraine in general and the objects of the aerospace complex, in particular.

Formation of basic foundations of sustainability and sustainable development of social systems was the report prepared by a commission headed by Dr. Gro Harlem Brundtland, for the first-time concept of sustainable development is used. This document contains the general principles of sustainable development:

Sustainable development should the central guiding UN principle, governments, private institutions, organizations and enterprises.

At the heart of sustainable development is a saving attitude towards available global resources and ecological potential and reproduction of the environment that are still undergoing destruction and overexploitation.

While addressing pressing environmental challenges is important, a strategy to prevent them early is the most effective and cost-effective means of achieving sustainable development.

The most important goals of environmental policy should include preserving peace, intensifying economic growth, changing its quality, solving poverty problems, meeting the urgent needs of people, demographic problems, preserving and strengthening the natural resource base, reorienting technology and taking into account risk factors, as well as an integrated approach to environmental and economic issues in decision-making.

Equitable distribution of environmental costs and economic development benefits between and within countries, as well as between present and future generations, is one of the key factors in achieving sustainable development [2, p. 41].

In recent years, the problems of sustainability at the national, regional, sectoral and facility levels are reflected in the works of Ukrainian and foreign scientists P. Martin-Brin and J. M. Anderis, M. Walsh-Deeley and W. Wolford, J. Walker and M. Cooper H. G. Bola, R. Biggs, L. P. Burbo, B. Oetzold, M. Keck, M.S. Nazarov, O. O. Reznikova, M. Schluter, M. Shun [3, 4, pp. 173–182, 5, pp. 143–160, 6, pp. 64–69, 7, 8, pp. 3–17, 9].

Analysis of scientific achievements of these and other scientists shows that the problems of building models and forming systems for ensuring national sustainability are developed only at the general fragmentary level.

Regarding the direction of information security of the aerospace complex, in this case, it should be based on the statement that information security as a component of security of space activities consists of a triad:

– activities to ensure assistance provision to entities to achieve their goals:

  - protection of intellectual property rights, state, military and commercial secrets;
  - ensuring the receipt of complete, timely, reliable, holistic information available;
  - compliance with the legislative regime for circulation of restricted information: confidential; state secrets; official information.

– support means: set of material, spiritual, financial, legal, organizational and technical means of carrying out activities to ensure;
– support subjects: individuals, organizations, state bodies that carry out activities to ensure space activities [10, p. 194]".

At the same time, the means of ensuring information security of space activities at the present stage of development of science and technology, and in the future, the subjects can include artificial intelligence. These prospects determine a number of challenges, philosophical, ethical, moral and legal content. On the one hand, taking into account the views of transhumanists, that the entry of society into information form of existence against the use background of computers and the World Wide Web has created the prerequisites for managing a person using algorithms that operate artificial intelligence.

We agree with opinions of scientists that there are a number of security, moral, ethical and legal problems of the use of androids in various fields of activity, including space, starting with scientific, research, production, maintenance work, ending with provision of various levels of information security [11, pp. 61–74, 12, pp. 116–120].

This is confirmed by the proposals provided in the article by Dr. Antonia Russo and Prof. Gianluca Lax «Our analysis has highlighted some future directions to follow. A first direction concerns applying artificial intelligence techniques to the field of satellite communication with the purpose of making communication systems more efficient and secure. Another interesting direction regards the next frontiers of artificial intelligence for navigation in terms of the global navigation satellite systems» [13].

Analysis of research papers in recent years indicates that in addition to the above, it is necessary to add the following conditions for the construction of artificial intelligence ( ): "how to construct this intelligence in such a way that no group of people can gain advantages over other people with its help, and that artificial intelligence does not direct its force against humanity, but, on the contrary, is used for its benefit" [14].

Statement of the research task. It should be noted that in Ukraine, research on national sustainability began not so long ago that became the basis for systematic research on theoretical and legal problems of the formation of technical, managerial and tactical principles of the sustainability model of objects of aerospace complex of Ukraine.

3 Main Content Presentation

In order to clarify the content of the problems associated with the issue of forming a sustainability model for the aerospace complex of Ukraine, it is necessary to understand the current content of space activities. In this regard, one should consider the opinion of O. P. Fedorov that "Until recently, in various international documents, space activities were defined as activities for the exploration and use of outer space related to creation and use of space facilities…. Now space activities include a wide range of industries that use space technologies and information (communications, navigation, space observations, technology transfer, information services, etc.) and which are not directly related to space facilities" [15, p. 5].

3.1 Sustainability of Objects of the Aerospace Complex

There is no unanimous opinion in domestic scientific community on development of theoretical foundations of the model of stability of aerospace complex objects of Ukraine.

Considering the issue of sustainability of a particular industry, we consider it necessary to proceed from the content of the concept of national sustainability. Thus, in his report, Academician S. I. Pyrozhkov, Vice President of the National Academy of Sciences of Ukraine, indicated that this term means ability of the State in interaction with society to maintain resistance to external and internal aggressive influences, respond promptly to asymmetric threats, as well as to recover from devastating consequences of aggressive actions of any nature. He further points out that "national resilience" covers counteraction in all fields: political, economic, military-political, social, environmental ones etc., so the main thing is not only to be able to resist, but to work proactively [16].

Generally theoretical approaches to sustainability as a component of security system are reflected in a number of regulatory legal acts of a programmatic nature: strategies, concepts, doctrines: The concept of ensuring the national system of sustainability [1]; "Strategy for ensuring state security [17]; Concept of combating terrorism [18]; Military doctrine of Ukraine [19], Information security strategy [20]? Cybersecurity Strategy of Ukraine] Cybersecurity Strategy of Ukraine [21], etc.

Research on modern regulatory framework and program documents on the tasks of forming a strategy in the field of the national sustainability system indicates that there is no proper scientific justification for the formation of the conceptual theoretical and legal foundations of this process, the choice of a certain model for ensuring national sustainability, key tasks that need to be solved, especially regarding the objects of the aerospace complex [1].

The period of Russia armed aggression showed that the aerospace industry forms the national stability of Ukraine and is the lever for shaping our victory on the basis of existing space technologies. Currently, the opinion has been formed that, in addition to certain vulnerabilities of space activities, an updated strategy is being developed within the framework of the development of national space capabilities and increasing the resilience of critical infrastructure for the security and defense of Ukraine, Europe and the whole world.

Despite cyberattacks against the space and aviation infrastructure of Ukraine and other countries before and after the start of the full-scale aggression on February 24, 2022, in 2022 alone, the global space budget grew by 9% to an absolute figure of 103 billion euros. Among these expenditures, the financing of "military" space increased by 16% and amounted to 48 billion euros, proportion in growth rates is an indication of what priorities humanity now provides in development of space technologies. Currently, about 5,500 satellites orbit the Earth, and almost 10% (about 500 units) are owned or operated by military organizations [22].

Significant impact of the aerospace complex on national security becomes the basis for the fact that there are challenges to formation of a managerial and legal model for aerospace industry security of Ukraine as a component of critical infrastructure.

At the same time, with regard to safety and risk monitoring in aerospace sector, a number of studies have been carried out, starting with general legal aspects and ending with doctrinal aspects of aerospace complex sustainability [23, pp. 9–16; 24], etc.

It should be agreed with scientists who consider activities in outer space to be risky. In addition, in its opinion, it creates threats of a global security nature, associated both with the use of relevant objects in open space and cyberattacks on relevant communication satellites, as well as identified man-made threats from an aggressive space environment [25, pp. 17–30].

In addition, taking into account that business entities of the aerospace complex carry out:

General scientific reconnaissance: research aimed at the use of outer space; research and design regarding the construction of space objects of space and ground-based activities;

Production activities in the field of construction of space objects (including their units and components) of space and ground-based;

Operational and technical maintenance and repair of space objects (including their units and components) of space and ground-based;

*Ensuring launch of spacecraft*s and their components [26].

All production cycles at the facilities of the aerospace complex and tests of rocket and space technology, units and components create a number of risks and security threats of local, regional and global nature [27, pp. 24–31].

Since the beginning of Russia full-scale aggression, the importance of the aerospace complex in the system of national stability has become actualized. Yuliia Svyrydenko, First Deputy Prime Minister – Minister of Economy of Ukraine at the opening of the World Economic Forum in Davos presented an action plan, the implementation of which will help maintain the stability and stability of the economic system during the war, indicating that one of the steps "should be the development of four key sectors:

Military-industrial complex and aerospace industry. We are talking about the production of modern weapons, the creation of joint ventures with NATO countries for the transfer of technology and the subsequent supply of weapons to these States.

Metallurgy and Mechanical Engineering: Ukraine needs to restore the plants, carry out their environmental modernization to achieve the decarbonization goals of global steel industry.

Agriculture and food industry. The goal of Ukraine is to get into the TOP 5 countries not only in terms of volume, but in terms of value of agricultural exports. Therefore, it is important to develop the processing of agricultural raw materials in order to increase the monetary value of exports.

IT industry: Ukraine has great potential in this area. The task of the Government is to help IT outsourcers become owners and developers of products" [28].

In our opinion, one of the gaps in the system construction of national stability in general and the stability of aerospace complex objects in particular is the implementation of reactive managerial, administrative and crime detection and investigation measures by law enforcement agencies in order to minimize risks and threats to the objects of the aerospace complex. We should support the opinion of scientists who believe that the direction of the National Police of Ukraine as a basic element of national stability should be taken into account during the development and implementation of the Concept of ensuring national stability [29, p. 198]. Taking into account the goals of sustainable development of Ukraine for the period until 2030 regarding creation of sustainable infrastructure, the promotion of comprehensive and sustainable industrialization and innovations, the tasks of ensuring the stability of the aerospace complex facilities by the forces of NPU, SBU, SBGS, the State Customs Service during the fight against crime and neutralization of security threats.

In fact, implementation of this goal exacerbates the contradictions between the target indicators, defined concepts and other program documents of Ukraine [31, p. 36.] in wartime and it is necessary to form models of an adequate response to threats in the field of destabilizing role of threats from criminal communities.

Moreover, it should be borne in mind that the signs of sustainability of economic objects are:

– ability to adapt to work in difficult destabilizing conditions;
– ability to adequately respond to all constituent elements to risks and threats [32].
– Taking into account the subjectivity and objectivity of the aerospace complex of Ukraine, the modern scientific community defines sustainability as ability to function and develop in a changing internal and external environment.
– Thus, the signs of sustainability at the level of specific facilities, industries and the state as a whole:
– ability to function reliably in normal mode;
– adapt to ever-changing conditions;
– resist and quickly recover after the implementation of threats of any kind: natural and anthropogenic ones, threats caused by illegal actions and other threats;
– equilibrium ratio of external and internal threats determining its dynamic development

We support the view that stability formation of system-object depends on the ability of security entities to form a system for monitoring risks and security threats, building an organizational and tactical model for preventing, deterring, neutralizing or mitigating the consequences of terrorist actions aimed at destroying, disabling or maliciously using critical infrastructure in general and objects of the aerospace complex of Ukraine in general.

As a result, sustainability model of any aerospace complex of Ukraine consists of:

regulatory support systems;

systems of bodies: subjects of protection;

systems for monitoring risk assessment and identifying threats to various types of security of facilities [33];

systems of algorithms of actions in regular and emergency circumstances.

3.2 Legal Problems of the Sustainability of the Aerospace Complex

According to scientists, specialists of the Ministry of Strategic Industries of Ukraine and the SSAU, the basis of stability of the aerospace complex is the adoption of the laws: *On State Regulation in the Field of Satellite Navigation* and *On State Regulation in the Field of Remote Sensing of the Earth.* The latest projects were agreed upon before the start of the Russian aggression in 2021. At the same time, we agree that the prospects for the development of national activity in the spheres of remote sensing of the Earth and satellite navigation require the introduction of new space concepts and terms into national space law: aerospace object of remote sensing of the Earth, remote sensing of the Earth, activity on remote sensing of the Earth, operator of aerospace objects of remote sensing of the Earth, space systems of remote sensing of the Earth, user of remote sensing data of the Earth, national market of space information technologies, satellite navigation, satellite communication, global navigation satellite systems, national satellite communication [23, pp. 9–16, 24] etc.

The Law of Ukraine: On Space Activity does not take into account modern challenges and threats in the field of national sustainability of space activities, the vast majority are norms that do not have an appropriate legal mechanism for their implementation, especially regarding existing risks and security threats.

Formative drafts of legislative acts on the construction of legal bases for sustainability of aerospace facilities should be taken into account that they should create a regulatory basis for their ability to function and develop in a changing internal and external environment, in a balanced and uncertain number of internal and external threats.

Legal principles of using artificial intelligence in the model of stability and information security of the aerospace complex.

Ensuring implementation of these tasks must be associated with the concept of information security and sustainability of space activities in general and the aerospace complex in general. This is impossible without introduction of innovative space technologies based on artificial intelligence and is determined by the fact that «The challenges to achieving ambitious exploration goals are driven largely by the need to enable reliable, safe and sustained operations of crew and machines in the harsh environment of space. These challenges require solutions that will provide benefits on Earth even before being employed in orbit, and they include: • Development of highly reliable human and robotic systems interacting with each other on Earth and in space with limited maintenance;

Long travel time and operation in confined spacecraft and shelters;

New transportation capabilities (e.g., launch, rendezvous, docking, refuelling, landing);

Operations in extremely hostile environments; Autonomous operations with limited communications and logistical supplies from Earth; Miniaturization of components and development of new in-situ capabilities» [34, pp. 15–16].

Research on components of space activities and legislation in the field of its regulation allows us to state that at this stage of human development, the question arises of how to realize the potential of artificial intelligence in the technological chain of object-computer-artificial intelligence - person with provision of processing of many data related to space activities:

– in the production of space and ground-based facilities, artificial intelligence-enabled equipment is used to optimize the production and support performance of tasks performed by people;
– management of space and ground-based facilities;
– satellite communication support;
– solving communication, monitoring tasks related to the receipt and processing of significant amounts of information.
– In addition to the above, artificial intelligence should solve the issue of stability at the level of specific subjects-objects of space activity:
– ability to function reliably in normal mode;
– adapt to ever-changing conditions;
– to resist and quickly recover after the implementation of threats of any kind: natural and man-made, threats caused by illegal actions, and other threats [35, pp. 17–18].

In accordance with the Concept for the Development of Artificial Intelligence in Ukraine, "Priority areas in which the tasks of the state policy for the development of the field of artificial intelligence are implemented are: education and vocational training, science, economics, cybersecurity, information security, defense, public administration, legal regulation and ethics, justice [36]".

Implementation of these tasks is determined by activities of sustainability entities using artificial intelligence tools and robotics within the framework of the system for monitoring risks and security threats, building a managerial and tactical model for preventing, deterring, neutralizing or mitigating the consequences of terrorist actions aimed at destroying, disabling or maliciously using critical infrastructure in general and objects of space activity of Ukraine, in general [2]. At the same time, scientists are of the opinion that there are a number of risks for humanity associated with uncontrolled, or with violation of the principles of morality and ethics of the use of artificial intelligence technologies:

– loss of jobs by people on the basis of automation of routine repetitive operations;
– violation of privacy, almost to its complete destruction;
– deepfakes (synthesis of the words: *deep learning* and *fake* is a technique for synthesizing an image or audio of a series of human speech based on artificial intelligence; it is used to combine and superimpose existing images and videos on the original images or videos");
– automated weapons that will kiss living objects without intervention of human operators;
– erroneously biased solutions of systems due to curvature of the initial training data (algorithmic bias) [37].

The last two risks are the most dangerous in the context of the Russian invasion. All these risks are directly related to the views of transhumanist representative Professor Nick Bostrom, head of the Oxford Institute for the Future of Humanity, on downloading the human mind to a computer and creating and creating "fast supermind". He notes that the speed of the superintelligence is ten thousand times higher than the speed of the biological brain [38].

As it is seen, all these risks can be interpreted as threats to national security and its subsystem of information security of space activities. To avoid these problematic issues, one should agree with the European legislator who developed and published the Recommendations on Ethics for Robust Artificial Intelligence (hereinafter referred to as the Recommendations) (European Commission, 2019).

The Recommendations define a system of principles for the of artificial intelligence formation: respect for human autonomy, prevention of harm, justice and explanation. In fact, these Recommendations create the conditions for the implementation of a system of artificial intelligence control methods proposed by Nick Bostrom:

isolation methods: place artificial intelligence in an environment where it will not be able to harm humanity;

stimulating control methods are to create conditions under which artificial intelligence will be beneficial to people;

methods of delaying development, consciously limiting the intellectual capabilities of the system or its access to information;

stretching methods are specific equipment that makes it possible to diagnose artificial intelligence, including without its knowledge [38].

These methods, in accordance with the Recommendations, form a reliable artificial intelligence that has three components that should be present throughout the life cycle of the system:

1. Legality;
2. Ethics
3. Reliability

We agree with the view that the goal of reliable artificial intelligence can be achieved only when a person takes responsibility for the formation of such reliability at various stages of development, circulation and use of artificial intelligence technologies [39, pp. 95–96].

Thus, a number of challenges arise regarding the use of artificial intelligence in general and in space activities in particular:

– threat to personal data;
– protection of the rights and freedoms of persons subject to influence of artificial intelligence;
– insufficient level of regulation of the use and control of artificial intelligence in general and ensuring the information security of space activities, in particular.

Research on modern research papers indicates that basis of such risks is:

– lack of researches on legal phenomenon of artificial intelligence and its status in implementation of tasks at different levels;

– there is no single categorical apparatus;
– general legal and scientific approaches to the definition of the concept of artificial intelligence and its place in modern system of social relations have not been formed [40, pp. 310–313].

These problematic issues are inherent not only in Ukraine, but also in global challenges to human security. This is evidenced by the fact that the countries of the world have signed the "Bletchley Declaration", which defining basic principles and goals of working together to understand and address the risks associated with the development of advanced artificial intelligence technologies [41]. In fact, the Declaration became the basis of the global security strategy in the field of using artificial intelligence. It is based on the principles of legality, ethics and reliability.

4 Conclusions

In accordance with performed researches, we can state that the legal regulation of formation of a sustainability model for aerospace complex of Ukraine should consist of the following steps:

Establishment in current aviation and space legislation of national interests that determine the content of the right to protect the sustainable development of aerospace complex of the State.

Modernization of national space legislation, taking into account the tasks of building the sustainability of Ukrainian space infrastructure facilities and the provisions of updated international treaties and legislation of other partner countries of Ukraine.

Amendment of legislation in the field of air transport and space activities in order to harmonize functions: tasks as a result of coordination of activities of subjects of counteraction to crime in this area.

In accordance with the Roadmap for the Regulation of Artificial Intelligence in Ukraine, develop and adopt a law on artificial intelligence in order to consolidate the principle of balanced use of artificial intelligence systems, protect the rights of citizens and support the innovative development of Ukraine in general and the aerospace complex in particular.

Ensuring activities of state bodies vested with the authority to ensure sustainability and security in the field of critical infrastructure in general and the aerospace complex, in particular, regulated at the level of central executive bodies.

In the field of ensuring the formation of the organizational and scientific component of the sustainability model of business entities and aerospace facilities, it is necessary to:

Carry out theoretical research in order to develop a legal concept of sustainability of aerospace complex objects, taking into account its place in the system of national sustainability, and to develop on its basis a model for the codification of space legislation.

In accordance with modern threats and security challenges, determine the theoretical and legal foundations of the concept, doctrine, strategy and policy for the use of artificial intelligence with the definition of its legal personality and the likelihood of liability for reliability requirements.

Conduct scientific research at the fundamental and applied level to determine the theoretical and applied algorithms for detecting and neutralizing threats from the use of artificial intelligence in the defense sector, aviation and space activities on the basis of the use of various methods of artificial intelligence control.

In order to ensure the effective component of the sustainability of business entities and aerospace facilities, conduct criminological research *on* the awareness of current threats and challenges, as well as opportunities to counteract them with a system of forces and measures of preventive neutralizing influence on certain criminogenic entities and factors of negative security nature.

Develop a managerial model of State monitoring and forecasting system for the development of national space activities, taking into account defense vectors, risks and security threats in order to solve the following tasks:

– timely identification of threats and risks arising from the misconduct of public relations entities in general and business entities of the aerospace complex of Ukraine, in particular;
– formation of legal relations between aviation and space entities, which are regulated by law.

In order to ensure unified methodological approaches to the formation of the organizational component of the stability of objects of the aerospace complex of Ukraine, develop and implement a unified methodology for assessing security risks and the state of relevant capabilities by analogy with existing one in civil aviation.

Taking into account the experience of countering hybrid threats during the period of repelling Russia's aggression, to develop models of interaction at the interagency and interstate levels in the field of sustainability, taking into account global and regional security processes.

References

1. The concept of ensuring a national sustainability system: Decree of the President of Ukraine "On the introduction of a national sustainability system" No. 479/2021, 27 September 2021. (in Ukraine). https://zakon.rada.gov.ua/laws/show/479/2021#Text
2. Shynkarenko, O.I., Shynkarenko, I.R., Shynkarenko, I.I.: Theoretical and legal problems of analysis and assessment of the security threat to objects of the aerospace complex of Ukraine. In: Ensuring Sustainability in Difficult Conditions: A Collection of Materials of Reports of Participants of the International Interdisciplinary Scientific and Practical Conference, (Kharkiv – Bristol, 8 June 2023), Kharkiv-Bristol, pp. 166–174 (2023). (in Ukraine)
3. Martin-Breen, P., Anderies, J.M.: Resilience: A Literature Review. Bellagio Initiative (2011). (in English). https://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/3692/Bellagio-Rockefeller%20bp.pdf?sequence=1&isAllowed=y
4. Walsh-Dilley, M., Wolford, W.: (Un) Defining resilience: subjective understandings of 'resilience' from the field. Resilience **3**(3), 173–182 (2015). (in English)
5. Walker, J., Cooper, M.: Genealogies of resilience: from systems ecology to the political economy of crisis adaptation. Secur. Dialogue **42**(2), Special Issue on The Global Governance of Security and Finance, 143–160 (2011). (in English)
6. Nazarov, M.S.: National resilience of Ukraine: from conceptual foundations to practical implementation. Sci. J. "Politikus" (2), 64–69 (2020). (in Ukraine)

7. Reznikova, O.O.: National resilience in a changing security environment: a monograph. NISD, Kyiv, p. 456 (2022). (in Ukraine)
8. Bourbeau, P.: Resiliencism: premises and promises in securitisation research. Resilience **1**(1), 3–17 (2013)
9. Biggs, R., Schlüter, M., Schoon, M.L.: Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems, p. 290. Cambridge University Press, Cambridge (2015). (in English). https://www.cambridge.org/core/books/principles-for-building-resilience/578EBCAA6C9A18430 498982D66CFB042
10. Shynkarenko, I.O.: Actual issues of legal support of information security of space activities. In: Actual Problems and Prospects for the Development of Legal Science, Education and Technology in the 21st Century in the Research of Young Scientists: A Collection of Materials of Reports of Participants of the All-Ukrainian Scientific and Practical Conference. (Kharkiv, 3 March 2023), Kharkiv, pp. 192–195 (2023). (in Ukraine). https://dspace.univd.edu.ua/server/api/core/bitstreams/5527496e-3372-40b5-b2dc-650e973e3df4/content
11. Bezhevets, A.M.: The legal status of robots: problems and prospects of definition. Inf. Law **1**(28), 61–67 (2019). (in Ukraine). https://ippi.org.ua/bezhevets-am-pravovii-status-robotiv-problemi-ta-perspektivi-viznachennya-st-61-67, https://doi.org/10.37750/2616-6798.2019.1(28).273347
12. Pozova, D.D.: Prospects for the legal regulation of artificial intelligence under EU law. J. Civilistics **27**, 116–120 (2017). (in Ukraine). http://nbuv.gov.ua/UJRN/Chac_2017_27_24
13. Russo, A., Lax, G.: Using artificial intelligence for space challenges: a survey/Department of Information Engineering, Infrastructure and Sustainable Energy (DIIES), University Mediterranea of Reggio Calabria, Via Graziella, Località Feo di Vito, 89122 Reggio Calabria, Italy. Appl. Sci. **12**(10), 5106 (2022). (in English). https://doi.org/10.3390/app12105106
14. Onyshchuk, I.: Legal regulation of artificial intelligence technologies: theoretical, applied and ethical principles. Scientific Notes of the Institute of Legislation of the Verkhovna Rada of Ukraine, vol. 3 (2020). (in Ukraine). https://risu.ua/tehnologiyi-shtuchnogo-intelektu-spivvidnoshennya-prava-i-morali_n116164
15. Fedorov, O.P.: Space Activities: Approaches to Developing a Strategy, Why Space for Ukraine?, p. 206. Naykova Dymka Publishing House NASU of Ukraine, Kyiv (2019). (in Ukraine). https://a-kosmos.com.ua/wp-content/uploads/2019/11/kniga-fedorov-2019.pdf
16. Pyrozhkov, S.I.: On the National Report of the National Academy of Sciences of Ukraine "National Resilience of Ukraine: Strategy for Responding to Challenges and Preventing Hybrid Threats" Based on the report at the meeting of the Presidium of the National Academy of Sciences of Ukraine on 6 April 2022 (2022). (in Ukraine). http://dspace.nbuv.gov.ua/bitstream/handle/123456789/185177/10-Pyrozhkov.pdf?sequence=1
17. Strategy for Ensuring State Security: Decree of the President of Ukraine "On the Strategy for Ensuring State Security": No. 56/2022, 16 February 2022. (in Ukraine). https://www.president.gov.ua/documents/562022-41377
18. Concept of Combating Terrorism in Ukraine: Decree of the President of Ukraine "On the Concept of Combating Terrorism in Ukraine" No. 53/2019, 5 March 2019. (in Ukraine). https://zakon.rada.gov.ua/laws/show/53/2019#Text
19. Strategy of Military Security of Ukraine: Decree of the President of Ukraine on the Decision of the National Security and Defense Council of Ukraine dated March 25, 2021 "On the Strategy of Military Security of Ukraine" No. 121/2021, 25 March 2021. (in Ukraine). https://www.president.gov.ua/documents/1212021-37661
20. Information Security Strategy: Presidential Decree "On Information Security Strategy" No. 685/2021, 28 December 2021. (in Ukraine). https://zakon.rada.gov.ua/laws/show/685/2021#Text

21. Cybersecurity Strategy of Ukraine: Decree of the President of Ukraine "On the Cybersecurity Strategy of Ukraine" No. 447/2021, 26 August 2021. (in Ukraine). https://www.president.gov.ua/documents/4472021-40013
22. Borel, Zh.: The war of the Russian Federation against Ukraine emphasized the importance of space in modern hostilities (2022). (in Ukraine). https://www.ukrinform.ua/rubric-polytics/3659739-borrel-vijna-rf-proti-ukraini-pidkreslila-znacenna-kosmosu-u-sucasnih-bojovih-diah.html
23. Shemshuchenko, Yu.S., Semenyaka, V.V.: The current state and the need to reform the space legislation of Ukraine. Chasopys Kyiv Univ. Law **2**, 9–16 (2019). (in Ukraine). https://doi.org/10.36695/2219-5521.2.2019.01
24. On approval of the draft Law of Ukraine On State Regulation in the Field of Satellite Navigation. (appeal (in Ukraine)). https://www.drs.gov.ua/wp-content/uploads/2022/07/3517.pdf
25. Netska, L.S.: Space activity: concept, types, legal regulation. Legal Bull. **3**(60), 17–30 (2021). (in Ukraine). https://doi.org/10.18372/2307-9061.60.15948
26. State Space Agency of Ukraine (2023). (in English). https://www.nkau.gov.ua/en/activity/concept-of-the-space-policy-to-2032
27. Milimko, L.V.: Legal regulation of state supervision (oversight) over the economic activities of aviation enterprises. Sci. Works Nat. Aviat. Univ. Ser. Legal Bull. "Air and Space Law" **3**(56), 24–31 (2020). Nau, Kyiv. (in Ukraine). https://doi.org/10.18372/2307-9061.56.14887
28. Action plan to preserve the stability and stability of the economic system during the war. (in Ukraine). https://dia.dp.gov.ua/plan-dij-dlya-zberezhennya-stijkosti-ta-stabilnist-ekonomichno%D1%97-sistemi-pid-chas-vijni
29. Kliman, M.R.: Some issues of improving the process of ensuring national sustainability in Ukraine. Legal Sci. Electron. J. **3**, 196–198 (2021). (in Ukraine)
30. On the Sustainable Development Goals of Ukraine for the period up to 2030: Decree of the President of Ukraine. No. 722/2019, 30 September 2019. (in Ukraine). https://zakon.rada.gov.ua/laws/show/722/2019#Text
31. Reznikova, O.O.: Formation of national resilience in the context of Ukraine's implementation of sustainable development goals. Strateg. Priorities **2**(50), 27–37 (2019). (in Ukraine)
32. Reznytska, T.O.: The essence of sustainability of economic activity of agricultural enterprises. Collection of scientific papers of Vinnytsia State Agrarian University. Issue 36 (2008). (in Ukraine). http://repository.vsau.org/card.php?lang=en&id=1703
33. Umantsiv, Y., Shkuropadska, D.: National resilience of Ukraine under the Martial Law. Scientia Fructuosa **5**, 4–19 (2023). (in English). https://doi.org/10.31617/1.2023(151)01
34. Benefits Stemming from Space Exploration. International Space Exploration Coordination Group September, p. 22 (2013). (in English). https://www.nasa.gov/wp-content/uploads/2015/01/benefits-stemming-from-space-exploration-2013-tagged.pdf
35. Organizational and legal aspects of ensuring the safety and sustainability of critical infrastructure of Ukraine: analytical add./(Bobro, D.H., Ivanyuta, S.P., Kondratov, S.I., Sukhodolya, O.M.)/under the general editorship of O.M. Sukhodoly, K.: NISD, p. 224 (2019). ISBN 978-966-554-258-2. (in Ukraine). https://niss.gov.ua/sites/default/files/2019-05/Dopov_Suchodolya_print.pdf
36. Concepts for the development of artificial intelligence in Ukraine: Order of the Cabinet of Ministers of Ukraine "On Approval of the Concept for the Development of Artificial Intelligence in Ukraine" No. 1556-r Kyiv, 2 December 2020 (as amended in accordance with the Order of the Cabinet of Ministers No. 1787-r, 29 December 2021). (in Ukraine). https://zakon.rada.gov.ua/laws/show/1556-2020-%D1%80#Text
37. Cherry, H.: Artificial Intelligence and Man: Threats and Opportunities, vol. 17, p. 50 (2021). (in Ukraine). https://www.radiosvoboda.org/a/shtuchnyi-intelekt-zagrozy-i-mozhlyvisti/31145992.html

38. Superintelligence: Paths, Dangers, Strategies. (in English). https://hub.kyivstar.ua/reviews/shtuchnyy-intelekt
39. Golovko, O., Ye, B.: Ethical and legal problems of using robots with artificial intelligence. Bull. NTUU "KPI" Polit. Sci. Soc. Legal **3**(55), 95–96 (2022). (in Ukraine). http://visnyk-psp.kpi.ua/article/view/269563/265042. https://doi.org/10.20535/2308-5053.2022.3(55).269563
40. Telichko, O.A., Rekun, V.A., Chabanenko, Yu.S.: Problems of definition and regulatory consolidation of the concept of "artificial intelligence" in the legislation of foreign countries and Ukraine. Legal Sci. Electron. J. **2**, 310–313 (2021). (in Ukraine). http://www.lsej.org.ua/2_2021/77.pdf
41. The Bletchley Declaration by Countries Attending the AI Safety Summit, 1–2 November 2023. (in English). https://www.gov.uk/government/publications/ai-safety-summit-2023-the-bletchley-declaration/the-bletchley-declaration-by-countries-attending-the-ai-safety-summit-1-2-november-2023

Force Majeure Circumstances in Aviation Activities

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Abstract. This research topic is the definition and classification of force majeure circumstances in aviation, their legal regulation. Special attention is paid to research on the impact of force majeure on legal relations arising in aviation activities, and managing these circumstances by means of planning, forecasting, and the use of alternative measures to deal with negative consequences.

In recent decades, of aviation activity importance in the world economy has been constantly growing that is due to technological development and the latest developments in aviation industry. Aviation activity increases the country investment attractiveness, expands opportunities for international companies to operate in Ukraine, promotes development of international trade and tourism, as it ensures extremely fast delivery of valuable and perishable goods to their destination. Considering that force majeure circumstances in the aviation industry are unforeseen events or circumstances that arise beyond the will and control of the air carrier and can affect the normal of aviation processes course, it is important to consider the aspect of legal regulation of this institution of aviation (air) law in combination with safety in the air. Such force majeure circumstances as weather conditions, geopolitical conflicts, technical problems and other unforeseen events can significantly affect operation of airlines and airports.

The main conclusion of performed research is that despite great negative consequences that force majeure has for the implementation of aviation activities and therefore for implementation of contractual obligations based precisely on implementation of such transportation by air transport, as well as despite recognition of a certain case by the authorized by State authorities as a force majeure circumstance in general, party that lost opportunity to fulfill the obligation should prove influence of the force majeure on the non-fulfillment of corresponding obligation. Force majeure circumstances, such as natural disasters, technical issues or socio-political events, can significantly affect functioning of aviation enterprises and global aviation system as a whole. Cooperation between States, aviation institutions and airline companies are essential for effective management of force majeure situations. There is specialized legislation and international agreements regulating responsibility and actions of airlines during force majeure circumstances determining the rights and obligations of participants in aviation relations in such situations.

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Obtained results can be used in theoretical legal researches, as well as in legislative and practical activities.

Keywords: force majeure circumstances · aviation activity · civil aviation · cooperation of international organizations · aviation risks · International Civil Aviation Organization (ICAO) · violation contractual obligations · aviation force majeure · exemption from liability · force majeure management

1 Introduction

This research consists of legislation analysis regulating force majeure in aviation industry, as well as the methods and strategies used for their prediction and management. The topic is relevant in the context of emergency situations, such as pandemics, natural disasters and geopolitical, military conflicts, that can have a serious impact on the aviation industry. Understanding and effectively managing force majeure in aviation industry is an important task to ensure safety, reliability and efficiency of legal relations arising in the aviation industry. Therefore, research on force majeure issue as a circumstance that can release a party to a contract from responsibility for non-fulfillment of the terms of the contract is an extremely important aspect, because occurrence of such a phenomenon does not depend on the parties to any contract, but can affect their legal relations. This article purpose is to determine specifics of the legal regulation of force majeure in aviation, in particular, in contracts for transportation of cargo and passengers by air concluded for implementation of economic activities of airlines, air carriers and other subjects of the aviation industry. Force majeure can have a significant impact on aviation operations, including financial costs, loss of profits, as well as reputational risks, lead to changes in schedules, routes. Therefore, monitoring and analysis of factors that can lead to force majeure is important to ensure the safety and efficiency of aviation activities.

1.1 Literature Review

Force majeure analysis in science and practice of law enforcement as within Ukraine as in EU countries is a necessary direction of research caused by the present. Research papers of Ukrainian and foreign scientists, as well as practicing lawyers, made a significant contribution to research on this issue. In particular, it is worth highlighting research papers of O. Kuzhko, V. Slobodianiuk, D. Lazebnyi, A. Melnichenko, O. Melnyk et al.

Occurrence issues of risks in transport were actively studied by domestic and foreign scientists. Among domestic authors, S.I. Andrusenko, S.M. Boniar, N.V. Tarelnyk, T.M. Berdychevska, O.S. Buhaychuk, V.B. Budnychenko, A.S. Dorosh, Ye.B. Demchenko, Yu. Konovalenko, R.V. Markul, V.S. Podpisnov, M.M. Tarashevskyi et al. dealt with these issues. Interesting issues are raised in the work of B. Vandeskyi, who analyzes risks, the level of trust and reputational influence in Norwegian offshore supply chain [1]. Among foreign researchers, it is especially necessary to note the research paper by K. Lianh et al. [2] regarding the analysis of cargo theft risks in supply chains, as well as research by I. Tseremohlu et al. [3], where the authors proposed a combined forecasting

model for air cargo loading based on risk minimization. Rybchuk A.V. [4], and Proboiv O.V. [5] studied specifics and issues of international tourism industry in global pandemic conditions.

Despite increased attention of scientists to force majeure in one or another field, many theoretical and practical issues are still debatable. As well, research on force majeure in aviation activity, during transportation by air during performance of contractual obligations including from foreign sources is overlooked.

2 Presentation of the Main Content

Aviation activity occupies important place in world economy, importance of aviation activity is constantly growing which is due to technological development and the latest developments in aviation industry. At the expense of aviation activity, investment attractiveness of the country increases, opportunities for the activities of international companies, tourism and international trade on the territory of Ukraine are expanded, since aviation activity ensures extremely fast delivery of valuable and perishable goods to their destination.

The Convention for the Unification of certain rules relating to international carriage by air (Warsaw Convention) dated on 1929 [5], Convention on International Civil Aviation (Chicago Convention) of 1944 [6], Convention on the International Recognition of Rights in Aircraft (Geneva Convention) are devoted to legal regulation of aviation activities) 1948 [7], Convention on Damage Caused by Foreign Aircraft to Third Parties on the Surface (Rome Convention) dated on 1952 [8], Convention on Offences and Certain Other Acts Committed on Board Aircraft (Tokyo Convention) dated on 1963 [9], Convention for the Suppression of Unlawful Seizure of Aircraft (Hague Hijacking Convention) dated on 1970 [10], Convention for the Suppression of Unlawful Acts against the Safety of Civil Aviation (Montreal Convention) dated on 1971 [11], Protocol for the Suppression of Unlawful Acts of Violence at Airports serving International Civil Aviation (Montreal Protocol) dated on 1988 [12], Treaty on Open Skies (Helsinki Treaty) dated on 1992 [13], as well as provisions of Air Code of Ukraine [14], Laws of Ukraine: *On Transport* [15], *On state program of civil aviation safety* [16], etc.

According to Article 1 of Air Code of Ukraine dated on 19.05.2011, aviation activity is activity of individuals and legal entities in the field of aviation and/or institution of air traffic of Ukraine. Order of the Minister of Defense of Ukraine №. 256 dated on 05/19/2010: *On approval of the Rules for the investigation of aviation events and incidents in the aviation of the Armed Forces of Ukraine* defines aviation activity as an activity related to airspace use with aircraft use [17].

Studying and analyzing doctrinal definition of aviation activity developed by national or international aviation institutions, government agencies and organizations regulating aviation industry, in order to ensure the safety, development and coordination of aviation activity, it is possible to single out certain risks that aviation activity has. These can be aviation safety risks, technical risks, weather risks, errors of pilots, controllers, flight personnel and other participants in the aviation process that can lead to accidents. Aviation activity is associated with economic risks, changes in the economy, including rising prices for fuel and other resources which can affect the financial stability of airlines and

lead to their bankruptcy or reorganization. The COVID-19 pandemic has significantly affected the aviation industry and led to emergence of new risks that have arisen due to the coronavirus spread. Restrictions on international and domestic routes, border closures and reduced international and domestic travel have led to a sharp decline in demand for air travel. This led to significant financial losses for airlines and airports [18]. Overall, the COVID-19 pandemic has created a challenging situation for the aviation industry and forced industry players to adapt to new realities. Risk management and search for innovative solutions have become key tasks for the recovery and stabilization of aviation activities in pandemic conditions.

On 24.02.2022, military aggression of Russian Federation against Ukraine spread to entire territory of Ukraine, in connection with which the Decree of President of Ukraine № 64/2022: *On imposition of martial law in Ukraine* dated on 02/24/2022 imposed martial law on the entire territory of Ukraine [19]. Subsequently, the Verkhovna Rada of Ukraine approved the above-mentioned Decree of the President of Ukraine by the Law of Ukraine: *On Approval of the Decree of the President of Ukraine* № 2102-IX dated on 24.02.2022, 2022. As a result of the full-scale invasion of the aggressor country on the territory of Ukraine, all spheres of life "froze" or began to function differently. One of the important areas of economic development in Ukraine was the air transportation industry. The war that currently is taking place on the territory of Ukraine has quite strongly undermined development of this industry, and not only in Ukraine. In particular, in international aspect, delivery routes, logistics companies, etc. overlap. Consequently, all of the above aviation risks require careful planning and coordination by civil aviation organizations or the military to ensure safety and stability of aviation operations in a conflict condition.

In our opinion, aviation risks are closely related to force majeure. However, force majeure in aviation activities has its own characteristics and properties. Connection between aviation risks and force majeure is that force majeure can create aviation risks or exacerbate existing risks. For example, a pandemic (force majeure) can reduce demand for air travel and increase the risk of financial instability for airlines. Weather disasters, considered as force majeure, can cause weather risks such as flight delays and cancellations.

Aviation industry typically has contingency plans and risk management strategies to deal with events related to both aviation risks and force majeure. For example, airlines can have plans to deal with situations where flights cannot take place due to weather conditions or other extraordinary circumstances. In such cases, it is important to comply with safety requirements and minimize risks to passengers and crew.

Force majeure is an event or condition beyond the control and ability of the party responsible for the performance of contractual obligations. *Force majeure* concept definition of the of is contained in the Law of Ukraine: *On the Chambers of Commerce and Industry in Ukraine* establishing in Part 2 of Art. 14–1 that such circumstances are extraordinary and unavoidable circumstances that objectively make it impossible to fulfill the obligations provided for in the contract terms (contract, agreement, etc.), obligations according to legislative and other regulatory acts [21].

In aviation, force majeure circumstances can have serious consequences for both air carriers and passengers, etc. In current international practice, the application of force

majeure is regulated by several normative acts. The norm established by Art. 79 of the Vienna Convention (United Nations Convention on Contracts for the International Sale of Good) [22]. This provision exempts a party to a contract from liability for non-fulfilment of its terms if it is proved that non-performance was caused by an obstacle beyond control of the party and it would be unreasonable to expect this obstacle to be taken into account at the time of the conclusion of the contract, and to avoid or it was impossible to overcome this obstacle (fulfill obligations in alternative way). Proving these circumstances rests with the party that violated the obligation.

Principles of UNIDRUA in the edition of 2016) [23], Principles of European Contract Law [24, 25 P.78] and a number of other acts contain provisions similar in content to the above-mentioned norms.

In order to perform the main goal of this research, it is necessary to define the concept of force majeure specifically in aviation activities and to determine which events in this field will have signs of force majeure. First of all, it is clear that force majeure circumstances in aviation activity are unforeseen events or circumstances that arise beyond the control and influence of aviation activity subjects and can complicate or even lead to the impossibility of fulfilling an agreement or obligations related to aviation activity. Force majeure circumstances can be of different nature and their classification can be determined depending on the context and sub-sector of this activity.

Thus, it is possible to systematize force majeure in aviation activities into natural force majeure circumstances, technical, personal (human), political (geopolitical), economic ones.

Natural force majeure includes weather disasters such as hurricanes, tornadoes, heavy snowfalls, thunderstorms, thunderstorms, heavy fog and other weather phenomena that may affect the safety of flights and lead to flight delays or cancellations; natural disasters such as earthquakes, floods, forest fires, volcanic eruptions and other natural disasters that may affect airport infrastructure and navigation systems and epidemics and pandemics. As the COVID-19 pandemic has indicated, epidemics and pandemics can lead to restrictions on air traffic and lead to reduced demand for air travel.

Technical force majeure includes accidents and incidents with aircraft and certain technical failures in navigation systems. Unforeseen technical malfunctions or aircraft accidents can affect safety of flights and require immediate intervention. Failures in navigation systems used for air traffic control and aircraft orientation can endanger all participants in air transportation.

Personal (human) force majeure includes behavior and actions of the crew and passengers that create an emergency situation, as well as acts of terrorism that can affect flight safety and airport infrastructure.

Political (geopolitical) force majeure includes armed conflicts and military actions that can lead to the closure of airspace, restrictions on flights and disruptions in aviation infrastructure. Economic crises, airline bankruptcies or other financial difficulties that can lead to limitation of aviation operations are classified as economic force majeure.

This is only a general overview of force majeure in aviation, and each of the following has a negative impact on. Thus, f for instance, main negative consequences of the COVID-19 pandemic are a reduction in demand for air passenger transportation due to restrictions and bans introduced by almost all countries of the world including

Ukraine. This led to a sharp reduction in the volume of air transportation of passengers and led to the unprofitable operation of airlines, airports, and all sectors of service of transport processes, because the operating costs of companies increased or remained at the previous level, and revenues decreased by 3–5 times. According to International Civil Aviation Organization (ICAO), in 2020 air transport had losses in the amount of $370 billion. Such consequences also occurred in some countries of the world. In the same year, China civil aviation had losses in the amount of $5.6 billion, the losses of the US aviation companies together amount to more than $40 billion, the aviation business was operating in almost all countries of the world in 2020 with loss [26].

Force majeure circumstances can have a significant impact on aviation activities, and lead to restriction or suspension of flights. Weather disasters, military conflicts or epidemics can lead to restrictions in the use of airspace or even to complete cessation of aviation operations in certain regions. Thus, on February 24, 2022, in connection with the military invasion of the Russian Federation, in accordance with the requirements of the Air Code of Ukraine and the Regulations on the Use of the Airspace of Ukraine, State Aviation Service of Ukraine took measures to close the airspace of Ukraine for civilian airspace users. Provision of air navigation services in the airspace of Ukraine has been suspended. As well, force majeure can lead to flight delays and cancellations due to weather conditions, infrastructure problems or other negative impacts that complicate aviation operations, causing significant financial losses to aviation organizations such as airlines and airports. The reduction in demand for air travel during COVID-19 pandemic is an example of such losses.

Force majeure can affect flight schedules and flight sequences, forcing airlines to re-plan routes and flight schedules to avoid restrictions and risks. Natural disasters or military operations can lead to disruptions in aviation infrastructure, such as destruction of airports or navigation systems. This can significantly complicate flights. Therefore, depending on nature and scale of force majeure circumstances, aviation institutions should develop contingency plans and response strategies to ensure the safety, reliability and stability of aviation operations during adverse events.

As already mentioned, important component of risk management, including force majeure in aviation, is development and implementation of emergency plans and strategies for responding to force majeure in order to ensure the safety, reliability and stability of aviation activities.

On November 29, 2018, agreement was concluded in Brussels between the airspace management unit of Ukraine (Ukraerorukh) and the European Organization for the Safety of Air Navigation (Eurocontrol) regarding coordination procedures and actions in emergency situations while ensuring flexible airspace [27].

In addition, noting the intention of Ukraine to incorporate into its aviation legislation the relevant requirements and standards of the European Union, including taking into account the further development of the EU legislative framework and wishing to ensure the highest level of flight safety and aviation safety of international air transportation and confirming the deep concern in in connection with actions or threats directed against the safety of aircraft, which endanger the safety of people or property, negatively affect the operation of aircraft and undermine the confidence of passengers in the safety of civil aviation On October 12, 2021, an Agreement was concluded between Ukraine, on

the one hand, and by the European Union and its member states, on the other hand, on European Common Aviation Area (hereinafter referred to as ECAA) [28].

The purpose of this Agreement is gradual establishment of an Agreement between Ukraine and the European Union and its member states based on identical rules in the field of flight safety, aviation security, air traffic management, environmental protection, consumer rights protection, computer systems booking, and on identical rules regarding social aspects. According to Clause 1 of the criteria specified in Article 26(4) of the Agreement, aid for compensation for damage caused by natural disasters or emergency situations is compatible with proper functioning of this Agreement.

Based on provisions of paragraph b) of Article 9 of the Convention on International Civil Aviation dated on 1944, each Contracting State also reserves the right immediately in exceptional circumstances or during emergency state or in the interests of public safety to temporarily restrict or prohibit flights over its territory or any which part thereof, provided that such restriction or prohibition applies to aircraft of all other States, regardless of their nationality.

Therefore, force majeure management in aviation activities is an important part of ensuring the safety, reliability and stability of aviation operations. Development of emergency plans can be called the key aspects of force majeure management in the aviation industry. Thus, aviation institutions such as airlines, airports and air navigation services must develop and maintain contingency plans for various types of force majeure including natural disasters, technical failures and others.

Staff of aviation organizations must be trained and prepared to respond to force majeure circumstances. This includes conducting drills, simulations and evacuation exercises. Thus, Jason Kelly, president of the Crisis Advisors company that provides emergency response training for airlines, noted that airlines should be ready to respond immediately to an air crash, serious incident, in-flight emergency, ground incident, security incident or other type of emergency. Emergency situation. Crisis management of an aviation accident or incident is a very complex and fast process, when command decisions must be made by the airline management quickly, correctly and decisively. After a plane crash, there is no time to train airline staff in emergency response or develop policies. Thus, most emergency response planning and training activities should be conducted early and on a regular basis [30].

Force majeure Management is a comprehensive procedure that requires planning, preparation, cooperation and rapid response to unforeseen events. Compliance with these principles helps to reduce risks and ensure safety of aviation activities. Force majeure management requires clear planning and coordination between the various structures of the aviation industry. Flexibility and adaptability, ability to respond quickly to changing circumstances and take alternative measures, such as rerouting flights or providing substitute services is a component of force majeure management procedure.

The bottom line that needs to be analyzed and determined in the context of this topic is the factor of force majeure on aviation activities that leads to cancellation or delay of flights due to bad weather conditions, technical issues or security restrictions, to financial losses, because air carriers lose profits due to flight cancellations and compensation to passengers and negative impact on reputation, given that non-compliance with flight schedules and unpredictability can affect passenger confidence and the image of airlines.

Therefore, the issue of compensation for flight delay or cancellation is relevant and requires special attention in research on force majeure in aviation.

The main special industry regulatory legal act regulating general conditions of passenger and baggage transportation by air transport, ensuring flight safety and passenger service quality is the Rules of Air Transportation and Passenger and Baggage Service (hereinafter referred to as Aviation Rules). Thus, Aviation Rules of Ukraine while defining and relating concepts of flight delay or flight cancellation, contain inaccurate wording regarding time: "two hours or more", "three hours or more", "four hours or more" [31].

Aviation rules were developed taking into account the provisions of the Montreal Convention, the Warsaw Convention, the Hague Protocol and the rules of the International Air Transport Association (IATA). While developing the Aviation Rules, the provisions of EU Regulation 261/20042: *On establishing general rules in the field of compensation and assistance to passengers in the event of denied boarding, cancellation or long flight delay and on the repeal of Regulation (EEC) N 295/91* (hereinafter referred to as Regulation 261/2004) that is valid on the territory of the European Union and which is governed by all airlines registered in the EU or operating flights from European airports and other air carriers during flights to/or from Europe.

Instead, EU Regulation No. 261/2004 on introduction of common rules for compensation and assistance to passengers in case of refusal of transportation and cancellation or long delay of flights, and cancellation of Regulation (EEC) No. 295/91 in case of flight delay absolutely and clearly defines the terms [32]. For example, a delay in the case of a flight distance of up to 1,500 km is two hours from the scheduled time of departure. The Aviation Rules of Ukraine do not clearly define criteria for delimiting flight delay periods, instead of which the concept of "reasonable periods" is included.

Here, delay in the case of a flight distance of up to 1,500 km is two hours or more, without determining its upper limit. This is a certain gap in the awarding of compensation, since it is disproportionate to equate the passenger's losses in the event of a flight delay of two hours and, for example, eight hours.

The official interpretation of the relationship between the terms: "flight delay" and "flight cancellation" during passenger compensation is established in the decisions of the European Court (Fourth Chamber) in the cases № C-402/07 *Christopher Sturgeon and others against the airline Condor Flugdienst GmbH* and No. C- 432/07, Stephan Beck, *Cornelia Lepushyts against Air France SA*. In accordance with these judicial acts, articles 5, 6 and 7 of Regulation No. 261/2004 to resolve the issue of compensation should be applied as follows: passengers whose flights are delayed are equated to passengers whose flights are canceled if the delay is equal to or exceeds three hours, i.e. passengers reach their final destination three or more hours later than specified in the air carrier's flight schedule [33]. Thus, according to the decisions of the European Court of Justice in cases № C-402/07 and № C-432/07, a flight delay of three or more hours is equated in terms of civil law consequences to flight cancellation and entitles the tourist to similar compensation in the amount of: 250 euros for flights with a flight distance of up to 1,500 km; 400 euros for flights with a flight distance of 1,500 to 3,500 km; 600 euros for all other flights. If the flight delay is less than three hours, then, applying the interpretation from the above-mentioned judgments of the European Court and the provisions of point a) paragraph 1 of Article 8 of Regulation No. 261/2004, the passenger has the right

to be provided with soft drinks and food while waiting for the departure of the flight, for accommodation in a hotel, if the waiting time in the event of a change of route is one or more nights, or for reimbursement of the full cost of a flight ticket. Ukrainian legislation, in contrast to the legislation of the European Union, establishes the right to receive monetary compensation in the maximum amount of the ticket price, regardless of the flight delay time.

The definition of the *delay* concept in transportation of a passenger and the delivery of his luggage delays, the Montreal Convention and the Warsaw Convention, do not provide a definition of the *delay* concept, although in the preparatory content of the Montreal Conference it was proposed to define it as "failure to carry out the transportation of a passenger or the delivery of luggage or cargo to the immediate or final destination within the time that can reasonably be expected from a diligent carrier, taking into account all the relevant circumstances" [34].

Aviation regulations determine responsibility of the carrier for non-fulfillment or improper fulfillment of the terms of the contract of carriage of a passenger by air, in particular, responsibility for denied boarding, delay or cancellation of a flight [31]. The rights of passengers in case of denied boarding, delay or cancellation of a flight are defined by Section XV of the Aviation Rules. The provisions of Section XV of Aviation Rules apply to passengers of scheduled and charter flights who are refused carriage or whose flight is canceled or delayed, provided that the passenger has a confirmed reservation for relevant flight and except in the case of cancellation, is present for check-in at the time provided by the rules air carrier and notified in writing, or, if the check-in time is not specified, not later than 45 min before the departure or booking time of the flight that was delayed/transferred by the air carrier or aircraft charterer (tour operator) to another flight, regardless of the reasons [35, C 102].

Air carrier has the right to deny boarding to passengers incase event of overbooking, i.e., in the case of a so-called "overbooked flight". The *overbooking* concept is a relatively new phenomenon in the field of civil aviation. The analysis of the passenger air transportation market proved that any flight always has a few percent of passengers who after booking a flight, do not arrive for departure on the specified date for personal reasons. In order not to fly on a half-empty plane, airlines sell more tickets than the aircraft can hold. As well, the overbooking concept is used in the case when, before departure, carriers change a technically defective aircraft to a new one, which is inferior in passenger capacity to the first one [34].

It is important to note that the protection of passengers' rights in case of flight delay or cancellation under Regulation № 261/2004 does not apply to flights outside the European Union. That is, the protection of passengers' rights under the Regulation will not work on the territory of the European Union if the flight was from outside the European Union to the interior of the European Union and the operator was not an airline of European Union. It is possible to use the rights in accordance with the laws of the European Union on the rights of air passengers in cases where the transportation is carried out within the European Union and does not depend on the airline that is its operator; if the flight arrives in the European Union and the operator is a company from the European Union; if the flight departs from the European Union to a country other than the European Union and it does not matter which airline is its operator [32].

In order to receive compensation for damages under Regulation 261/2004, it is necessary to submit a corresponding application on the airline website and fill out a special form. For this purpose, it is necessary to save all documents that confirm the fact of the delay or cancellation of the flight. If the transfer from one flight to another is on the same reservation and the passenger is late for the second flight due to cancellation of the first, the carrier should either reimburse the cost of tickets for the entire reservation chain, or offer an alternative to reach the destination. If the flight was canceled at the airport and the passenger is waiting for an alternative flight, he should be provided with the same conditions as in the case of a delayed departure [32].

Some countries and regions may set their own mandatory standards and regulations for handling passenger delays. These rules can complement international standards and provide additional rights and protection to passengers. For example, the European Union (EU) has its own rules on passenger rights, including rules for handling flight delays. One such initiative is Regulation (EC) № 261/2004 defining the rights of passengers in case of flight cancellations and significant delays. According to this regulation, passengers whose flights are cancelled or delayed for a certain time can be entitled to compensation, food and beverages, hotel rooms and reorientation to another flight.

Some other countries and regions may have their own laws or regulations relating to passenger handling in case of flight delays. These rules may be country-specific and may vary in scope and responsibilities.

It will not be superfluous to note that effective solutions to problems in the aviation industry require close cooperation between various interested parties, including air carriers, government authorities of the aviation industry, airports, passengers and other organizations. The interaction between them plays an important role in ensuring the safety, reliability and stability of aviation operations, which positively affects the management and forecasting of force majeure in aviation activities. Cooperation in the field of prevention of force majeure in aviation activities is of great importance for ensuring safety and reliability of aviation operations. It is known that force majeure circumstances mentioned above can become serious threats to aviation safety and workflow. Interaction between all interested parties in the field of prevention and of force majeure management in aviation activities contributes to increasing safety and stability of aviation operations and ensures the protection of passengers and staff.

Thus, one of the key aspects of preventing force majeure is meteorological observation and forecasting. Meteorological services cooperate with aviation institutions to provide information on weather, storms, turbulence and other meteorological conditions that can affect flight safety. These services serve as aerodromes as air routes [37].

In accordance with Article 7, part two of Article 45 of the Air Code of Ukraine [14], the Rules of State Aviation of Ukraine, approved by the order of the Ministry of Defense of Ukraine dated January 5, 2015 № 2 registered with the Ministry of Justice of Ukraine on January 26, 2015 under No. 82/26527 [38], taking into account the standards and recommended practice of the International Civil Aviation Organization (hereinafter referred to as ICAO), the European Organization for the Safety of Air Navigation (hereinafter referred to as Eurocontrol) and Technical Regulations of the World Meteorological Organization [39], the Rules of Meteorological Support of Flights of State Aviation of Ukraine have been adopted in Ukraine [37]. It is these rules that determine the content,

purpose and procedure of meteorological support for flights of state aviation aircraft, the main types and terminology of aviation weather forecasts, the duties of officials of the meteorological service of aviation entities and are mandatory for the management and implementation of all services of the entity's objects of aviation activity.

As well, in their cooperation on forecasting and force majeure management, aviation institutions use incident detection systems, such as radars and other technologies, to detect possible threats, such as drones, other aircraft or objects that may cause force majeure. Various aviation organizations, such as air navigation services, airports, airlines and others, should cooperate and exchange information on possible force majeure. This can include sharing weather data, airport infrastructure, aircraft movements, etc. After force majeure situations, it is important to analyze them to study the causes and develop measures to prevent similar situations in the future.

Talking into account that force majeure is grounds for exemption from liability for breach of assumed obligations, aviation force majeure is not an exception. Special attention should be paid to the regulation of this legal phenomenon in contractual terms. Thus, in accordance with Part 1 of Art. 14^1 of the Law of Ukraine: *On the Chambers of Commerce and Industry in Ukraine*, the Chamber of Commerce and Industry of Ukraine and the regional chambers of commerce and industry authorized by it certify force majeure circumstances (circumstances of force majeure) and issue a certificate of such circumstances within seven days from the date of the subject application business activity. Article 617 of the Civil Code of Ukraine [40] stipulates that a person who has violated an obligation is released from responsibility for obligation violation an if he proves that this violation occurred as a result of an accident or force majeure.

As well, in accordance with the provisions of Article 218 of Economic Code of Ukraine, unless otherwise provided by law or agreement, a business entity shall bear economic and legal liability for violation of an economic obligation, unless it proves that proper fulfillment of the obligation was impossible due to force majeure, that is extraordinary and inevitable circumstances under these economic activity conditions [41].

Usually, contracts of carriage and aviation agreements contain provisions regarding force majeure and procedures to be followed in the event of their occurrence. The contract can contain a clause exempting the parties from liability in case of force majeure. This means that parties will not be liable for failure to fulfill their obligations, if this is impossible due to force majeure. The contract terms should require the parties to notify each other of force majeure circumstances and their impact on the performance of the agreement. This can help the parties to interact and find a solution in case of force majeure. Thus, force majeure can lead to postponement or cancellation of aviation operations, such as flights. Provisions in the contract can regulate issues regarding refunds, transfer to another flight or other alternative options for passengers. Contracts can determine methods of cooperation and dispute resolution in the event of force majeure. This can include negotiations, search for alternative solutions and other cooperation mechanisms.

It is important to note that content and scope of force majeure provisions can vary from one contract to another. International conventions, such as the Montreal Convention of 1999, contain provisions on liability of air carriers in case of force majeure. According to these documents, air carriers may be exempted from liability for certain losses if it

can be proved that these losses were caused by force majeure that could not have been avoided, as we noted above.

In order to be successfully released from liability, air carriers should usually provide evidence that force majeure was unforeseeable, could not have been avoided and prevented normal performance of carriage contract. In particular, relevant documentation that shows that the event was unforeseeable at the time of contract conclusion or planning of aviation operations. Reports of meteorological services, news about extraordinary events, information about other unforeseen circumstances can be important evidence. If similar force majeure circumstances have occurred earlier, previous reports and analyzes of these events can confirm their unpredictability. If other cases of a similar nature have already occurred, this can indicate that the situation was unpredictable. Testimony from experts, such as meteorologists, geologists, engineers or other specialists, can be important to prove that circumstances were unforeseeable. Experts can provide their assessments and analysis confirming the unpredictability of the event. Information found in publicly available sources, such as mass media, official government statements or other communications, may serve as evidence of force majeure. Gathering and presenting this evidence can be a difficult task and in many cases the case can be resolved in court or other arbitral body.

In general, addressing liability issues in case of force majeure in aviation activities can be comprehensive and requires compliance with international and national regulatory requirements. Detailed situation analysis to determine whether force majeure circumstances belong to the category that can relieve the parties from liability, the collection of evidence confirming the unpredictability and impossibility of avoiding such circumstances. In cases where the parties cannot reach an agreement on liability, the case can be referred to arbitration or court. In these processes, all evidence and arguments of the parties will be considered, and the court will decide whether force majeure circumstances are grounds for exemption from liability.

Thus, force majeure in air transportation contracts is an important legal concept that defines the circumstances that, in accordance with legislation and international conventions, can exempt the parties from responsibility for non-fulfillment of their obligations. Air transportation contracts often contain provisions regulating the of force majeure impact on the parties' liability and the terms of dispute resolution in such situations. Defining and establishing force majeure is an important task to ensure justice and understand the legal consequences of events beyond the control of the parties. Significantly, force majeure is an important tool to ensure the stability and reliability of air transport in the event of unforeseen circumstances and it can be different in different aviation agreements and contexts.

3 Conclusions

Despite significant negative consequences of force majeure in implementation of aviation activities and therefore for implementation of contractual obligations based precisely on the implementation of such transportation by air transport, as well as despite recognition of a certain event by authorized state bodies as a force majeure circumstance in in general, the party that lost the opportunity to fulfill the obligation must prove the influence of

force majeure on non-fulfillment of the corresponding obligation. Force majeure in aviation is an important aspect that can significantly affect the safety and reliability of aviation operations. The main types of force majeure include natural disasters, technical malfunctions, strikes, acts of terrorism, pandemics and other unforeseen events. Aviation institutions and air carriers must have plans and procedures for managing force majeure situations in order to ensure the safety of passengers and personnel. It was determined that an important part of resolving issues of responsibility in case of force majeure is compliance with international conventions and national legislation.

Cooperation between aviation organizations, meteorological services and other stakeholders plays an important role in prevention and force majeure management. Taking into account that force majeure can cause significant changes in air transport schedules, they require reorganization of logistics and planning. Contracts of air carriage usually establish liability conditions and procedures for resolving disputes related to force majeure. However, analysis and study of previous force majeure cases helps to improve plans and procedures for crisis management in the aviation industry. In addition, force majeure can affect legal relationships and liability in the field of aviation, so it is important to consider international conventions and agreements that regulate this field and develop dispute resolution strategies in accordance with.

By properly responding to force majeure and ensuring the highest level of safety, the aviation industry can overcome challenges while maintaining a high standard of quality and passenger confidence. It is important to constantly update approaches and respond to new challenges in order to ensure stability and development of the aviation industry in the future.

References

1. Vandeskog, B.: Risk, trust and reputation in the Norwegian offshore supply chain. Saf. Sci. **163**, 106118 (2023). https://trid.trb.org/view/2132384, [in English]
2. Liang, X., Fan, S., Lucy, J., Yang, Z.: Risk analysis of cargo theft from freight supply chains using a data-driven Bayesian network. Reliab. Eng. Syst. Saf. **226**, 1–15 (2022). https://doi.org/10.1016/j.ress.2022.108702 [in English]
3. Tseremoglou, I., Bombelli, A., Santos, B.F.: A combined forecasting and packing model for air cargo loading: a risk-averse framework. Transp. Res. Part E: Logistics Transp. Rev. **158**, 102579 (2022). https://doi.org/10.1016/j.tre.2021.102579 [in English]
4. Rybchuk, A.V.: Problems of functioning of the international tourist industry in the conditions of a global pandemic. Bull. Khmelnytskyi Nat. Univ. Econ. Sci. **1**(2), 204–210 (2022). [in Ukrainian]
5. Convention for the Unification of Certain Rules for International Carriage by Air. https://www.icao.int/secretariat/legal/list%20of%20parties/mtl99_en.pdf. (15.09.2023) [in English]
6. Convention on International Civil Aviation signed at Chicago on 7 December 1944. https://www.icao.int/secretariat/legal/List%20of%20Parties/Chicago_EN.pdf. (15.09.2023) [in English]
7. Convention on the International Recognition Of Rights In Aircraft, Signed At Geneva On 19 June 1948. https://www.icao.int/secretariat/legal/Administrative%20Packages/geneva_en.pdf. (15.09.2023) [in English]
8. Convention on International Liability for Damage Caused by UN Space Objects. Convention, International Document dated March 29, 1972. https://zakon.rada.gov.ua/laws/show/995_126#Text. (September 16, 2023) [in Ukrainian]

9. Convention on Offences and Certain Other Acts Committed on Board Aircraf 14 September 1963. https://www.unodc.org/documents/treaties/terrorism/Commonwealth_Chapter_2.pdf. (15.09.2023) [in English]
10. Convention on Combating Unlawful Seizure of Aircraft UN, Convention, International document, 16.12.1970. https://treaties.un.org/doc/db/Terrorism/Conv2-english.pdf. (16.09.2023) [in English]
11. Convention for the suppression of unlawful acts against the safety of civil aviation (with Final Act of the International Conference on Air Law held under the auspices of the International Civil Aviation Organization at Montreal in September 1971). Concluded at Montreal on 23 September 1971. https://treaties.un.org/doc/Publication/UNTS/Volume%20974/volume-974-I-14118-english.pdf. (16.09.2023) [in English]
12. Protocol for the Suppression of Unlawful Acts of Violence at Airports serving International Civil Aviation. https://www.refworld.org/docid/3ddcac634.html. (17.09.2023) [in English]
13. Treaty on Open Skies. Adopted at Helsinki 24 March 1992
14. Depositaries Government of Canada, Government of Hungary. https://treaties.unoda.org/t/open_skies. (12.09.2023) [in English]
15. Air Code of Ukraine: Law of Ukraine dated May 19, 2011 No. 3393-VI. Information of the Verkhovna Rada of Ukraine. 2011. No. 48–49. Art. 536 [in Ukrainian]
16. About transport. Law of Ukraine dated November 10, 1994. Information of the Verkhovna Rada of Ukraine dated December 28, 2015 [in Ukrainian]
17. About the State Program of Aviation Safety of Civil Aviation. Law of Ukraine dated March 21, 2017 No. 1965-VIII. https://zakon.rada.gov.ua/laws/show/1965-19#Text. (September 12, 2023) [in Ukrainian]
18. On the approval of the Rules for the investigation of aviation events and incidents in the aviation of the Armed Forces of Ukraine: Order of the Ministry of Defense of Ukraine dated 19.05.2010 No. 256. https://zakon.rada.gov.ua/laws/show/z0386-10#Text. (17.09.2023) [in Ukrainian]
19. The impact of COVID-19 on the economy and society of the country: the results of 2020 and the challenges and threats of post-pandemic development. Consensus forecast/Department of Strategic Planning and Macroeconomic Forecasting April 2021 No. 53, p. 63. https://www.me.gov.ua/Search/Result?lang=uk-UA&query=%25d0%25ba%25d0%25be%25d0%25bd%25d1%2581%25d0%25b5%25d0%25bd%25d1%2581%25d1%2583%25d1%2581
20. On the introduction of martial law in Ukraine: Decree of the President of Ukraine dated February 24, 2022 No. 64/2022. https://zakon.rada.gov.ua/laws/show/64/2022#Text. (17.09.2023) [in Ukrainian]
21. On the approval of the Decree of the President of Ukraine. On the introduction of martial law in Ukraine: Law of Ukraine dated February 24, 2022 No. 2102-IX. https://zakon.rada.gov.ua/laws/show/2102-20#Text. (September 15, 2023) [in Ukrainian]
22. About Chambers of Commerce and Industry in Ukraine: Law of Ukraine dated 02.12.1997 No. 671/97-BP. https://zakon.rada.gov.ua/laws/show/671/97-%D0%B2%D1%80#Text. (17.09.2023) [in Ukrainian]
23. United Nations Convention on Contracts for the International Sale of Goods, Vienna, 11 April 1980, S.Treaty Document Number 98–9 (1984), UN Document Number A/CONF 97/19, 1489. https://uncitral.un.org/sites/uncitral.un.org/files/media-documents/uncitral/en/a-conf-97-19-ocred-eng.pdf. (16.09.2023) [in English]
24. Principles of UNIDRUA in the edition of 2016: Art. 1.6(2) UNIDROIT Principles 2016. https://www.unidroit.org/english/principles/contracts/principles2016/principles2016-e.pdf. (14.09.2023) [in English]
25. Principles of European Contract Law, Parts I and II, prepared by the Commission on European Contract Law, p. XXVII. https://www.trans-lex.org/400200/_/pecl/. (13.09.2023) [in English]

26. Smits, J.M.: A European private law as a mixed legal system: towards a Ius commune through the free movement of legal rules. Maastricht J. Eur. Comp. Law **5**, 328–340 (1998). https://doi.org/10.1177/1023263X9800500402 (14.09.2023) [in English]
27. Passenger airlines–Statistics and Facts. The Statistic Portal Statista. www.statista.com/topics/1151/passenger-airlines/. (22.09.2023) [in English]
28. Official website of the State Aviation Service of Ukraine. https://avia.gov.ua/derzhavne-pidpriyemstvo-obslugovuvannya-povitryanogo-ruhu-ta-yevrokontrol-vregulyuvali-protseduri-koordinasiyi-ta-dij-u-vipadku-nadzvichajnih-obstavin/. (14.09.2023) [in English]
29. Agreement between Ukraine, on the one hand, and the European Union and its member states, on the other hand, on common aviation space: International document dated 10.12.2021. https://zakon.rada.gov.ua/laws/show/984_004-21#Text. (September 15, 2023) [in Ukrainian]
30. Convention on International Civil Aviation. https://www.icao.int/publications/Documents/7300_cons.pdf. (16.09.2023) [in English]
31. Jason Kelly, Emergency Response training for airlines. 01.03.2027. https://www.linkedin.com/pulse/emergency-response-training-airlines-jason-kelly
32. On the approval of the Aviation Rules of Ukraine. Rules of Air Transportation and Passenger and Baggage Handling: Order of the State Aviation Service of Ukraine Rules dated November 26, 2018 No. 1239. https://zakon.rada.gov.ua/laws/show/z0141-19#Text. (16.09.2023) [in Ukrainian]
33. Regulation (EC) No 261/2004 of the European Parliament and of the Council of 11 February 2004 establishing common rules on compensation and assistance to passengers in the event of denied boarding and of cancellation or long delay of flights, and repealing Regulation (EEC) No 295/91. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004R0261
34. Joined Cases of European Court No. C-402/07 and No. C-432/07 from November, 19, 2009. https://curia.europa.eu/juris/liste.jsf?language=en&num=C-402/07. (18.09.2023) [in English]
35. LE 4/51 – 97/65. Attachment A to State Letter. Draft Convention for The Unification Of Certain Rules For International Carriage By Air (Text Approved By The Legal Committee). 27 June 1997, p. 23 [in English]
36. Khohlenko, V.M.: Legal principles for the protection of passengers' rights during air transportation. Dictum Factum **2**(7), 102 (2020). https://df.duit.in.ua/index.php/dictum. (September 20, 2023) [in Ukrainian]
37. Gerard Parr, D.W., Malone, M.Ó.F.: Autonomic principles of IP operations and management. In: 6th IEEE International Workshop on IP Operations and Management, IPOM 2006, Dublin, Ireland, October 23–25, 2006; Proceedings Springer, 2006. ISBN 9783540477013. https://books.google.com/books?id=5ij6EG_fKGAC&pg=PA72&dq=overbooking&hl=ru&cd=6#v=onepage&q=overbooking&f=false. (14.09.2023) [in English]
38. On the approval of the Rules for Meteorological Support of State Aviation Flights of Ukraine: Order of the Ministry of Defense of Ukraine dated September 29, 2015 No. 516. https://zakon.rada.gov.ua/laws/show/z1264-15#Text. (September 20, 2023) [in Ukrainian]
39. On the approval of the Rules for the execution of flights of the state aviation of Ukraine: Order of the Ministry of Defense of Ukraine dated 05.01.2015 No. 2. https://zakon.rada.gov.ua/laws/show/z0082-15#n11. (19.09.2023) [in Ukrainian]
40. Standards and recommended practices: World Meteorological Organization (WMO). 2021. https://library.wmo.int/records/item/48992-basic-documents-no-1-convention-general-regulations-staff-regulations-financial-regulations-and-agreements. (20.09.2023) [in English]
41. Civil Code of Ukraine: Law of Ukraine dated January 16, 2003 No. 435-IV. https://zakon.rada.gov.ua/laws/show/435-15#Text. (September 23, 2023) [in Ukrainian]
42. Economic Code of Ukraine: Law of Ukraine dated January 16, 2003 No. 436-IV. https://zakon.rada.gov.ua/laws/show/436-15#Text. (September 23, 2023) [in Ukrainian]

Innovative Biotechnological Methods Treatment of Combined Wastewater

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Abstract. The presented work analyzes the existing methods of cleaning combined wastewater. It is indicated that the most common solutions in the field of highly concentrated wastewater treatment methods and technologies are the combination of classical treatment methods (mechanical, physico-chemical, biological, etc.) with innovative methods (reverse osmosis, ultrafiltration, microfiltration, electrodialysis, improvement of biological methods, etc.). Based on the analysis of existing methods, it is proven that phytotechnological methods using their ecological and energy-saving potential and the advantages of such technologies for sustainable development are promising methods of wastewater treatment. The ecological expediency and effectiveness of innovative methods of cleaning combined wastewater using biofilm and bioplateau (swamps) to ensure the sustainable development of urbanized and industrially saturated territories are considered and proven.

Keywords: wastewater · biotechnology · innovative technologies · sustainable development

1 Introduction

1.1 The Relevance of the Topic

The need to organize and ensure a balanced use of nature, improve the quality of the environment, and reduce the impact of production implies the social and economic development of society. Inefficient use of water, pollution of water bodies will threaten the food security of mankind, the health of ecosystems and access to high-quality drinking water [1, c. 23].

Today, there are many definitions of wastewater concepts, while they are divided into wastewater from enterprises, domestic consumers, municipal wastewater, etc. When researching and choosing a method of cleaning and further cleaning, it should be taken into account that these waters have a changed composition, both chemical and physical. Wastewater is a complex multi-component substance mixture that contains impurities of organic and mineral origin, they can be in an undissolved, colloidal and dissolved

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state. The degree of their pollution, which is estimated by the concentration - the mass of impurities per unit volume of mg/l or g/m3, will depend on the multicomponent composition. To determine the quantitative and qualitative indicators of the multicomponent composition, measurements, analysis and evaluation are carried out, namely: sanitary and chemical analyzes to determine the amount of COC (chemical oxygen consumption - the total concentration of organic substances); BOC (concentration of organic compounds that are oxidized biologically); concentration of suspended substances; active reactions of the environment; color intensity; degree of mineralization; concentration of biogenic elements (nitrogen, phosphorus, potassium), etc. [2].

Wastewater is treated at mechanical and biochemical (biological) treatment facilities. Wastewater treatment technology is developing in the direction of intensification of biochemical treatment processes, sequential implementation of biochemical and physico-chemical treatment processes, the purpose of which is the reuse of deeply purified wastewater at industrial enterprises. For a complex and energy-efficient solution to this problem, a combination of physico-chemical (pressure flotation, treatment with reagents) and biological (oxidation of microorganisms orium in anaerobic and aerobic conditions) methods. Such a combination eliminates the shortcomings of each of the methods and makes it possible to solve the given tasks in the most effective way. Promising methods of wastewater treatment are phytotechnological methods using their ecological and energy-saving potential and the advantages of such technologies for sustainable development.

1.2 Research Methodology

The methodological basis of the work is the dialectical method, the use of which allows studying the object and subject of research in their epistemological unity, interconnection and differences. The methodology of the article is based on the use of several basic methods of scientific knowledge. The historical method was used to clarify the historical and general theoretical issues of the essence of scientific approaches and practice of applying wastewater treatment methods. The use of the methods of analysis and synthesis made it possible to identify the most effective and environmentally friendly methods of wastewater treatment. The logical and semantic method identified the interrelationships and interactions of the method of using biofilms, bio-plateaus, mochars and other phytobiological methods of treatment with other environmentally friendly methods of wastewater treatment. Scientific abstraction and generalisation of scientific and theoretical information as a process of establishing common properties and features allowed us to reach and formulate final conclusions about the subject of the study.

2 Main Content Presentation

Biochemical cleaning methods are based on the use of the vital activity of microorganisms that oxidize organic substances found in wastewater in colloidal and dissolved states. Biochemical methods can almost completely get rid of organic impurities that remain in water after mechanical cleaning.

Facilities for biological (biochemical) wastewater treatment can be divided into two main types:

– structures in which biological treatment is carried out under conditions close to natural ones (filtration fields and biological ponds). Wastewater is cleaned on them quite slowly due to the oxygen supply in the soil and in the water of biological ponds, and also as a result of the vitality of micro-organisms-mineralizers that oxidize in soil and water organic pollution;
– facilities in which wastewater treatment is carried out in artificially created conditions (biological filters and aerotanks). In these structures, conditions are artificially created under which wastewater treatment processes are much more intensive [3].

Purified wastewater should be disinfected before discharge to the reservoir to destroy and destroy disease-causing microorganisms that remain. Since the requirements for the level of wastewater treatment are increasing, they are subjected to additional treatment.

Biological water purification was, is and will be the main method of protecting natural waters from chemical and biological pollution. Hydrobionts take part in the permanent and eternal self-purification of water from the moment of their appearance in the water. Absolutely all of them owe their existence to an incomprehensible, worthy of wonder, a mad urge to reproduce, as well as to those organic substances that enter the water from the soil or air or water occur as a result of photosynthesis and which from the human point of view are substances that pollute water, and for hydrobionts -heterotrophs, they are the only source of nutrition. Biotechnology of water purification in all highly developed countries is the most high-tonnage not only among biotechnologies (as old as baking bread, production of fermented milk products and fermentation products; new ones, such as the biosynthesis of medicines such as antibiotics, interferon, or insulin), and among the well-known technological ones in general.

Like any other biotechnology, biological methods of water purification are based on the use of certain living organisms, their complexes - biocenoses. Five such biocenoses in water purification are currently known: a) biofilm; b) activated sludge; c) anaerobic microorganisms, especially granular sludge; d) selected microorganisms - destroyers of certain pollutants; e) hydrobiocenoses, which constitute a spatial succession (bioconveyor) [4].

These biological groups are the basis of all existing biotechnological water purification: the most diverse biofilters (with gravel, sand or synthetic loading; vertical or they are horizontal, which are called “wetlands” - swamps (bioplato), immersed in water, or intensively ventilated, etc.); aerotanks, oxygen tanks of various types and calibers (extruders, mixers, circulation, shafts, towers, etc.), bacterial bioreactors, a number of anaerobic structures with an upward or downward flow, with or without recirculation; finally, direct flow microbial, zoo and phytoreactors. Man has invented a great number of technical devices, structures, devices for biological water purification, but all of them rely on the five types of biological agents listed above, which have always existed live in nature. In any stream, stones and other solid objects are slippery from the biofilm; there is no lake without silt at the bottom - the upper layer is aerobic, the lower layer is anaerobic; the best bacteria-destructors live in soil irrigated with polluted water; in every river that is intensively polluted by organic substances, you can observe a spatial succession of hydrobionts, which ensures the gradual self-purification of the water in it. The principle technological scheme of mechanical-biological-chemical wastewater treatment is based on the realization that biological treatment is the basis, the core of

the outwardly simple to primitiveness, but in fact and the extremely complex process of transforming a dirty, toxic liquid - industrial or domestic wastewater - into clean, ecologically safe, biologically pure water. The complete set of this traditional, one might even say classical, process includes the following three stages: primary – mechanical cleaning; secondary – own biological purification; tertiary – physico-chemical treatment of wastewater (Fig. 1).

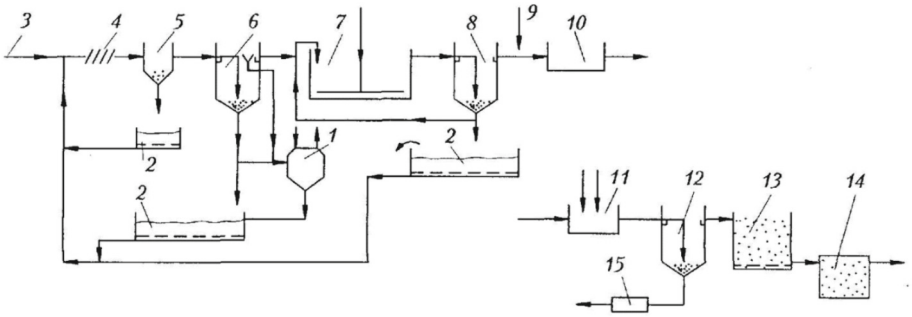

Fig. 1. General scheme of wastewater treatment 1 – methane tank; 2 – mud playgrounds; 3 – waste water; 4 – grids; 5 – sand catcher; 6 – primary spacer; 7 – bioreactor (air tank); 8 – secondary spacer; 9 – container for chlorination; 10 – contact tank; 11 – container for flocculation-coagulation; 12 – spacer; 13 – sand filter; 14 – filter with activated carbon; 15 – sediment thickener

During mechanical cleaning, wastewater 3 passes through grates 4, where coarse mechanical impurities are retained, then through a sand trap 5, where sand is separated, and finally flows into primary reservoirs, where, thanks to the forces of gravity, everything heavier than water settles on the bottom, is collected and pumped into methane tanks 1 for fermentation or after a certain period of time (sometimes once a quarter) is released to sludge fields with drainage 2, and everything that is easier than water - rises to the surface of the water, where it is collected by special devices in a bunker and is also sent to the methane tank [5].

Biological processes occur in water at all stages of its passage through treatment plants. Moreover, they begin at the moment of wastewater generation, continue during the collection and transportation of this water to treatment facilities (in sewage networks), and do not stop after any, even the most thorough cleaning and disinfection of water.

However, the most noticeable biological treatment of wastewater occurs only at the second - biological - stage, where the already mentioned biofilm, active aerobic or granular anaerobic and silts, specially selected destructive microorganisms or formed in the trophic chain of hydrobiocenosis in conditions specially created for them in appropriate structures multiply intensively, consuming organic compounds and other substances from the water, which we consider as pollution. Biomass of hydrobionts, which grows during water purification, is separated in the so-called secondary separators 8, from where it is fed either to methane tanks/or to sludge fields 2.

Tertiary water purification consists mainly in an attempt to decontaminate the water - to destroy the potentially epidemically dangerous organisms and germs (causing agents

of diseases of the alimentary canal - cholera, dysentery, hepatitis, etc.). For this, chlorination is used mainly, sometimes – irradiation with ultraviolet light, even less often – ozonation. In the case of treatment of sewage treated with chlorine 9, they are kept for 20–30 min in contact tanks 10, after which they are discharged into open reservoirs. It has been experimentally proven that such water treatment, which contains significant amounts (tens of milligrams per liter) of organic substances (and this includes all without exception, even the most accuratly treated wastewater and the vast majority of surface natural waters), leads to the formation of a wide variety of chlorinated organic substances - from very harmful chloroform to hypertoxic dioxins, among which are very active and deadly mutagens. Therefore, some scientists consider the chlorination of waste water to be absolutely unacceptable, even a criminal act. For complete, reliable and safe water purification, various schemes are being developed around the world, the most typical of which include the processes of treatment with flocculants and coagulants 11, maintenance 12, filtering through sand 13 and, finally, through activated carbon 14. Precipitates formed as a result of coagulation and retention, thickened in centrifuges, filter presses or drum vacuum filters 15 and stored in beams, ravines or landfills.

Biofilters do not require special costs for aeration. However, it is believed that the biofilter cannot function normally without recirculation of the liquid being purified, because the bulk of the water passes through the biofilter very quickly, and in such a short period of time all the dirt does not have time to settle on the biofilm that is on the nozzle. However, recirculation has its drawbacks, associated not only with significant consumption of electricity for water circulation, but also with an increase in the volume of the radiators, an increase in the load on the biofilter for pollution, tendency to clogging of the load, and most importantly - with the equalization of the qualitative composition of the biocenoses of the biofilm by the entire height of the biofilter. It is worth noting that the biofilm on sand grains plays perhaps the most important role in the purification of drinking water from dissolved organic compounds during its passage through the sand layer, especially in and so-called slow filters [5].

A relatively new type of treatment plant, which is gaining increasing popularity in the USA, Great Britain, the Netherlands and other countries, can be considered a peculiar type of biofilter, these are wetlands. Swamp or bioplato (Fig. 2) is an engineering structure in the ground, a “lying biofilter” with a gravel load 2, placed with a small thickness (up to 1 m) on reliable waterproofing with synthetic films:

Wastewater 4, after careful mechanical cleaning, is distributed across the width of the swamp by a perforated pipe 3 and very slowly seeps through the vegetation over a long period of time (1–3 days) and loading film 2, on which, in addition, aquatic plants 5 grow densely - rye, comfrey, water pepper, sardines, etc., which contribute to the aeration of the water being purified, remove biogenic elements from it, in particular phosphorus, potassium, nitrogen, as well as heavy metals, and thanks to their intelligence these root systems increase the surface of the biofilm.

Naturally purified water is collected by a perforated pipe 6 and discharged into the nearest stream. Such a treatment plant does not require any energy costs for aeration, water movement, it is easy to maintain, ecologically flawless and should occupy a suitable place in the system wastewater treatment in Ukraine.

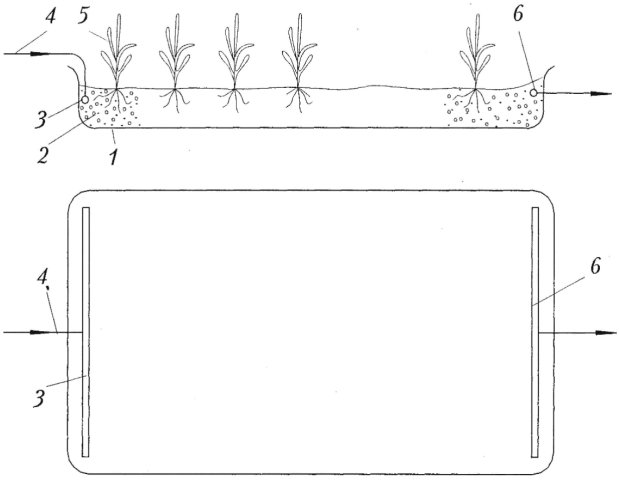

Fig. 2. – Bioplato (Swamps) 1 – waterproofing; 2 – game load; 3 – distribution pipe; 4 – waste water; 5 – aquatic plants; 6 – pipe for collecting purified water

The biofilm is the basis of the functioning of another type of treatment facilities, united under the general name "rotating biocontactors". These are metal or plastic discs, drums made of various synthetic materials, in the form of sheets of slate, fiber cords glued together at different angles, half-immersed in waste water. "eyes" that are intensively overgrown with a biofilm. These discs or drums are attached to a shaft that rotates slowly (1–4 revolutions per minute), and the biofilm that grows on the developed surface of the biocontactors is constantly immersed in the sewage air, stirring and sorbing and adsorbing dissolved and suspended organic substances, then it rises into the air, where it is well aerated and oxidizes (decomposes, mineralizes) the specified pollution. Part of the biomass is broken down by water, suspended in it, and also takes part in cleaning. Surplus biomass is carried out with purified water into the secondary separator, where it settles.

Biofilm has a number of indisputable advantages. It is very resistant to any changes in the composition and quantity of wastewater, is not afraid of volley discharges, withstands the short-term negative effect of toxic substances, quickly restores its cleaning functions after removal from drilling factors.

Active sludge is an autoflocculated biomass of microorganisms, bacteria, actinomycetes, fungi, and protozoa, which is dominated by capsule, gram-negative, stick-shaped, monotrichial bacteria the first is Zoogloea ramigera, and the most common are bacteria of the genus Pseudomonas. In addition, sludge is inhabited by representatives of the genera Bacillus, Arthrobacter, Corynebacterium, Micrococcus, Nocardia, Sarcina, Mycobacterium and many others, as well as Actinomyces, fungi of the genera Mucor, Rhizopus, Aspergillus, Penicillium, Fusarium, Trichoderma.

The most common protozoa in activated sludge are flagellates (Mastigophora), sarcodina (Sarcodina), ciliata (Ciliata), suckers (Suctoria) and infusoria (Infusoria).

The composition of active sludge varies significantly depending on the nature of wastewater, sludge loading, aeration, and other technological parameters. Since the composition of wastewater is constantly changing, the composition of sludge is constantly changing, even in a certain place of the same air tank. In the aerotank-extruder, which works stably and cleans the water well, the active silts that are contained in it at the beginning and at the end are very different, and it is hard to believe that these biocenoses are the same structures. After all, there is nothing surprising in this, since the water after cleaning with activated sludge is also a little similar to the wastewater that is used for cleaning.

The biofilm of a biofilter that works normally is even thinner than active sludge. In addition to all those microorganisms that inhabit active sludge, algae, various worms and even fly larvae (Psychodidae, Chizonomidae) get into it [6].

An inhabited sludge, which is contained in the menthins, is derived from the bactaries, which are given three in the field of physiological groups: hydrolytic, acid-forming and intrinsically methanogenic.

Hydrolytic bacteria are able to split complex polymer molecules of proteins, carbohydrates, nucleic acids, lipids into appropriate monomers. This includes bacteria of the genera Clostridium, Peptococcus, Bacteroides, Butyrivibrio, Eubacterium, Bifidobacteria, Bacillus, etc.

Acid-forming (heteroacetogenic) bacteria transform fatty acids, some alcohols, and aromatic compounds into acetic acid. They include bacteria of the genera Acetobacterium, Synthrobacter, Synthrophomonas, etc.

Methanogenic bacteria transform acetic acid into methane and carbon dioxide (IV), synthesize methane from hydrogen and carbon dioxide (IV). These are bacteria of the genera Methanobacterium, Methanospirillum, Methanococcus, Methanosarcina, Methanothrix, Methanogenium, Methanobrevibacter and others (a total of 13 genera are currently known).

Dense sludge that settles well has a sludge index of about 60 ml/g, less dense sludge is 80–90 ml/g, and a sludge index higher than 300 ml/g indicates a violation of the normal operation of the treatment plant.

The rate of sedimentation of activated sludge depends on its density, which is determined by the composition of the microflora. Small microorganisms form dense activated sludge that settles quickly, and long filamentous and branched organisms create loose sludge that settles poorly [6].

Microbiocenoses of biological treatment plants are formed by autoselection, in which the composition of treated wastewater and the mechanical and physico-chemical parameters of treatment.

Higher plants, algae, and microorganisms are also used to clean wastewater in bioplatos, which carry out the process of filtration, sedimentation, and adsorption. In order to achieve the best cleaning result, a bio-plate is offered for the cleaning of reservoirs, which includes phytoblocks and microbial elements made in a single body. The phytoblock consists of plants embedded in a highly porous filler with immobilized bacteria [7].

Combined type of bioplat with a phytoblock for the use of a microbial element for water purification. The combined type of bioplato with phytoblock for the use of a

microbial element for water purification contains a combined ecological floating layer and a microbial element, and the combined ecological the floating layer contains the surface block of aquatic plants, the middle block of aquatic animals, and the lower block of the artificial environment from top to bottom (Fig. 3).

In the figure (Fig. 3), the block of aquatic plants consists of higher aquatic plants (1) and conductive material (2) for fixing aquatic plants; the installation for aquatic animals is used for aquaculture of molluscs of predatory aquatic animals (3); in the artificial environment block, the artificial environment made of nanoparticles of activated carbon (4) is enriched with a large number of microbes to form a highly efficient biomembrane cleaning zone, bacteria of the Nitrosomonas group and Nitrospira; combined ecological device with a floating bed for the use of a microbial element for water purification is characterized by the fact that the conductive material (2) is discharged from the device through a conductive wire (5) for grinding of the air cathode electrode of the microbial layer. The combined type of bioplato with phytoblock to use the microbial element to purify water can significantly improve water quality and can process energy, and is applicable to a large scale new, modeled and mechanical works.

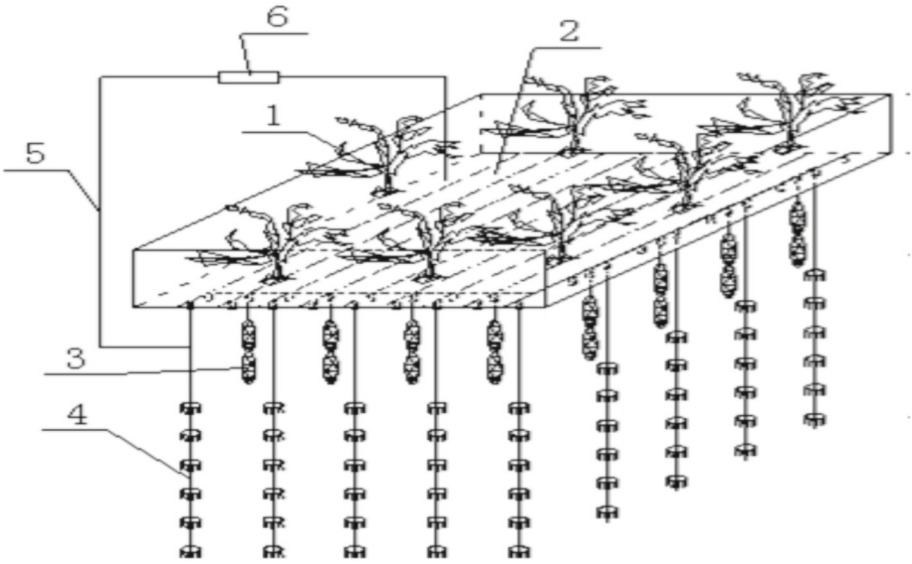

Fig. 3. – Phytoblock combined bioplat

Nitrogen compounds (ammonium and nitrites) enter the phytoblock together with wastewater. Nitrifying bacteria of the Nitrosomonas and Nitrospira groups transform toxic nitrogen compounds (ammonium and nitrites) into safer nitrates in the course of bacterial metabolism. Phytoblock plants assimilate nitrification nitrates formed during the reaction, the concentration of organic substances decreases at the expense of work.

As already mentioned, wastewater is a mixture of domestic and industrial wastewater. In the process of treating these waters at treatment facilities, a significant part of undissolved pollution falls out in remote facilities, forming sediment. This sediment has

high humidity. Depending on the type of buildings in which this sediment is formed and its composition, the humidity varies between 90–99.5%. The sediment consists of organic and mineral substances. To estimate the ratio of these substances, the concept of salinity is used, which characterizes the amount of mineral substances in the sediment. It is expressed in percentages. The salinity of urban sewage sludge is 25–35%. Organic substances are called ashless. 65–75% of it is contained in urban sewage sludge [8].

Wastewater contains thousands of different organic compounds. It is impossible to determine each of them separately, therefore, group analyzes are carried out for both dominant and minor components of flows. Domestic wastewater usually has a pH of 7.2–7.6, i.e., a weakly alkaline reaction. Some types of industrial wastewater can have a strongly acidic or strongly alkaline reaction. For the possibility of biological purification of such waters, their preliminary neutralization is necessary [9].

Chemical analyzes are carried out quite quickly, but they do not always allow to measure what is necessary. Chemical oxygen consumption (COC) is characterized by the amount of oxygen (or oxidizing agent in terms of oxygen) in mg/dm3, necessary for the complete oxidation of inorganic substances contained in the sample. The presence of heavy oxygen substances in wastewater inhibits the speed of the process, which is recently taken into account in calculations.

Oxidability by potassium permanganate conditionally characterizes the content of easily oxidizable organic and mineral substances.

The method is based on the oxidation of substances present in a water sample by potassium permanganate in a sulfuric acid medium during boiling. This method can also serve as a conditional quantitative characteristic of the content of organic substances in the sample. It is necessary to keep in mind that permanganate in reaction conditions oxidizes not only organic but also inorganic compounds, such as iron (II) ions, sulfides, nitrites, chlorides.

Oxidability by potassium permanganate indicates the presence of substances and their concentration during treatment with strong oxidants. The value of the KSC parameter is most evident when determining the propensity of wastewater pollution to biochemical oxidation by estimating the ratio BOC/COC = 0.7–0.8, and for biochemicaly cleaned - 0.4–0.1. If the BOC of the treated water does not reach the required value (15–20 g/m3), but the BOC/COC ratio is less than 0.4, then the efficiency of the work of the biochemical treatment plant cannot be demonstrated, but you need to achieve the desired effect of the post-cleaning work and decontamination [10].

Bichromate oxidation is always much higher than permanganate and more objectively characterizes the degree of water pollution by organic impurities. This chemical oxidation, which is carried out under harsher conditions, is compared to permanganate oxidation with the use of a stronger oxidizing agent - potassium bichromate. It is often used as a measure of the content of organic substances in water. Oxidation with potassium bichromate is more complete, even some inorganic substances are oxidized (N02-, S2-, S2O3-, Fe2 +, SO32-). Ammonia and ammonium ions, which are formed during the oxidation of organic nitrogen, are not oxidized. Some nitrogen-containing substances, such as trimethylamine, which is usually present in fish factory effluents, and cyclic nitrogen compounds, such as pyridine, are also not oxidized in COC analysis. In general, the analysis of COC as a whole allows to estimate the content of organic matter in

urban sewage, possibly in the range of 90–95% of the theoretical oxygen consumption, necessary for complete oxidation of all present organic substances [10, 11].

Microorganisms present in water in the process of life use dissolved oxygen to oxidize organic and inorganic compounds. The amount of oxygen consumed in a certain period of time in the process of biochemical oxidation of substances contained in the analyzed water under anaerobic conditions is called biochemical oxygen consumption. This indicator is a somewhat conventional measure of water pollution by organic compounds that are quite easily subjected to biochemical degradation. Biochemical oxidation of compounds of different classes takes place at different rates - there are compounds that are easily oxidized (alcohols, phenols), at the same time, surface-active substances, hydroquinone, etc. in. Thus, complete oxidation of all organic substances takes a considerable amount of time. It is believed that 99% of organic compounds are oxidized within 20 days of the process. Such a long analysis is, of course, very inconvenient, therefore the value of BOC5 (biochemical oxygen consumption for 5 days of oxidation) is more often used. Although the BOC determination methods are standardized for natural and wastewater, all of them have been implemented for a long time and characterize the content of organic substances very tentatively [8].

BOC analysis was developed in England at the end of the 19th century. Its idea is that microorganisms contained in water consume oxygen, and the required amount of oxygen is a measure of pollution. Since oxygen consumption increases with increasing temperature and duration of the reaction, it was initially accepted to conduct analyzes at 18 °C (65 °F) for 5 days. Now the standard analysis temperature is 20 °C. BOC characterizes the content of biodegradable substances in water, that is, those that can be oxidized biochemically. This quality indicator is used in the analysis of wastewater to determine the possibility of its biochemical treatment: the content of biodegradable substances in wastewater must be at least 70% of the total of organic pollution.

The oxidation of various organic substances requires a different amount of oxygen per 1 g of the substance, and this means that BOC gives only an approximate estimate of the mass of the oxidized substance.

Total oxygen consumption (TOC) can be determined by carrying out oxidation at high temperature in the presence of a suitable catalyst. Under the specified conditions, it is possible to oxidize some organic substances that are not oxidized during the usual COC analysis. In addition, in this case, ammonium is also oxidized. Thus, the TOC indicator is usually a little higher than the COC indicator.

Total organic carbon(TOC) is an important indicator of the analytical series. In this analysis, organic substances are oxidized to CO2 when heated. The difference in the CO2 concentration before and after oxidation is used to calculate the CO2. The TOC parameter is not directly related to other characteristics of an organic substance: it shows the number of carbon atoms, but not the degree of their oxidation and, therefore, nothing tells how much oxygen should be consumed for oxidation. The values of TOC, BOC and BOC20 for some substances are presented in the Table 1.

The main condition for purification in biological ponds is that the parameters of wastewater should not exceed 200 mg/l of total BOC - the same for ponds with the use of natural aeration, but with artificial aeration above 500 mg/l is allowed. Taking into account the pre-treatment system, the wastewater considered in the work can be

Table 1. Carbon content, TOC, BOC and BOC20 for some organic substances [12]

Substance	Formula	Carbon, %	TOC[1]	BOC	BOC_{20}
			g O_2/g substance		
1	2	3	4	5	6
Methane	CH_4	75	4	–	–
Ethan	C_2H_6	80	3,74	–	–
Hexane	C_6H_{14}	84	3,54	–	–
Ethylene	C_2H_4	86	3,43	–	–
Acetylene	C_2H_2	92	3,07	–	–
Trichloromethane	$CHCl_3$	10	0,36	–	–
Tetrachloromethane	CCl_4	8	0,21	–	–
Ethyl ether	$C_4H_{10}O$	65	2,59	–	–
Acetone	C_3H_6O	62	2,21	0,54	–
Formic acid	CH_2O_2	26	0,35	0,09	0,25
Acetic acid	$C_2H_4O_2$	40	1,07	0,70	0,90
Propionic acid	$C_3H_6O_2$	49	1,52	1,30	1,40
Butyric acid	$C_4H_8O_2$	55	1,82	1,15	1,45
Valerian acid	$C_5H_{10}O_2$	59	2,04	1,40	1,90
Palmitic acid	$C_{16}H_{32}O_2$	75	2,88	1,68	1,84
Stearic acid	$C_{18}H_{36}O_2$	76	2,93	1,13	1,59
Oxalic acid	$C_2H_2O_4$	27	0,18	0,10	0,12
Succinic acid	$C_4H_6O_4$	41	0,95	0,64	0,84
Malic acid	$C_4H_4O_4$	41	0,83	–	–
Lactic acid	$C_3H_6O_3$	40	1,07	0,54	0,96
Tartaric acid	$C_4H_6O_6$	31	0,53	0,35	0,46
Citric acid	$C_6H_8O_7$	37	0,75	0,46	0,67
Glycine	$C_2H_5O_2N$	31	0,96[2]	0,55	–
Alanin	$C_3H_7O_2N$	40	1,35[2]	0,94	–
Valin	$C_5H_{11}O_2N$	51	1,84[2]	–	–
Glutamic acid	$C_5H_9O_4N$	41	1,14[2]	–	–
Tyrosine	$C_9H_{11}O_3N$	60	1,81[2]	–	–
Methanol	CH_4O	37	1,50	0,96	1,26
Ethanol	C_2H_6O	52	2,09	1,35	1,80
Isopropanol	C_3H_8O	60	2,40	1,42	–
Amyl alcohol	$C_5H_{12}O$	68	2,73	1,27	1,73

directed to further treatment. Biological ponds should be arranged on non-filtering or weakly filtering soils. Anti-filtration measures should be implemented in soils that are unfavorable for filtration. The efficiency of cleaning with suspended liquids on structures of this type is on average from 70% to 80%, respectively. Organic substances provide very good conditions for the decomposition of organic substances, as evidenced by the concentration of dissolved oxygen in wastewater, the BOC5 removal effect of 95% and 87% respectively, COC −89% and 91%, respectively. The experience of different countries of the world shows that the removal efficiency of BOC5 and COC in vertical bio-plats ranges from 87% to 96% and from 82% to 87%, respectively [See for example: 14–19].

Phytotechnology can also be used to clean surface runoff from agricultural lands, built-up areas and streets, collector drains, quarries, etc. industrial wastewater, wastewater from animal husbandry complexes, filtrate from landfills of solid household waste, during the treatment of industrial wastewater and its mixtures with household wastewater with water, phytotechnology is used as a further purification. Phytotechnology is also used for the intensification of the work of sludge fields of city sewage treatment plants. Cultivation of the most water-rich vegetation on the mud maps due to transpiration contributes to intensive drying of the mud sediment, acceleration of the turnover of the mud maps, and also mud purification on the basis of biological self-cleaning processes.

The biobotanical method of wastewater purification is based on the use of higher aquatic plants in the purification process. When cleaning wastewater, such types of higher aquatic plants are most often used, such as reed, lake reed, narrow-leaved and broad-leaved cattail, combed and curly reed, spirodella multibark nna, elodea, water hyacinth (eichhornia), yellow cassia, susak, common arrowroot, amphibious buckwheat, Rizuha morska, urut, hara, iris, etc. [19].

3 Conclusions

Taking into account what is stated in the article, the following conclusions can be made:

- wastewater is a mixture of domestic and industrial wastewater, therefore it contains thousands of different organic and inorganic compounds. It is impossible to determine each of them separately, therefore, group analyzes are carried out for both dominant and minor components of flows;
- the content of total organic carbon in different types of water characterizes pollution by harmful organic compounds. This parameter is one of the key parameters for quality control of natural, potable, water supply, technological, and sewage water;
- wastewater contains impurities of mineral and organic origin. Mineral pollution in the form of undissolved substances makes up 5%, suspensions −5%, colloids −2% and soluble substances −30%. For organic substances, these percentages are as follows: insoluble −15%, suspensions −15%, colloids −8% and soluble −20%;
- when water containing organic substances enters the reservoir, oxidizability increases, BOC (biological oxygen consumption), the concentration of dissolved oxygen decreases;
- wastewater is treated at mechanical and biochemical (biological) treatment facilities;

– waste water treatment technology is promising, which is developing in the direction of intensification of biological treatment processes, sequential implementation of biological treatment processes, until the main purpose of which is the reuse of treated wastewater.

Treatment plants based on phytotechnology in different countries have different names: Constructed wetland, Reed bed, Artificial wetland, bioplato, bioengineering structures, biological fields, etc. The use of phytotechnology is most suitable for the treatment of domestic wastewater in small settlements, separately located houses, schools, sanatoriums, camping sites in other places of rest of the population.

Therefore, the significant ecological and energy-saving potential and advantages of phytotechnology for sustainable development become obvious. Phytotechnology is a method of wastewater treatment based on the use of natural self-purification processes of water bodies, using higher aquatic vegetation, aquatic microflora and microorganisms that are widespread in the countries of Western Europe (Great Britain, Denmark, Switzerland, Finland, Spain, France, Germany, Norway, Austria, Estonia), as well as in the countries of North America, such as the USA and Canada, as well as in New Zealand25]. We hope that Ukraine will not remain aloof from the processes of implementation and use of innovative ecological methods for economical use of nature, restoration of the environment and sustainable development.

References

1. Teljura, N.O., Sorokina, K.B., Lomakina, O.S., Lukashevych, D.S.: Kompleksne obgruntuvannja ekologhichnykh innovacijnykh rishenj shhodo zmenshennja vyrobnychogho vplyvu na dovkillja // Komunaljne ghospodarstvo mist. Serija : Tekhnichni nauky ta arkhitektura. Kharkivsjkyj nacionaljnyj universytet misjkogho ghospodarstva imeni O.M.Beketova. 173. s. 23–30 (2022). https://doi.org/10.33042/2522-1809-2022-6-173-23-30
2. Ghyryna, N.P., Shljanina, A.V., Kovaljchuk, I.S.: Tekhnika laboratornykh robit: navchaljnyj posibnyk/2-e vydannja. Kyĭv: Pravo, 304 s (2019)
3. ASTIM D 4779–93. Standard Test Method for Total, Organic, and Inorganic Carbon in High Purity Water by Ultraviolet (UV) or Persulfate Oxidation, or Both, and Infared Detection. https://www.astm.org/d4779-93.html. Accessed 14 Jun 2023
4. Fizyko-khimichni osnovy tekhnologhiĭ ochyshhennja stichnykh vod: pidruchnyk/A. K. Zapoljsjkyj ta in.; Kyĭv: Libra, 552 s (2000)
5. Stoljbergh F.V. Ekologhyja ghoroda: uchebnyk. Kyĭv: Lybra, 464 s (2000)
6. Mykrobyologhyja ochystky vodы: uchebnyk. Kyev: Naukova dumka, 268 s (1978)
7. Eikelboom, D.H.: Process Control of Activated Sludge Plants by Microscopic Investigation, p. 156. IWA Publishing, London (2000)
8. Combined ecological floating bed device for using microbial fuel cell to purify lake water: pat. 102531181 Southeast University CN: МПК C02F 3/32 (2006.01); H01M 8/16 (2006). https://patentscope.wipo.int/search/ru/detail.jsf?docId=CN85170367&_cid=P12-K7LTK8-09286-1
9. Iurchenko, V., Smyrnov, O., Yesin, M., Levashova, Y.: Effect of the redox-potential on sludge liquor phosphatation in biological phoaphorus removal technologies. Water Ecol. (24), 26–37 (2019). https://doi.org/10.23968/2305-3488.2019.24.3.26-37. last accessed 2023/03/06
10. Dolyna, L.F.: Ochystka stochnыkh vod ot byoghennыkh эlementov: uchebnyk. Dnepropetrovsk: Kontynent, 198 s (2011)

11. EPA/600/R-09/012:2009. Nutrient control design manual. State of technology review report. Environmental protection agency. Cincinnati, Ohio. URL: https://www.epa.gov/sites/default/files/2019-02/documents/nutrient-control-design-manual-state-tech.pdf. Accessed 06 Mar 2023
12. Snizhko S.I.: Ocinka ta proghnozuvannja jakosti pryrodnykh vod: pidruchnyk. Kyĭv: Nika Centr, 264 s (2001)
13. Stoljbergh, V.F., Ladьızhenskyj, V.N., Spyryn, A.Y.: Byoplato – эffektyvnaja malozatratnaja эkotekhnologhyja ochystky stochnьıkh vod. Ekologhija dovkillja ta bezpeka zhyttjedijaljnosti. # 3. S. 32–34 (2003)
14. Kowalik, P., Obarska-Pempkowiak, H.: Polish experience, with sewage purification in constructed wetlands. Constructed Wetlands for Wastewater Treatment in Europe. Leiden: Backhuys Publishers, pp. 217–225 (1998)
15. Öövel, M., Tooming, A., Mauring, T., Mander, Ü.: Schoolhouse wastewater purification in a LWA-filled hybrid constructed wetland in Estonia. Ecol. Eng. (29). 17–26 (2007)
16. Gajewska, M., Obarska-Pempkowiak, H.: 20 Years of experience of hybrid constructed wetlands exploitation in Poland. Rocz. Ochr. Sr. (11), 875–888 (2009)
17. Ye, F., Li, Y.: Enhancement of nitrogen removal in towery hybrid constructed wetland to treat domestic wastewater for small rural communities. Ecol. Eng. 35, 1043–1050 (2009)
18. Mucha, Z., Wójcik, W., Jó´zwiakowski, K., Gajewska, M.: Long-term operation of Kickuth-type constructed wetland applied to municipal wastewater treatment in temperate climate. Environ. Technol. (39), 1133–1143 (2018)
19. Pryrodni i shtuchni bioplato. Fundamentaljni ta praktychni aspekty: monoghrafija/V. D. Romanenko ta in. Kyĭv: Nauk. dumka, 110 s (2012)

Labor Legislation in the Era of Artificial Intelligence

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Abstract. The outlined research encompasses an overview and analysis of various aspects of labor relations that have undergone substantial changes due to integration of artificial intelligence into work processes. Authors refer to international institutional acts, experiences from foreign countries, analytical, and statistical reports, enabling a comprehensive understanding of the current state of legal regulation on labor in the context of adopting digital technologies, particularly artificial intelligence. The study considers specific aspects of labor relations affected by the evolution of artificial intelligence: employment, organization and supervision of work processes, occupational safety and health, professional training. Authors come to the conclusion about the necessity of developing an ethical code of conduct during implementation of AI technologies in labor processes. It is proposed to introduce into labor legislation the obligation of the employer to involve labour collective in adopting decisions regarding AI implementation in workplaces and developing safety standards on AI technologies Emphasis is placed on the necessity of prohibiting decisions that produce legal effects for the life and work of workers and are based solely on AI conclusions. Furthermore, the importance of developing and implementing a state support program for businesses that educate their employees in digital skills at their own expense, by providing specific financial or tax benefits, is highlighted.

Keywords: artificial intelligence · impact of artificial intelligence on labor relations · acquisition of digital skills by employees · impact of artificial intelligence on occupational safety · work organization using AI

1 Introduction

Implementation of new digital technologies alters economic structure, accelerates the development of companies and their competitiveness, leads to the creation of new highly productive jobs, and contributes to the emergence of new professions. Digital technologies transform the nature and content of work, enhance its intellectual aspect, and create demand for workers with digital skills and creative thinking. Research conducted by

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the consulting company McKinsey indicates that generative AI, such as ChatGPT, could annually add $2.6–4.4 trillion to global GDP. For comparison: throughout the year 2022, global economy grew by $3.6 trillion [1].

Thus, production digitization logically entails changes in organization, management, and control of work processes. The labor market is changing. Artificial intelligence poses new challenges to labor law science. There is an urgent need to transform labor legislation as the primary regulatory factor for labor. Within this research, we will examine those areas of labor relations requiring the most significant legal changes due to the implementation of artificial intelligence technologies. In our view, these include: 1. Employment relations; 2. Organization of work and control over labor processes; 3. Occupational safety and health; 4. Training staff in digital skills. The study of these issues enabled us to develop recommendations for further transformation of Ukrainian labor legislation while observing international labor standards and the needs of digital society.

The impact of artificial intelligence on labor market and employment procedure.

Implementation of information technologies, including artificial intelligence technologies, is an integral part of the development of socio-economic, scientific-technical, defense, legal, and other activities in areas of state significance. The OECD defines an AI system as follows: "an AI system is a machine-based system that is capable of influencing the environment by producing an output (predictions, recommendations, or decisions) for a given set of objectives. It uses machine and/or human-based data and inputs to (i) perceive real and/or virtual environments; (ii) abstract these perceptions into models through analysis in an automated manner (e.g., with machine learning), or manually; and (iii) use model inference to formulate options for outcomes. AI systems are designed to operate with varying levels of autonomy" [2]. Artificial intelligence will likely alter the working environment for many people, transforming the content and appearance of their workplaces, as well as how workers interact with each other and with machines. That's why, it is crucial to understand what digital technologies, artificial intelligence, and robotization are for a modern human and how to cope with them in the work process.

In this context, indicative are the results of a survey (commissioned by ZN.UA) conducted from June 23rd to 28th, 2023, using a face-to-face method in 22 regions of Ukraine and in Kyiv. A total of 2018 respondents aged 18 and above were interviewed. Nearly 34% of surveyed Ukrainians responded negatively to the question "Do you know what artificial intelligence is?". Only 24% are confident they have a good understanding of what it entails, while another 42% have a rough idea about this technology. In response to the question "Do you use ChatGPT or another AI-powered chatbot?" 64% of respondents replied that they do not use such chatbots, 8.7% do not know what it is at all, while the rest primarily experiment with the technology: 10.2% of those surveyed use them for familiarization purposes, and 12% for personal use. Only 5.6% use AI-powered chatbots for educational purposes, and 8.6% for work-related tasks. Certainly, most of these individuals fall within the age range of 18 to 39 [3].

General trends in implementing artificial intelligence at the company level in the European Union and the United States are similar: 8% of all enterprises with more than 10 employees used AI technologies in 2021. At the same time, figures vary slightly in the private sector. For example, the number of Americans using voice assistants (Siri, Cortana, or Alexa) increased from 47 to 72% between 2017 and 2019. Around 80%

of all U.S. companies employing AI did so to improve their product or service quality, 65% aimed at updating their existing procedures, and 54% focused on automating their current processes [4].

The World Economic Forum's Future of Work Report is based on data from a survey of the world's largest employers. Researchers have studied employers' expectations for the next five years. The survey involved 803 companies, collectively employing over 11 million workers, covering 27 sectors and 45 economies from all global regions. Technology implementation will remain a key factor in business transformation over the next five years. Over 85% of surveyed organizations consider the broader adoption of new and advanced technologies and the expansion of digital access as trends likely to drive transformation within their organizations. As part of technology implementation, big data, cloud computing, and artificial intelligence have a high probability of adoption. More than 75% of companies plan to implement these technologies within the next five years. The impact of most technologies on jobs in the next five years is expected to be positive. All technologies, excluding two types of robots, will contribute to creation of net jobs (Fig. 1) [5].

Employers expect a structural job outflow of 23% in the labor market within the next five years. This can be interpreted as a general measure of disruption, representing a mix of new and reduced job opportunities. Respondents to this year's *Future of Jobs* survey expect above-average outflow rates in supply, transportation, media, entertainment, and sports sectors, and lower than average in production, as well as in retail and wholesale trade of consumer goods. Out of the 673 million jobs reflected in this report's dataset, respondents anticipate a structural increase of 69 million jobs and a reduction of 83 million jobs. This corresponds to a net loss of 14 million jobs, or 2% of the current employment (Fig. 2).

However, artificial intelligence remains a lesser threat to job prospects in contrast to other macroeconomic factors such as slowing economic growth, supply shortages, and inflation.

Over the past five years, we have observed a significant amount of scientific and statistical research on the impact of AI on the labor market. For instance, Acemoglu and Restrepo [6] provide a theoretical basis for understanding the influence of new technologies on the labor market. They break down the impact of these new technologies on labor into three broad effects: displacement effect, productivity effect, and augmentation effect (new technologies may serve as a platform for creating new tasks in many service sectors where human labor has an advantage over machines, increasing the demand for workforce). Also, in literature, we see a division of researchers' viewpoints regarding consequences of implementing artificial intelligence in the labor market into two major categories: a doomsayer's perspective and an optimist's perspective. The former believe that AI labor replacement will harm employment: it will result in the disappearance of a lot of professions, reduction of job positions, and increase in unemployment. The optimists argue that AI productivity and the augmentation effect will be more than sufficient to offset the displacement effect. Some researchers claim that artificial intelligence automation is unlikely to have a negative impact on the job market due to its significant positive side effects (the augmentation effect) that could counteract the negative direct displacement effects in the labor market. They believe that automation will likely

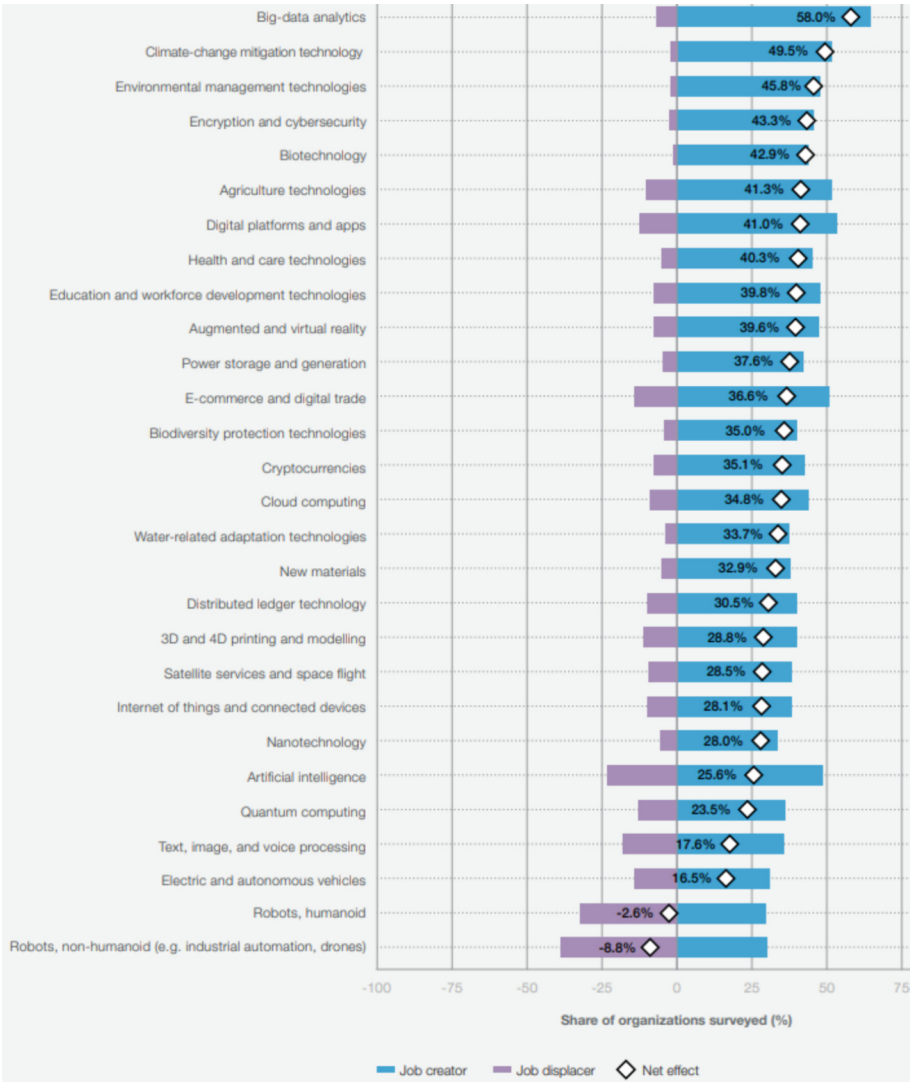

Fig. 1. Expected impact of technology adoption on jobs, 2023–2027

change, rather than destroy, jobs [7]. We have already discussed the impact of artificial intelligence and robotization on the labor market and labor relations in previous studies. Therefore, we deem it appropriate to focus on the legal mechanisms for involving artificial intelligence in the area of employment and employment provision in this paper.

As of today, the use of algorithms and artificial intelligence in staff selection has become quite widespread. Major employers are already employing certain forms of artificial intelligence in making hiring decisions. Artificial intelligence is beneficial in various areas related to diverse hiring practices, including anonymizing resumes and interviewees, conducting structured interviews, and employing neuroscience games to

Fig. 2. The ratio of created to reduced job positions during the period of 2023–2027.

identify traits, skills, and behavior. Some companies conduct video interviews with candidates and use artificial intelligence to analyze factors such as facial expressions, eye contact and word choice that are unique to candidates. A survey conducted by the Society for Human Resource Management in the US in February 2022 revealed that 79% of employers use artificial intelligence and/or automation for hiring and recruiting staff [8]. At the same time, AI is primarily engaged in communication with candidates and resume screening (Fig. 3). The priority for using AI is to save time and enhance the quality of the final result in candidate selection (Fig. 4). Automated tools can be used at various stages of the recruitment procedure, including skills assessment or personality evaluation, and even for monitoring body language during interviews or reviewing social media profiles. Chatbots for recruiters can provide real-time responses to candidates' questions, generate proposals, ensure swift 24/7 feedback, and propose next steps for employment. They can provide links to promising job descriptions, specify working hours and the company's location, and schedule interviews.

While technologies can make processes better and faster, employers should be mindful of some problematic aspects when using AI. Indeed, imperfect AI algorithms can lead to negative outcomes and human rights violations in employment. Global practice already has sufficient experience of failures resulting from errors in candidate selection algorithms. There have been numerous court decisions regarding recognition of discrimination, disclosure of personal data, and interference in personal life during employment procedure. The main problems of using AI in the recruitment and employment process are:

– potential bias. Artificial intelligence systems are only as good as the data they provide, and incomplete or inaccurate data can lead to biased results. This may result in the exclusion of qualified candidates based on factors such as race, gender, or age.
– potential breach of confidentiality. Artificial intelligence-based hiring systems may require access to personal data, such as social media profiles or criminal records. This could result in potential violations of privacy laws or other regulatory acts.

On the 19th of September, 2018, the European Economic and Social Committee (EESC), an advisory body assisting the European Parliament, the European Council, and the European Commission, published a conclusion titled *Artificial intelligence: anticipating its impact on jobs to ensure a fair transition.* In this conclusion, it calls for the ethical use of AI within economy. The EESC examines artificial intelligence systems

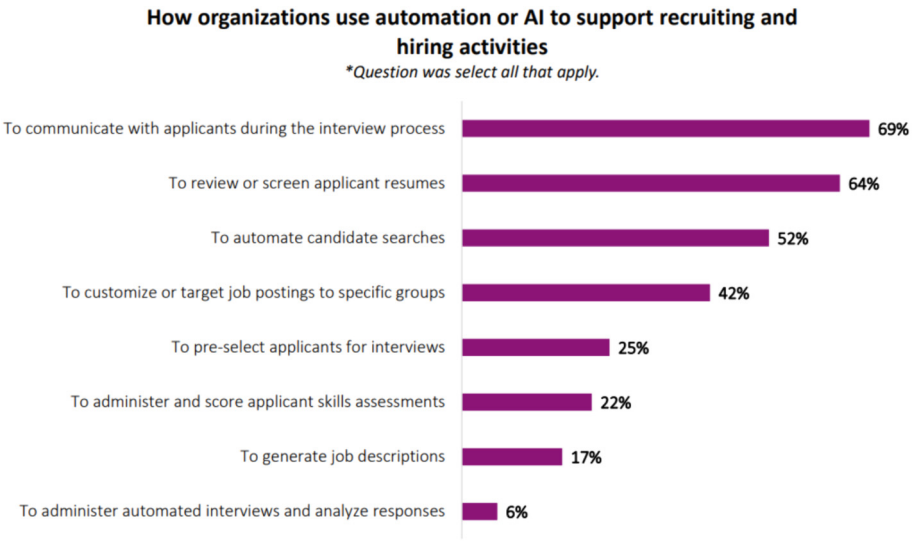

Fig. 3. How organizations use AI in employee recruitment.

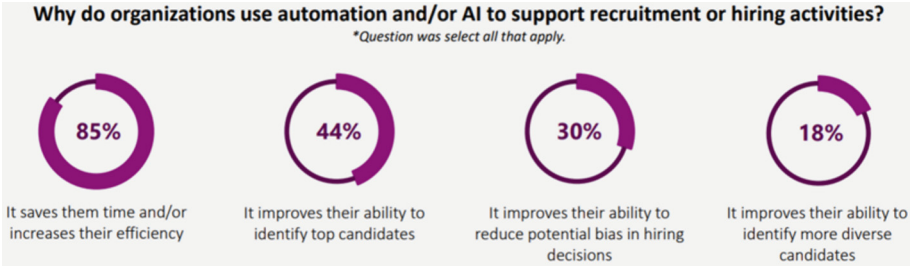

Fig. 4. Reasons for using AI in staff recruitment

that assess employee performance and facilitate the recruitment process. It notes that the use of such systems should "guarantee the rights and freedoms regarding the processing of workers' data while observing the principles of non-discrimination". The EESC also addresses the issue of "algorithm bias": the code indeed reflects the values of a person who has created and developed it. Therefore, the dataset might reveal bias.

Certain countries across the world already have some experience in addressing these issues at the legislative level. For example, Germany's Works Constitution Act (BetrVG) grants works councils the right to participate in establishing guiding principles for recruitment with the support of AI or if AI tools are used for automation of recruitment procedure (Section 95 (2a) BetrVG).

USA. Two states – Maryland and Illinois – have adopted laws regulating the use of artificial intelligence. The Illinois state law requires employers to inform applicants about the use of artificial intelligence and secure the applicant's consent. Legislation proposed in the third state, California, takes a page from the European Union's General

Data Protection Regulation (GDPR), imposing responsibility on suppliers of AI tools. The New York City Council has introduced legislation that came into effect on the 1st of January, 2023, aimed at regulating artificial intelligence connected with typical staff management technology. This presupposes the use of "automated decision-making tools for employment" if such tools have not undergone bias testing. Before using such a tool to assess a candidate or employee for employment decisions, the employer must first notify a person of its use, define job qualifications and characteristics the tool will use while assessment, and publish a brief summary of the bias audit on their website, along with the date of tool deployment. A candidate or employee possesses the right to request an alternative recruitment or placement procedure after being informed of the tool's use. In addition, in certain states within the US, there are laws aimed at protecting the rights and freedoms of a man and a citizen while employment [9]. Currently, the U.S. does not have federal laws concerning the use of artificial intelligence in employment decisions; however, anti-discrimination laws are enforced, namely Title VII of the Civil Rights Act (CRA), the Americans with Disabilities Act (ADA), and the Age Discrimination in Employment Act (ADEA).

In Ukraine, there is no specific legislation regulating employers' use of such employee selection methods. Therefore, the process of searching, recruiting, and employing workers should comply with common rules in this area. Article 2–1 of the Labor Code of Ukraine (LCU) envisages the following: "Any discrimination in the sphere of work is prohibited, in particular violation of the principle of equality of rights and opportunities…or other grounds not related to the nature of work or conditions of its performance". Accordingly, the violation of this right results in consideration of other articles of the Labor Code (Articles 5–1, 22) regarding guarantees for employees against unjustified refusal of employment: "Unjustified refusal of employment, meaning refusal without any grounds or based on reasons unrelated to the qualifications or professional qualities of the employee, or on other grounds not provided for by law, is prohibited". The state guarantees to able-bodied citizens permanently residing on the territory of Ukraine legal protection against unjustified refusal of employment. What is more, it is important to remember that among other principles of the development and use of artificial intelligence technologies outlined in the Concept of Artificial Intelligence Development in Ukraine, the following are specified:

- compliance of the activity and decision algorithms of artificial intelligence systems with the requirements of personal data protection legislation, as well as adherence to the constitutional right of each individual to non-interference in personal and family life in connection with personal data processing;
- ensuring transparency and responsible disclosure of information about artificial intelligence systems;
- ensuring the reliable and secure operation of artificial intelligence systems throughout their life cycle, their continuous evaluation, and management of potential risks;
- placing responsibility on organizations and persons involved in the development, deployment, or use of artificial intelligence systems for their proper functioning in accordance with the specified principles.

Conclusion: Artificial intelligence systems also pose unique challenges for protecting employees, namely related to confidentiality and discrimination, which require a careful

analysis of existing laws to determine their efficiency in this new context. Furthermore, to ensure fairness and prevent discrimination, clear guidelines on the use of artificial intelligence in hiring, career advancement, and dismissal decisions are necessary.

2 Organization and Control of Labor Processes Using AI

Artificial intelligence (AI) technologies are slowly but steadily permeating the workplace. More and more employers are using digital technologies and AI to organize work and monitor its efficiency. Within the scope of this study, we will analyze the legal bases for delegating managerial functions to these technologies and ensuring the exercise of disciplinary powers.

One of the key aspects of labor relations involves mutual rights and obligations established between an employer and an employee. For instance, the Labor Code of Ukraine specifies that employees shall work honestly and conscientiously, timely and accurately follow the orders of the owner or their authorised body, comply with labour and technological discipline, the requirements of labour protection regulations, carefully treat the property of the owner with whom the employment contract has been concluded (Article 139 of the LC). Furthermore, labor discipline at enterprises is maintained by creating necessary organizational and economic conditions for normal, highly productive work, as well as fostering a conscientious attitude towards work through persuasion methods, training, as well as incentives for conscientious work. The owner or their authorised body must properly arrange the work of employees, create conditions for productivity growth, ensure labour and production discipline, strictly comply with labour laws and labour protection rules, pay attention to the needs and demands of employees, improve their working and living conditions (Art. 141 of the LC).

Hence, labor relations encompass a certain degree of subordination that may require application of disciplinary measures to guide an employee towards correcting results or behavior by identifying problems, causes, and solutions. Disciplinary penalties can lead to social and economic consequences that ultimately might result in the termination of an employment contract. In light of this situation and considering the technological advancements in the workplace, it is not only advisable but necessary to ask the following: can employers delegate some of their authority to AI tools or services, allowing them to initiate disciplinary proceedings against employees without human intervention?

We already have sufficient experience with the misuse of AI algorithms for monitoring and controlling human labor. One well-known case is that of Amazon, where machines were granted unprecedented control over employees and the company was accused of using technology to impose unjustifiably high demands on its workers. Similar instances have been documented in European countries, prompting legislative initiatives at both the pan-European and individual government levels.

Companies can employ artificial intelligence not only to study their employees' professional contacts but also their profiles on social networks. Digital technologies based on AI enable the use of new, continuous, and less costly forms of monitoring and managing employees by collecting large amounts of real-time data about employees. These data can be collected during and outside working hours, at workplaces, as well as beyond the workplace, sometimes beyond what is strictly necessary or legal.

Employee data can be collected using mobile devices, portable or embedded monitoring devices (can be found in clothing, PPE, or even implanted within the body). These data include keystrokes, email content, visited websites, phone call numbers and content, social media information, GPS tracking for location, body movements, vital signs, stress and fatigue indicators, facial microexpressions, voice tone, and mood analysis. Companies start monitoring how much time their employees spend on breaks. Thanks to the implementation of digital technologies, employers know when their employees are distracted or behave inappropriately. Veriato, for example, has gone so far as to track every keystroke its employees make on their keyboards to keep up to date with their activity levels. Slack assists managers in evaluating how quickly employees complete tasks. The startup Humanyze sells smart ID badges capable of tracking employees' movements in the office and assessing their level of interaction with colleagues. The number of such tools is increasing every year. Artificial intelligence not only tracks, controls, and analyzes data but also gets involved in the processes of hiring, relocating, and disciplining employees. Machines can accurately determine who deserves a promotion or a salary increase and, conversely, document violations of work discipline and identify potential candidates for dismissal. These trends exacerbate social tension and labor conflicts. All of this necessitates the review of labor laws by governments and legislators, taking into account digital challenges.

In May 2022, a study conducted by the Scientific Foresight Unit (STOA) under the guidance of the European Parliamentary Research Service titled *AI and digital tools in workplace management and evaluation: An assessment of the EU's legal framework* [10] was published. This is highly interesting and informative research, the results of which could be taken into consideration while shaping the modern national labor legislation of Ukraine. For instance, researchers have analyzed various methods and algorithms for assessing workers' performance efficiency and ratings of workers generated with the help of AI algorithms. Conclusions are far from ideal. Facts of violating fundamental human and citizen rights, restricting labor rights in pursuit of high ratings or "improvement of working conditions" have been established. For example, the Oxford Internet Institute employed an AI bot aimed at detecting instances of intimidation and persecution by checking workplace emails. Initially seen as a good initiative, such a practice clearly conflicts with workers' rights to privacy. In other cases, taxi drivers, delivery personnel, or household service workers were evaluated based on customer feedback, which may not always be objective. Consequently, fearing a decrease in ratings, fine imposition, or dismissal, they were compelled to give up their rights and not defend them against clients. There are also instances where AI sets unachievable productivity goals using subjective data, leading employees to shorten their break times or work overtime to meet established work quotas.

Despite the fact that no active EU regulation specifically addresses the use of artificial intelligence for workplace discipline, the General Data Protection Regulation (GDPR) typically mandates companies to acquire consent prior to gathering data about individuals. Article 22, paragraph 1 of the GDPR stipulates the following: "The data subject shall have the right not to be subject to a decision based solely on automated processing, which produces legal effects concerning him or her or similarly significantly affects him or her". The primary argument supporting this position is the absence of human judgment

in AI, resulting in heightened scrutiny of these technologies. AI systems are generally highly analytical and objective, a characteristic that may not always be advantageous when making a proportional decision with legal effects. GDPR pertains to personal data protection. Data is a crucial component of labor relations and is present at every stage of interaction, from hiring to employee dismissal. The second argument revolves around the issue of AI legal standing. Because AI lacks the capacity to assume legal responsibility for disciplinary actions or the termination of employment contracts, it cannot be deemed a legally autonomous entity. Additionally, labor legislation in Europe (for example, in Portugal, France, and Germany) specifically envisages that disciplinary powers should be exercised by the employer or a superior hierarchical employee.

In 2021, Judges in the Netherlands ruled in favor of drivers using ride-sharing apps who complained of being dismissed as a result of automated decision-making. Referring to Article 22 of the GDPR, in February 2021, the Amsterdam District Court decided that one platform deactivated drivers solely based on automated processing, and mandated the company to reinstate the dismissed drivers and compensate them. Changes in Germany's recently amended law on labor councils include a provision granting councils increased participation in decisions concerning the use of artificial intelligence at the workplace, which also excludes uncontrolled legal effects resulting from automated decisions.

We agree with Eduardo Matos's perspective that currently artificial intelligence is not sufficiently advanced to guarantee its ability to analyze workplace events and continue exercising employers' disciplinary powers in an ethical, fair, and proportionate manner. Therefore, ungrounded decisions made by autonomous systems should not produce significant legal effects on company employees. Consequently, artificial intelligence should not be granted, neither de facto nor de jure, the capability to autonomously exercise the employer's disciplinary powers. At most, the discussion should focus on employers using AI as a tool to aid in making decisions regarding disciplinary procedures [11].

By signing the Association Agreement with the EU, Ukraine has agreed to ensure the protection of personal data in accordance with the highest European and international standards. According to Article 15 of the Agreement between the European Union and Ukraine, Ukraine has committed "to ensure an adequate level of protection of personal data in accordance with the highest European and international standards, including the relevant Council of Europe instruments". In this case, the highest European and international standards refer to two documents. The first is the Convention for the Protection of Individuals with regard to Automatic Processing of Personal Data, known as Convention 108 +. The second is the General Data Protection Regulation (GDPR). Therefore, when developing legal rules in the field of labor relations, it is necessary to consider the GDPR provisions, including regarding the use of artificial intelligence.

From our standpoint, the current labor legislation needs to introduce a provision requiring the employer not only to notify the employee about the use of AI technologies while organizing and monitoring work but also about the criteria, algorithms, and other methods for collecting, processing, and analyzing data serving as the basis for legally-relevant decisions. Another important addition should be the obligation of the employer to ensure compliance with fundamental human and labor rights and freedoms when implementing digital technologies and AI in the work process.

3 Artificial Intelligence in the Field of Occupational Safety

Ensuring an adequate level of occupational safety and health by the employer has already become a widely accepted standard in legislation and labor protection rules. Safe working conditions are a key component of decent work for all employees [12]. Artificial intelligence represents a powerful tool in occupational safety, showing considerable potential in areas such as data and text analysis, risk management, video monitoring, and training. Typically, AI is defined as the use of computers and/or machines attempting to replicate human decision-making, problem-solving, and other abilities. However, although artificial intelligence can identify patterns and correlations, it lacks genuine understanding of safety. Human knowledge and experience in this field remain crucial.

AI tools and methods can be applied in many safety scenarios. AI-supported safety technologies include smart equipment, augmented reality (AR) and virtual reality (VR), computer vision, robotics, drones, wearables, sensors, mobile applications, and analytical software. Hardware components collect data (such as sensors) or perform actions (e.g., robots). Software components rely on machine learning to analyze patterns and generate forecasts about safety threats.

There is an opinion that AI solutions are successful in many critical occupational safety scenarios, including gathering, organizing, and analyzing substantial volumes of data, providing and processing information from sources like legal texts, simulating situations, and monitoring processes and resources.

One of the safety-related examples involves the use of cameras that can determine whether employees wear personal protective equipment (PPE). In particular, these devices can monitor workers, especially those working at heights and required to wear safety harnesses. “Cameras can not only detect whether workers are wearing harnesses but also check whether they are properly secured (wear PPE)” [13]. AI-supported cameras can track interactions between workers and equipment, evaluate the status of machine safeguards, verify whether employees are in designated areas or outside them, and perform ergonomic assessments. Devices can also be connected to sensors or worn on helmets, vests, or other items. This continuous monitoring of employees means that safety experts don’t have to rely solely on observation, inspections, or checks to ensure that employees are wearing PPE or to identify other safety issues. Instead of occasional checks, monitoring occurs continuously. What is more, cameras and/or sensors and wearable devices can also generate heatmaps showing where high-risk activities are taking place at the facility.

Another valuable function of using AI in the field of occupational safety is natural language processing. Reading hundreds or thousands of reports that possibly contain millions of words is a time-consuming task for humans. Comprehending all this data requires even more time and “bandwidth”. Moreover, reports may consist of conversational narratives or contain unstructured data. Natural language processing has the capability to receive these reports and identify patterns or incidents occurring at specific times or in specific parts of the facility. Artificial intelligence supports businesses by almost instantly analyzing thousands of data elements and documents. This can assist the employer in ensuring that workplaces comply with industry standards, thus saving a substantial amount of time.

These new forms of monitoring and managing employees can raise legal, regulatory, and ethical issues in the field of occupational health and safety, particularly concerning mental and physical health of workers.

Let's refer to the experience of the European Union in researching the impact of technology on occupational safety. Thus, in the European Commission's document *EU strategic framework on health and safety at work 2021–2027: Occupational safety and health in a changing world of work*, it is stated that new technologies pose several problems due to increased irregularity in when and where work is performed, as well as risks associated with new tools and equipment. The Commission has also proposed to revise the Machinery Directive [14], which addresses risks deriving from digitalisation and the use of machinery that are also relevant to workers' health and safety [12]. The findings of the European Agency for Safety and Health at Work, published on October 8, 2022, are of particular interest. The agency has published the report *Artificial intelligence for worker management: implications for occupational safety and health* [15], along with the analytical review *Impact of artificial intelligence on occupational safety and health* dated January 7, 2021 [16]. The documents outline adverse consequences of implementing automatic algorithms in production. For instance, employees may feel that their privacy is being violated, leading to anxiety and stress. They might not have the opportunity to take breaks when needed, which can result in accidents and health issues. Irregular work schedules determined automatically by algorithms have various negative effects on employees, including increased conflict between work and family, workplace stress, and financial instability. Cobots' utilization in shared workspaces can increase the risk of accidents due to collisions or the equipment used by the cobots. Overreliance on technology can also lead to deskilling. As cobots are connected to the Internet of Things, issues related to cybersecurity as well as associated risks to functional safety arise. Workers striving to match the pace and level of cobot performance may feel pressure to reach a similar level of productivity.

AI has the potential to both create opportunities and introduce new challenges for occupational safety and health. Robots integrating artificial intelligence become mobile, intelligent, and ready for collaboration. Consequently, the implementation of AI-based systems is expected across various sectors and environments, from production and agriculture to the service industry and transportation.

The Occupational Safety and Health Summit held in Stockholm on May 15–16, 2023, has reached similar conclusions. The final version of conclusions acknowledges the potential of artificial intelligence and robotics to create safer and healthier workplaces for everybody [17].

In the studies by American researchers titled *Occupational Safety and Health Equity Impacts of Artificial Intelligence: A Scoping Review*, we can follow the trends and challenges of implementing artificial intelligence in the field of occupational safety. Among other issues, the indicated paper notes the existence of a gap between the research on artificial intelligence and occupational safety and health [18].

In our view, all documents and scientific developments in this field boil down to the following recommendations and proposals:

Development of an ethical code to ensure fairness and equality while implementation of artificial intelligence in labor relations.

Introduction of educational programs that promote equal learning opportunities for employees in working with AI, increase awareness, and enhance digital skills.

Invitation of all stakeholders including developers, employers, workers, and the government to engage in social dialogue on occupational safety guarantees when implementing technologies in the production process.

Mandatory involvement of trade unions and labor collectives in the process of implementing AI into work processes, informing them about the principles and criteria of AI algorithms' operation.

Concerns about confidentiality can be alleviated by increasing transparency in power structures, providing algorithmic audits and multidisciplinary approaches to the design, implementation, maintenance, and evaluation of artificial intelligence.

Conclusions. Overall, the use of artificial intelligence in labor legislation and employee protection can produce both positive and negative effects. AI technology can improve efficiency at the workplace by automating certain tasks, allowing employees to focus on higher-level tasks requiring human experience. At the same time, AI implementation raises legal issues due to the lack of a sufficient legal framework. Existing legal acts predominately have declarative and recommendatory nature, which is insufficient for the safe use of AI technologies in labor relations. In our opinion, standards and regulations regarding occupational safety and health should be reviewed and supplemented considering the requirements of the digital society and humanity's transition to the level of Industry 5.0.

4 Impact of AI on the Level of Staff Qualification

Cooperation with advanced AI-based robots offers a collaborative learning model that encompasses how employees interact, learn, and educate their robots for collaborative work. Currently, HR's scientific interest in artificial intelligence technology focuses on using machine learning for HR activities, namely individual assessment, performance forecasting, identifying training needs, measuring training efficiency, and defining teamwork patterns. Trends like globalization, robotization, and advancements in artificial intelligence are changing the labor market's skill requirements for employees. To gain success and remain competitive, people must rely on their unique (for now) human capacity for creativity, responsibility, and the ability to "learn and relearn" throughout their lives.

Artificial Intelligence (AI) adds depth and scale to the challenges that technologies face. Society needs to determine what AI expects from human intelligence, how to collaborate with AI, and how human and artificial intelligence can complement each other. Understanding this will help define the new knowledge and skills required for employee training [19]. As artificial intelligence systems become capable of learning in increasingly sophisticated ways, human intelligence also undergoes refinement [20]. Compared to other technologies, artificial intelligence has an unprecedented range of applications that can be maximized only through the creativity and imagination of AI users and designers. It is believed that these advancements will significantly influence the demand for skills by 2030 [21].

Artificial intelligence is less likely to replace jobs that require creativity. Workers engaged in roles demanding originality – "the ability to generate novel or clever ideas

about a specific topic or situation or develop creative ways to solve a problem" – are significantly less likely to be replaced by robots or AI algorithms. In other words, while technology permeates many fields, it is unlikely to replace workers whose jobs involve creating new ideas. Therefore, many employees will need to acquire creative skills in order to adapt to modern technology trends [21].

Since digital technologies are increasingly applied in workplaces, the importance of acquiring and retaining digital skills grows substantially for most employees. As stated by the European Commission, the demand for workers with specialized digital skills is increasing by approximately 4% annually [19]. Due to significant workplace restructuring in response to the implementation of AI and ICT, many digital skills are rapidly becoming outdated. As a result, employees must continually support their professionalism by acquiring new skills or improving existing ones to remain competitive. This demands flexibility, a lifelong learning mindset, and inquisitiveness from employees. Employers require workers who can adapt to technological changes. Experts recommend focusing on acquiring "fusion skills": a combination of creative, entrepreneurial, and technical skills that enable employees to adapt and move into emerging professions [21].

However, employer surveys indicate a perceived lack of employees' desires to learn and acquire relevant skills. On average, they consider that only about a quarter (26%) of their employees are ready for AI implementation. Nearly every fourth employer identifies workforce resistance as a key obstacle. However, as the research shows, 68% of highly skilled workers and nearly half (48%) of their less skilled counterparts embrace the introduction of AI and learning new skills. In general, 67% of employees deem it important to develop their skills in working with smart machines. In turn, only 3% of employers are ready to invest in such training. (Fig. 5) [22].

The issue of changes in the labor market and the workforce due to the introduction of technology is the subject of increased attention from the International Labour Organization (ILO). This international organization has conducted dozens of studies in this field over the last 10 years. For instance, in 2018, the report titled *Global Skills Trends, Training Needs and Lifelong Learning Strategies for the Future of Work* was published by the ILO and the OECD for the G20 Employment Working Group. Among other things, it points out that initial acquisition of professional skills through basic training for a single lifelong qualification is no longer sufficient and effective, increasingly being at risk due to rapidly changing skill demands. Future education and education systems must be flexible and prepare individuals for lifelong learning continuously. The majority of ILO documents urge countries to provide "lifelong learning opportunities for youth and adults that include formal, informal, and non-formal learning" [23].

A lasting impact of robotics and artificial intelligence on staff qualifications indicates that researchers and practitioners should reconsider professional education at both government and organizational levels. The foundation of organizational education lies in adapting to changes within the organization at individual, group, and organizational levels, facilitating knowledge creation and learning. The state should support businesses in organizing and financing their employees' training.

For example, consider the initiatives undertaken by French society in this area. France has a long tradition of professional training and retraining of its staff, supported by both

Fig. 5. Employee motivation prior to AI implementation in the workplace.

government and company-level practices. The challenge of adapting business to AI and employees to the occupied position is addressed through specific legal instruments. One of the most efficient among them is "forward-looking job and skill management policy (GPEC)". It is a crucial component of human resource management in companies, aiming to bridge the gap between company needs and employee skills in line with the evolution of job roles, while also engaging employees in career advancement projects [24]. The obligation to implement the GPEC policy is enshrined in the French Labor Code. An employer is obligated to ensure that their employees adapt to their job positions (L.6321–1 of the French Labor Code). Additionally, upon hiring an employee, it is vital to inform them that it would be advantageous to have discussions with their employer about career development every two years (L. 6315–1 of the French Labor Code). Moreover, the Code mandates that companies with more than 300 employees initiate discussions every three years concerning job management, professional careers, and gender diversity, taking into account the GPEC policy.

For companies with fewer than 300 employees, there is state support available for retraining staff. For instance, the state assists in funding HR diagnostics and preparing recommendations/action plans for the GPEC. In this case, the state covers 50% of the costs up to a maximum of 15,000 euros.

State programs supporting employers who train their employees within their own production facilities are not new in legal practice. Reimbursement packages or tax benefits have always been effective tools in the mechanism of state regulation. From our perspective, Ukraine should also introduce such methods into the system of professional training and retraining of employees. Today, the national legislation contains a number of mandatory rules requiring certain categories of workers employed in particular

branches of the national economy or professions (education, medicine, pharmacy, etc.) to systematically undergo retraining and advanced training. However, the responsibility for funding such training falls on the employer only in cases where the employer is under state ownership. In the private sector, typically, the financial burden of professional skills improvement rests with employees themselves. Nevertheless, the government acknowledges the inevitability of transformational processes in Ukrainian society due to the development of information technology and artificial intelligence. Hence, on March 3, 2021, by Cabinet of Ministers Order No. 167-r, the Concept for the Development of Digital Competencies until 2025 was approved [25]. It states the following: "With the increased pace of development in digital technologies and the implementation of innovative solutions across all areas of public life, there arises a necessity to improve the quality of employee training in order to create opportunities for the country's economy modernization in line with current requirements". The Concept primarily focuses on the development of digital technologies and the incorporation of innovations across all areas of public life. It defines *digital competence* as a dynamic combination of knowledge, skills, abilities, thinking patterns, perspectives, and other personal qualities in the field of information and communication technologies, determining a person's ability to socialize successfully and engage in professional and/or further educational activities with the use of such technologies.

Among the key provisions envisaged by the Concept, the following should be highlighted:

- providing citizens with digital education using informational resources;
- establishing the Unified State Digital Education Portal called *Diia. Digital Education*;
- ensuring legal regulation concerning the formation of state policies in the development of digital skills and competencies;
- creating indicators for monitoring digital skills and competencies development.

The document specifies that the implementation of this Concept will have a positive impact in terms of ensuring legal regulation aimed at developing digital skills and competencies, defining directions and main tasks in the specified field, improving the level of digital literacy among the population, enhancing the efficiency of using digital technologies and electronic services, raising the citizens' security level in the digital environment, and accelerating the processes of digital transformation in the economy and society of Ukraine. All of the above will ultimately contribute to the development of the digital economy and the country's competitiveness as a whole.

The aforementioned provisions were planned to be implemented by 2025. By 2024, the Ministry of Digital Transformation aimed to increase the digital literacy of 6 million Ukrainians. It is crucial to note that the funding for all measures related to the implementation of the Concept is allocated to government authorities.

In our opinion, the emergence of this document is the first step in shaping state policy for the formation and support of digital skills among workers, which is an integral component for the successful implementation of ICT into the economy and production.

Conclusions. With the rapid advancement of digital technologies and the implementation of innovative solutions and AI algorithms across all sectors of the economy, there is a need to enhance the quality of training for professionals in the field of developing digital skills and competencies. We believe that the most effective way to address

these challenges is through the implementation of comprehensive state regulation in this area by establishing mandatory rules for professional training and financial support (reimbursement or beneficiary programs) for businesses.

5 Conclusions

The use of artificial intelligence is expanding into more and more areas and sectors of economy. The number of companies utilizing AI to varying degrees is growing exponentially. Countries are developing national AI strategies while competing to attract talent in this field. Ethical norms and limits of use are being established. In Ukraine, the development of the digital economy will become possible through targeted state policy, including in the area of labor. The initial steps on this path were the adoption by the government of the Concept for the Development of the Digital Economy and Society of Ukraine for 2018–2020 and the approval of the action plan for its implementation [26], the Concept for the Development of Artificial Intelligence in Ukraine [27], and the Concept for the Development of Digital Competencies and the approval of the action plan for their implementation [25]. The next stage should involve the development of relevant legislative initiatives in the field of labor relations. In our view, to fulfil the goal of the state policy on digitalizing the economy in the labor sector, the following recommendations should be put into action:

Develop an ethical code for the implementation and utilization of artificial intelligence algorithms in the workplace. This task requires the involvement of AI experts, manufacturers, representatives of employer associations, and trade unions. The discussion must be broad-based, and the final document should reflect the interests of all participants in the social dialogue.

Ukrainian labor legislation requires profound transformation considering the global digitalization of the economy and society. Integration of AI necessitates amendments to the Labor Code to ensure guarantees for employees against opaque and discriminatory automated algorithms. Employers must be obliged to inform candidates/employees about AI application and its operating principles.

Legislation on occupational health and safety needs to be supplemented with standards for the safety of collaborative work between humans and robots. A prohibition must be introduced against establishing work quotas (including performance quotas, work schedules, and duration of work and rest) solely through automated algorithms without any human input or involvement.

Enforce the prohibition on AI decisions that produce legal effects for the life, health, and career of an employee.

Supplement legislation on conducting social dialogue with rules mandating the involvement of labor collective in decisions regarding the implementation of AI in workplaces and the development of its operating principles and criteria.

Enforce the employer's responsibility for breaching rules concerning the handling of employees' personal data obtained during AI-related work processes.

Develop state programs that help employers establish their own training centers and programs, or send their employees to upgrade digital skills at the employer's expense.

References

1. McKinsey & Company «The economic potential of generative AI: The next productivity frontier». 14 June 2023 | Report. https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-economic-potential-of-generative-AI-the-next-productivity-frontier#introduction
2. Organization for Economic Cooperation and Development (OECD). "OECD AI Principles Overview" (2019). https://oecd.ai/en/ai-principles
3. Samaeva, Y.: The attitude of Ukrainians to artificial intelligence is surprisingly frivolous. And in vain. https://zn.ua/TECHNOLOGIES/otnoshenie-ukraintsev-k-iskusstvennomu-intellektu-na-udivlenie-lehkomyslennoe-a-zrja.html
4. Report «The impact of artificial intelligence on the future of workforces in the European union and the United States of America» 05 December 2022. https://digital-strategy.ec.europa.eu/en/library/impact-artificial-intelligence-future-workforces-eu-and-us
5. World Economic Forum «Future of Jobs Report 2023». INSIGHT REPORT. MAY 2023. https://www3.weforum.org/docs/WEF_Future_of_Jobs_2023.pdf
6. Acemoglu, D., Restrepo, P.: Modeling Automation (February 4, 2018). MIT Department of Economics Working Paper No. 18–02., SSRN. https://ssrn.com/abstract=3123798 or https://doi.org/10.2139/ssrn.3123798
7. Ilzetzki, E., Jain, S.: The impact of artificial intelligence on growth and employment/ 20 Jun 2023. https://cepr.org/voxeu/columns/impact-artificial-intelligence-growth-and-employment
8. Automation & AI in HR. from February 1, 2022 to February 17, 2022. https://advocacy.shrm.org/SHRM-2022-Automation-AI-Research.pdf?_ga=2.112869508.1029738808.1666019592-61357574.1655121608.)
9. Lindsey Wagner Artificial Intelligence in the Workplace. The Future is Now. June 10, 2022. https://www.americanbar.org/groups/labor_law/publications/labor_employment_law_news/spring-2022/ai-in-the-workplace/
10. Valerio De Stefano AI and digital tools in workplace management and evaluation. An assessment of the EU's legal framework. https://www.europarl.europa.eu/thinktank/en/document/EPRS_STU(2022)729516
11. Eduardo Matos AI and enforcement of disciplinary powers February 2, 2022. https://whatnext.law/2022/02/02/ai-and-enforcement-of-disciplinary-powers/
12. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions EU strategic framework on health and safety at work 2021–2027 Occupational safety and health in a changing world of work. EUROPEAN COMMISSION. Brussels, 28.6.2021. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0323#PP1Contents
13. Kashyap Kompella «How AI can transform industrial safety». 05 May 2023. URL: https://www.techtarget.com/searchenterpriseai/tip/How-AI-can-transform-industrial-safety
14. EU Framework Strategy for Safety and Health at Work 2021–2027 Safety and Health at Work in a Changing World of Work. URL: https://www.ilo.org/budapest/what-we-do/projects/declared-work-ukraine/WCMS_811860/lang--en/index.htm
15. Artificial intelligence for worker management: implications for occupational safety and health. Summary. URL: https://osha.europa.eu/en/publications/summary-artificial-intelligence-worker-management-implications-occupational-safety-and-health
16. Impact of artificial intelligence on occupational safety and health. 07/01/2021. URL https://osha.europa.eu/en/publications/impact-artificial-intelligence-occupational-safety-and-health
17. Conclusions of the Occupational Safety and Health Summit held in Stockholm on 15–16 May 2023, an opportunity to analyze the EU strategic framework for health and safety at work 2021–2027 - Occupational safety and health in a changing world of work. URL: https://ec.europa.eu/social/main.jsp?langId=en&catId=89&newsId=10582&furtherNews=yes

18. Fisher E, Flynn MA, Pratap P, Vietas JA. Occupational Safety and Health Equity Impacts of Artificial Intelligence: A Scoping Review. International Journal of Environmental Research and Public Health. 2023; 20(13):6221. URL: https://doi.org/10.3390/ijerph20136221
19. OECD. OECD Future of Education and Skills 2030 Conceptual learning framework, OECD Publishing, Paris, URL: https://www.oecd.org/education/2030-project/teaching-andlearning/learning/skills/Skills_for_2030.pdf
20. Luckin, R., Issroff, K.: Education and AI: preparing for the future, OECD (2018). http://www.oecd.org/education/2030-project/about/documents
21. Bialik, M., Fadel, C.: Knowledge for the Age of Artificial Intelligence: What Should Students Learn? January 2018, Center for Curriculum Redesign. https://curriculumredesign.org/wpcontent/uploads/CCR_Knowledge_FINAL_January_2018.pdf
22. Romanhuk, A.: Reworking the Revolution. Future workforce (2019). https://www.academia.edu/38048342/Reworking_the_Revolution_2019
23. ILO. Global Skills Trends,Training Needs and Lifelong Learning Strategies for the Future of Work. Report prepared by the ILO and OECD for the G20 Employment Working Group. 2nd Meeting of the Employment Working Group Geneva, Switzerland 11 – 12 June 2018 (2018). https://www.ilo.org/wcmsp5/groups/public/---dgreports/---inst/documents/publication/wcms_646038.pdf
24. Labor law and the challenges of Artificial Intelligence: 2nd part of a trilogy. https://www.soulier-avocats.com/en/labor-law-and-the-challenges-of-artificial-intelligence-2nd-part-of-a-trilogy/?pdf=33751
25. Concept of development of digital competences. Order of the Cabinet of Ministers of Ukraine dated March 3, 2021 No. 167-p. https://zakon.rada.gov.ua/laws/show/167-2021-%D1%80#Text
26. Concept of development of the digital economy and society of Ukraine for 2018–2020 and approval of the plan of measures for its implementation. Decree of the Cabinet of Ministers of Ukraine dated January 17, 2018 No. 67. https://zakon.rada.gov.ua/laws/show/67-2018-%D1%80#Text
27. Concept of development of artificial intelligence in Ukraine. Decree of the Cabinet of Ministers of Ukraine of December 2, 2020 No. 1556. https://zakon.rada.gov.ua/laws/show/1556-2020-%D1%80#Text

Legal and Psychological Principles of Preventing Sexual Violence Against Children: International Experience and Realities of Ukraine

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1 Introduction

Currently, Ukraine is experiencing worsening of the crime situation, with an increase in the number of serious and increasingly serious crimes, including crimes against a person's life and health. Notably, crimes against sexual freedom and sexual inviolability, especially those involving juveniles, hold a distinct place in this regrettable list. Analysing the sad criminal statistics, it can be observed that these crimes too have a tendency to increase.

Such crimes are characterized by exceptional amorality and cynicism amorality and cynicism in the actions of the perpetrators towards their victims. Typically, these crimes inflict deep moral and psychological traumas on the victims, causing serious harm to their physical and mental health.

Summarizing researchers' approaches to studying the origins of violence, particularly sexual violence against children, the following groups of reasons may be distinguished:

– sociocultural factors: risks for children from families with low income, educational and cultural background, who live in difficult living conditions, are part of communities or religious associations where violence is tolerated or the value of the child is disregarded, where individuals, communities and larger social and cultural associations are hushed up, and where topics related to sexual relationships, upbringing, issues involving sexual identity and sexual satisfaction are taboo;

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https://doi.org/10.1007/978-3-031-60549-9_21

- family factors: summarize observations regarding correlation between dysfunctionality, conflictuality in family relationships, instability in relationships among adult family members, changes in family structure, and an increased risk for the child as a potential victim of sexual violence;
- individual factors related to parents: indicate a higher risk of children experiencing sexual violence when their parents or caregivers employ a parenting style characterized by dominance over the child, excessive demands, neglect of the child's needs, children whose parents have emotional and behavioural disorders, exhibit explosive (i.e., irritable-aggressive) personality traits, or are addicted to psychoactive substances;
- individual factors concerning children indicate that there are much greater risks for premature babies, unwanted children, those born after their parents have previously lost a child, children in large families, those with health disorders, behavioural disorders, or a low level of social skill proficiency;
- crisis factors: point to a higher risk for children to become victims of violence during periods of family troubles, economic and social upheaval, and wars. The impact of the Russian-Ukrainian war, particularly Russia's full-scale invasion of Ukraine, has had a substantial effect in two aspects. Firstly, it addresses one of the methods used in conducting warfare and suppressing civilian resistance, which includes sexual violence against children by Russian soldiers during the occupation. Secondly, it entails the growth in the level of aggression within a society undergoing prolonged and severe upheaval.

Understanding the patterns of human existence as social beings and studying the results of scientific research allows us to assume that these factors act in concert.

In a broad sense, sexual violence is understood as the use of a child by an adult or an older child to satisfy their own sexual needs, with or without the use of violence, relying on the child's trust or their own capabilities. In Germany, for example, research by foreign experts has shown that the victims of sexual violence can be very young children (under the age of 5) as well as older children. In 42% of cases, sexual encroachments begin from the age of 6–7, but can even occur against infants! The majority of child sexual violence and exploitation take place between the ages of 7 and 13 (75%)[1].

Crimes involving child sexual violence and exploitation are particularly dangerous as they result in severe consequences and cause substantial harm to the life and health of a juvenile. Experts point out that individuals who have experienced childhood violence may sometimes subconsciously carry those "life experiences" into their adult lives. The most common statistically recorded consequences for such persons include alcoholism, drug addiction, domestic violence involving abusive behaviour towards family members, and in some cases, even suicide[2]. In other words, adapting these children to normal life becomes a very challenging, time-consuming, and not always successful task for a range of professionals, including lawyers, juvenile prevention workers, medical professionals, psychologists, psychiatrists, and others.

[1] Keine Gewalt gegen Kinder. Bonn: Bundesministerium für Familie, Senioren, Frauen und Jugend, 1998. 24 p.

[2] Джужа А.О. Кримінально-правові та кримінологічні засади запобігання злочинам проти статевої недоторканності дитини: монографія/НАВС. К., 2013. 193 с. С. 5.

That's why comprehensive strategies to end violence against children should encompass all forms of violence, whether it is physical, emotional, sexual abuse, or neglect. However, there is a need for a specific, coordinated focus on the issue of child sexual violence and exploitation. In many parts of the world, sexual violence against children remains a taboo, hidden, and stigmatized topic. Child sexual violence and exploitation have unique driving forces, risks, and protective factors.

The research and policy on child maltreatment are primarily focused on caregivers and families, and although many cases of sexual violence may occur in homes, perpetrators and contexts of child sexual violence and exploitation are much more diverse. This becomes a focal point in the context of child sexual violence and exploitation on the Internet. While other strategies for preventing violence consider childhood sexual violence, there are significant gaps in knowledge and practices for protecting young children and boys, along with children who are intersex or identify as non-binary. Peers make up a significant portion of those responsible for acts of sexual violence against other children and adolescents, but interventions are primarily intended for adult offenders.

Strategies for preventing child sexual abuse and exploitation, as well as responding to them, should be based on the evidence of meeting the developmental and protective needs of children as both victims and offenders, recognizing that a child can both experience violence and harm others.

The international community is making significant efforts to combat child sexual violence and exploitation. For example, the International Agreement to End Violence against Children by 2030 has been adopted, and an interdepartmental package of seven evidence-based prevention strategies, known as INSPIRE[3], is being developed. The process of creating the Global Partnership to End Violence Against Children is reaching its conclusion. To address the issue of the rapidly growing illicit use of information and communication technologies aimed at sexual exploitation of children, WePROTECT Global Alliance has been formed, and countries are following its National Response Model[4]. Efforts to combat violence against women and children are increasingly interconnected and mutually reinforcing, as indicated within the RESPECT3 framework. The Oak Foundation has recently funded considerable work on preventing child[5] sexual violence, leading to the development of a crucial index for measuring the comprehensiveness of national responses[6].

[3] WHO (2016) INSPIRE: Seven strategies for ending violence against children, World Health Organisation: Geneva; WHO (2018) INSPIRE Handbook: action for implementing the seven strategies for ending violence against children, Geneva, World Health Organisation.

[4] Меры по прекращению сексуального насилия и эксплуатации детей. UNICEF (2020). Опубликовано в рамках секции ЮНИСЕФ по защите интересов детей, программмное подразделение 3, United Nations Plaza, Нью-Йорк 10017 Email: childprotection@unicef.org Сайт: www.unicef.org © Детский фонд Организации Объединенных Наций (ЮНИСЕФ), Декабрь, 2020. С.2.

[5] Ligiero, D., Hart, C., Fulu, E., Thomas, A., & Radford, L. (2019) What works to prevent sexual violence against children: Evidence Review. Together for Girls. www.togetherforgirls.org/svsolutions.

[6] Economist (2018) Out of the shadows: Shining the light on the response to child sexual abuse and exploitation: A 40 country benchmarking index, Economist Intelligence Unit, London.

When it comes to combating child sexual violence and exploitation in Ukraine, this issue has become especially acute in the last two years as our country courageously resists armed aggression from the Russian Federation. According to the data from criminal proceedings, children have become the most vulnerable group of victims, also because they have been exposed to sexual violence by the aggressors. As reported by the Ministry of Justice of Ukraine, Russian military forces have committed hundreds of sexual violence cases in the occupied territories since the beginning of the war. As stated by the Prosecutor General of Ukraine, there are officially known cases of 175 such incidents. Among the victims are not only women but also men and children (40 cases involving men and 13 involving children aged 4 to 17: 12 girls and 1 boy). However, these are far from all the cases[7].

That's why addressing the issue of combating child sexual violence and exploitation in Ukraine and the world is highly relevant and requires further in-depth research.

2 Literature Review

Overall, many Ukrainian and foreign legal scholars, including O. M. Bandurka, O. I. Buhera, D. O. Hnylitska, O. V. Hubanov, A. O. Dzhuzha, S. S. Kostenko, L. V. Levytska, O. M. Lytvynov, A. S. Lukash, Yu. V. Orlov, M. O. Siemykin, O. S. Riabchuk, S. V. Chmut, N. Ye. Filipenko, O. V. Shved, O. B. Shyhonin, and others, address the issue of combating child sexual violence and exploitation in Ukraine and worldwide in their research papers. However, most researchers have developed one or several aspects of the raised issue without addressing the problem in a comprehensive and integrated manner.

Great theoretical and applied contributions to the prevention of child sexual violence and exploitation have been made by both foreign and domestic psychologists and sociologists, including Bessel van der Kolk, Judith Herman, Roland Summit, Patricia Riker, Elaine Carmen, O. V. Baulin, M. O. Zhuravlova, T. P. Kryvak, O. O. Sadchenko, A. V. Starushkevych, O. O. Slipets, O. V. Yudina, and others. However, many psychological and sociological issues remain understudied and require thorough theoretical and applied research.

Particularly underdeveloped are the issues related to combating child sexual abuse and exploitation during armed conflicts.

3 Aim

The aim of the article is to consider the current Ukrainian and foreign experience in combating child sexual violence and exploitation from the perspective of psychology and law.

[7] Валерія Коломієць: Сексуальне насильство під час війни — це воєнний злочин, який не має строку давності. 16-05-202315. URI: https://minjust.gov.ua/news/ministry/valeriya-kolomiets-seksualne-nasilstvo-pid-chas-viyni-tse-voenniy-zlochin-yakiy-ne-mae-stroku-davnosti.

3.1 Results and Discussion

All manifestations of child sexual violence have a high level of latency. Very often, victims do not want publicity, fear, or feel ashamed of the events, and they do not turn to law enforcement agencies. It is widely recognized that official data on the number of registered crimes do not even approximately reflect the true picture of criminal encroachments on the sexual freedom or sexual inviolability of a child[8].

As stated in documents by the World Health Organization (WHO), violence against children includes all forms of violence against people under 18 years old perpetrated by parents or other caregivers, peers, romantic partners, or strangers[9].

A review of studies[10] has demonstrated that every eighth child in the world (12.7%) experiences sexual violence before reaching the age of 18.

UNICEF estimates that approximately one in 20 girls aged 15–19 (about 13 million) have been coerced into sex in their lifetime[11]. Sexual violence against children has a gendered nature, with approximately 90% of the perpetrators being males. Girls tend to report significantly higher rates of victimization (2–3 times higher) compared to boys. It has been found that victimization among boys is higher in certain contexts and organizational settings[12].

Globally, it is estimated that up to 1 billion children aged 2–17 years have experienced physical, sexual, or emotional violence or neglect[13]. The majority of child violence cases involve, at least, one of the six main types of interpersonal violence that may occur at various stages of the child's development.

[8] Див. докладніше: Суп В. Злочини проти статевої свободи та статевої недоторканності неповнолітніх та малолітніх: окремі аспекти визначення правової природи та напрямків профілактики/В. Суп//Новітні кримінально-правові дослідження – 2021: Альманах наукових праць/за ред. проф. Є. Л. Стрельцова, проф. О. В. Козаченка, PhD О. М. Мусиченко. Миколаїв: МІП НУ "ОЮА", 2021. С. 230-235. URI: https://hdl.handle.net/11300/17612; Джужа А.О. Кримінально-правові та кримінологічні засади запобігання злочинам проти статевої недоторканності дитини: монографія/НАВС. К., 2013. 193 с.; Костенко С.С. Віктимологічна профілактика статевих злочинів щодо неповнолітніх: Автореферат дисертації на здобуття наук. ступеня канд. юр. наук, Спеціальність 12.00.08 - кримінальне право та кримінологія, кримінально-виконавче право. 2004. 20 с. та ін.

[9] Посібник INSPIRE. Дії для впровадження семи стратегій задля припинення насильства стосовно дітей. URI: https://apps.who.int/iris/bitstream/handle/10665/272996/9789241514095-ukr.pdf.

[10] Stoltenborgh, M. van Ijzendoorn, M. Euser, E. & Bakermans-Kranenburg, M. (11) A Global Perspective on Child Sexual Abuse: Meta-analysis of prevalence around the world, Child Maltreatment, 16:2, Pp. 79-101.

[11] UNICEF (2020) A new era for girls: Taking stock of 25 years of progress, UNICEF/UNWomen/Plan International: New York.

[12] Меры по прекращению сексуального насилия и эксплуатации детей. UNICEF (2020). Опубликовано в рамках секции ЮНИСЕФ по защите интересов детей, программмное подразделение 3, United Nations Plaza, Нью-Йорк 10017 Email: childprotection@unicef.org Сайт: www.unicef.org © Детский фонд Организации Объединенных Наций (ЮНИСЕФ), декабрь, 2020. С.5.

[13] Susan Hillis, PhD; James Mercy, PhD; Adaugo Amobi, MD; Howard Kress, PhD Global Prevalence of Past-year Violence Against Children: A Systematic Review and Minimum Estimates. Pediatrics. Volume 137, Issue 3. March 2016. URI: https://publications.aap.org/pediatrics/article-abstract/137/3/e20154079/81439/Global-Prevalence-of-Past-year-Violence-Against?redirectedFrom=fulltext.

Maltreatment, including severe punishment, encompasses physical, sexual, and psychological/emotional violence, as well as neglect towards children of young age and other age groups and adolescents by parents, caregivers, and other authoritative people, primarily at home but also in such institutions as schools and orphanages.

Bullying, including cyberbullying, is unwanted aggressive behaviour by another child or a group of children who are not siblings or in romantic relationships with the victim. It involves repeatedly inflicting physical, psychological, or social harm and often occurs in schools and other child-related institutions, as well as through the Internet.

Violence among adolescents and youth is violence among individuals aged 10–29 which predominantly takes place in communities among acquaintances and strangers. It includes bullying and physical attacks with or without weapons (such as firearms and knives) and may involve violence perpetrated by criminal groups.

Intimate partner violence (IPV), or domestic violence, encompasses physical, sexual, and emotional violence by an intimate partner or ex-partner. While men can also be victims of partner violence, women disproportionately suffer from it. This type of violence typically occurs against girls and young women in child and early/forced marriages. Among teenagers in romantic relationships but not yet married, this violence is sometimes referred to as "dating violence".

More and more pieces of evidence indicate that there are connections between intimate partner violence and violence against children. These types of violence share similar risk factors, such as family stress related to poverty or unemployment, high levels of community violence, social isolation, mental health issues, and substance abuse[14]. They also have similar negative medical and psychological effects for victims. Both are influenced by social and gender norms that justify violence and punitive forms of child discipline, reinforcing gender inequality[15].

IPV and violence against children often occur repeatedly within families, and this behaviour can be passed from generation to generation. If a child is a witness to IPV or a victim of maltreatment, this increases the risk that the individual may either become a perpetrator or a victim of violence in the future. Keeping in mind these connections allows for a collective approach to address these issues and implement more effective and efficient interventions[16]. Some programs that fight IPV such as SASA!, Soul City, IMAGE, and Stepping Stones are included in INSPIRE. Other programs supporting parents and caregivers also keep working to improve parental communication and relationships. Identifying cases of IPV and offering resources and referrals within healthcare can be part of support and response efforts.

[14] INSPIRE Посібник з показників та матриці результатів. Нью-Йорк: ЮНІСЕФ; 2018 рік.

[15] Протокол міжгалузевого управління сексуальною наругою та насильством Зімбабве. Хараре: Комітет Юридичних Послуг; 2012рік. URI: http://www.togetherforgirls.org/wp-content/uploads/2017/10/Multi_Sectoral_Protocol_2012-Zimbabwe.pdf.

[16] Marcy L, Messner L, Duffy M, Casto J. Зміцнення зв'язків між клінічними соціальними/громадськими послугами для дітей та підлітків, що зазнали сексуального насильства: супровідний посібник. Арлінгтон, Вірджинія: Проект «Зміцнення високоефективних інтервенцій для покоління без СНІД». 2016 рік. URI: https://aidsfree.usaid.gov/resources/prc-companion-guide.

Particular concern is raised by sexual violence and exploitation of children through online resources. Over the past two decades, there has been a rapid growth and spread of digital technologies worldwide, leading to the emergence of new forms of harm on the Internet and exacerbating offline child maltreatment, such as sexual violence against young children. Gaining the confidence of the child online for the purpose of sexual violence and exploitation, live streaming of sexual violence against children through the Internet, and dissemination of materials involving sexual violence against children have all significantly increased. The volume of materials on child sexual violence, available both in the clearnet and the dark web, has reached a new high point, totalling millions of images[17].

A review of surveys conducted among men community regarding their use of online materials related to child sexual violence and their sexual behaviour towards children has demonstrated that in 1 in 10 to 1 in 5 studies conducted in Finland, Germany, and Sweden, adults engaged in sexualized online conversations with children last year. One out of twenty men admitted to engaging in inappropriate behaviour towards children under 12 years old on the Internet[18].

Sexual violence includes non-consensual sexual contact or acts of a sexual nature carried out without physical contact (such as voyeurism or sexual harassment), or attempts to engage in such contacts and acts. It also includes acts involving sexual exploitation of persons who are incapable of giving consent or refusing, as well as exploitation that occurs online.

Emotional or psychological violence includes restricting a child's movements, humiliation, ridicule, threats and intimidation, discrimination, rejection, and other non-physical forms of hostile behaviour.

Any of these types of violence directed towards girls or boys based on their biological sex or gender identity can also be viewed as gender-based violence.

Child violence has long-lasting consequences for the health and well-being of children, families, communities, and countries. According to research findings, the multitude of consequences of violence for the child can be categorized into several primary ones[19]:

1. Leading to death. Homicides, often involving weapons such as knives and firearms, are one of the top three causes of death for adolescents, with boys making up more than 80% of victims and perpetrators.

[17] Unicef.org. URI: https://static1.squarespace.com/static/5630f48de4b00a75476ecf0a/t/5deecb0fc4c5ef23016423cf/1575930642519/FINAL+-+Global+Threat+Assessment.pdf.

[18] Wager, N. Armitage, R. Christmann, R. Gallagher, B. et al (2018) Rapid evidence assessment: quantifying the extent of online-facilitated child sexual abuse: Report for the Independent Inquiry into Child Sexual Abuse, University of Huddersfield, Huddersfield. URI: https://www.iicsa.org.uk/document/rapid-evidence-assessment-quantifying-extent-onlinefacilitated-child-sexual-abuse.

[19] Див. докладніше: Джудіт Герман. Психологічна травма та шлях до видужання: наслідки насильства – від знущань у сім'ї до політичного терору. Львів: Видавництво Старого Лева, 2019. 424 с.; Краснокутський М.І. Деякі аспекти щодо надання психологічної допомоги дітям, які пережили насильство. Проблеми екстремальної та кризової психології. 2015. Вип. 17.

2. Leading to severe injuries. Each homicide results in hundreds of victims among youth (mostly male) who suffer injuries as a result of fights and assaults.
3. Impacting brain and nervous system development. Violence experienced during childhood may lead to disruptions in brain development and have lifelong negative consequences for other parts of the nervous system, as well as the endocrine, circulatory, musculoskeletal, reproductive, respiratory, and immune systems. Consequently, violence against children can adversely affect cognitive development and impact performance and success in professional activities.
4. Resulting in negative stress responses and behaviours that pose health risks. Children who experience violence and the influence of other adverse factors are much more likely to smoke, abuse alcohol and drugs, engage in high-risk sexual behaviours. They also exhibit higher rates of anxiety disorders, depression, and other mental health issues, as well as suicide.
5. Leading to unplanned pregnancies, induced abortions, gynecological problems, and sexually transmitted infections, including HIV.
6. Contributing to the development of a wide range of non-communicable diseases later in life. The higher risk of developing cardiovascular diseases, cancer, diabetes, and other health disorders is significantly associated with negative stress responses and high-risk behaviours resulting from violence.
7. Harming personality development, which is due to the disruption or deformation of the fundamental conditions for development: a sense of trust, negative self-perception, distrust of one's own perception and judgments; violation in the formation of communicative competencies, socialization; experiencing intense psychological trauma and its consequences; regression of cognitive, emotional, and volitional development.
8. Influencing the opportunities and future generations. Children who experience violence and other adverse factors are more likely to drop out of school, struggle to find and keep jobs, and face an increased risk of becoming victims of interpersonal violence or self-harm or commit such violence later in life. This, in turn, can have a lasting impact on future generations.

That is why sexual violence and exploitation of children is a violation of human rights and a public health issue with severe consequences for global health and development[20].

Prior to addressing the issue of combating sexual violence and exploitation of children in Ukraine and developing a full-fledged strategy on these matters, it is vital to address and analyse several pressing questions. In particular, what do we understand by sexual violence and exploitation of children, and what do we mean by the concept of *combating* these crimes?

Let's study them in detail.

The concepts of sexual violence and exploitation in Ukraine and abroad.

The need to develop the *sexual violence* legal category at the present stage is associated with the public demand to study, understand, and somehow formally acknowledge the existence of this antisocial phenomenon[21].

[20] WHO (2017) Responding to children and adolescents who have been sexually abused: WHO clinical guidelines, World Health Organisation, Geneva.

[21] Джужа О. М. Запобігання злочинам, пов'язаним із сексуальним насильством: монографія. К.: Атіка, 2009. 240 с. С. 8.

Great Explanatory Dictionary of the Modern Ukrainian Language defines violence as follows: 1) the use of physical force against someone; 2) the application of force to achieve something; coercive influence on someone or something[22]. Legal Encyclopedia interprets violence as "deliberate influence of one person on another against the will of the latter, resulting in physical, moral, or property damage to that person, or containing a threat to cause such harm with criminal intent"[23]. A form of violence, such as sexual violence, can be perpetrated in the ways mentioned previously.

The *sexual violence* category, although used in international law, differs in its content and definitions in national legislations and is not always consistent with each other. As a result, this concept encompasses a wide range of unlawful behaviours: from sexual offenses to other violations[24].

In the Council of Europe Convention on Protection of Children against Sexual Exploitation and Sexual Abuse[25] dated October 25, 2007 (Lanzarote Convention), these concepts are amended as follows:

Sexual abuse is: a) engaging in sexual activities with a child who, according to the relevant provisions of national law, has not reached the legal age for sexual activities; b) engaging in sexual activities with a child where: use is made of coercion, force or threats; or abuse is made of a recognised position of trust, authority or influence over the child, including within the family; or abuse is made of a particularly vulnerable situation of the child, notably because of a mental or physical disability or a situation of dependence (Art. 18).

Offenses involving child prostitution: a) recruiting a child into prostitution or causing a child to participate in prostitution; b) coercing a child into prostitution or profiting from or otherwise exploiting a child for such purposes; c) having recourse to child prostitution.

For the purpose of the present article, the term "child prostitution" shall mean the fact of using a child for sexual activities where money or any other form of remuneration or consideration is given or promised as payment, regardless if this payment, promise or consideration is made to the child or to a third person (Art. 19).

Offenses related to child pornography: a) producing child pornography; b) offering or making available child pornography; c) distributing or transmitting child pornography; d) procuring child pornography for oneself or for another person; e) possessing child pornography; f) knowingly obtaining access, through information and communication technologies, to child pornography.

For the purpose of the present article, the term "child pornography" shall mean any material that visually depicts a child engaged in real or simulated sexually explicit

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[22] Великий тлумачний словник сучасної української мови/уклад. і гол. ред. В. Т. Бусел. К.; Ірпінь: ВТФ «Перун», 2003. 1440 с. С. 579.

[23] ЮРидична енциклопедія: в 6 т./за ред. Ю. С. Шемшученко та ін. К.: Українська енциклопедія, 2002. Т. 4: Н–П. 720 с. С. 68.

[24] Джужа А. О. Алкогольне сп'яніння як віктимогенний фактор, що сприяє вчиненню сексуальних злочинів. Науковий вісник КНУВС. 2010. № 2. С. 184–186. С. 185.

[25] КОНВЕНЦІЯ Ради Європи про захист дітей від сексуальної експлуатації та сексуального насильства (Конвенцію ратифіковано з заявами Законом № 4988-VI від 20.06.2012). Офіційний переклад. https://zakon.rada.gov.ua/laws/show/994_927#Text.

conduct or any depiction of a child's sexual organs for primarily sexual purposes (Art. 20).

Offenses associated with a child's involvement in pornographic performances: a) recruiting a child into participating in pornographic performances or causing a child to participate in such performances; b) coercing a child into participating in pornographic performances or profiting from or otherwise exploiting a child for such purposes; c) knowingly attending pornographic performances involving the participation of children.

In the Istanbul Convention of the Council of Europe (Istanbul Convention)[26] dated May 11, 2011, Article 36 is titled *Sexual violence, including rape* and addresses various forms of criminal behaviour, such as: a) engaging in non-consensual vaginal, anal or oral penetration of a sexual nature of the body of another person with any bodily part or object; b) engaging in other non-consensual acts of a sexual nature with a person; c) causing another person to engage in non-consensual acts of a sexual nature with a third person. The title of this rule directly indicates that rape is a form of sexual violence.

In clause 189 of the Explanatory Report to the Convention under consideration, it is noted that the above-mentioned rule "covers all forms of sexual acts against another person without their consent, which are intentionally committed"[27].

Analysing child sexual violation manifestations under the Criminal Code of the Federal Republic of Germany (FRG), it can be concluded that the list of forms of child sexual violence is quite extensive, and therefore, they can be categorized as follows:

a) forms of contact: 1) sexual abuse of wards (Section 174); 2) sexual abuse of children (Section 176); 3) aggravated sexual abuse of children (Section 176a); 4) child abuse causing death (Section 176b); 5) promotion of sexual acts by minors (Section 180); 6) exploitation of prostitutes (furnishing a person under 18 years of age with accommodation, or premises or a particular place for the purpose of engaging in prostitution) (Section 181); 7) sexual abuse of juveniles (Section 182);
b) non-contact forms: 1) dissemination of pornographic printed content (Section 184); 2) engaging in prostitution that harms juveniles (e.g., near a school) (Section 184b)[28].

Section three of the French Penal Code outlines the following forms of sexual violence against children: 1) rape (including incestuous rape); 2) other types of sexual aggression (not classified as rape) can be identified as distinct elements of a crime; 3) exhibitionism; 4) sexual harassment[29].

As stipulated in the Criminal Code of Austria, sexual abuse against children includes: 1) grave sexual acts against juveniles (Article 206); 2) child molestation (Article 207); 3) possession of pornographic images featuring juveniles (Article 207a); 4) threats to

[26] Конвенція Ради Європи про запобігання насильству стосовно жінок і домашньому насильству та боротьбу із цими явищами (Стамбульська конвенція) від 11 травня 2011 р. URL: https://zakon.rada.gov.ua/laws/show/994_001-11#Text.

[27] Пояснювальна доповідь до Конвенції Ради Європи про запобігання насильству стосовно жінок і домашньому насильству та боротьбу із цими явищами (Стамбульської конвенції) від 11 травня 2011 р. URL: https://rm.coe.int/1680093d9e.

[28] Уголовный кодекс ФРГ/перевод и предисл. канд. юрид. наук А. В. Серебренниковой. М.: Зерцало, 2000. 208 с.

[29] Уголовный кодекс Франции/науч. ред. Л. В. Головко, Н. Е. Крылова; пер. Н. Е. Крыловой. СПб.: Юрид. центр пресс, 2002. 650 с.

the moral integrity of individuals under the age of 16 (Article 208); 5) homosexual acts with individuals under the age of 18 (Article 209); 6) incest (Article 211); 7) abuse of parental and other rights (Article 212)[30].

Chapter 6 of the Swedish Criminal Code establishes responsibility for committing the following forms of sexual abuse against children: 1) sexual exploitation of juveniles or severe sexual exploitation (Article 4); 2) sexual intercourse with a descendant or a biological brother or sister (Article 6); 3) sexual harassment (Article 7); 4) child molestation (Article 10)[31].

Japan's Penal Code is quite restrained in defining forms of sexual violence: 1) public indecency (Article 174); 2) distribution of obscene objects (Article 175); 3) indecency through compulsion (Article 176); 4) forcible sexual intercourse (Article 177); 5) constructive indecency through compulsion (Article 178)[32].

Section 3 *Crimes Against Human Dignity in the Sexual Sphere* of the Czech Criminal Code envisages the following forms of sexual violence against children: 1) rape (Article 185); 2) sexual duress (Article 186); 3) sexual abuse (Article 187); 4) intercourse among relatives (Article 188); 5) prostitution threatening moral development of children (Article 190); 6) distribution of pornography; production and other disposal with child pornography; abuse of a child for production of pornography (Articles 191, 192, 193); 7) seduction to sexual intercourse (Article 202)[33] [274].

As stipulated in Art. 200 of the Penal Code of Poland, whoever subjects a minor under 15 years of age to sexual intercourse shall be subject to the penalty of the deprivation of liberty for a term of between 1 and 10 years. It is worth highlighting Part 2 of this article, which envisages that punishment shall be imposed on anyone, who records pornographic material with the participation of such a person[34].

International health organizations classify the forms of sexual violence as follows: 1) rape and attempted rape; 2) unwanted sexual touching or compelling someone to touch another person; 3) voyeurism or photographing a person in an intimate situation without their consent; 4) sexual harassment and stalking; 5) exhibitionism, forced exposure to pornography; 6) any other sexual acts involving a person who does not provide consent or is unable to refuse the rapist or resist them[35].

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[30] Уголовный кодекс Австрии/науч. ред. Н. Е. Крылова; пер. А. В. Серебренникова. М.: Изд-во Зерцало-М, 2001. 144 с.

[31] Уголовный кодекс Швеции/науч. ред. Н. Ф. Кузнецова и С. С. Беляев; пер. с англ. С. С. Беляева. М.: Изд-во Моск. ун-та, 2000. 168 с.

[32] Уголовный кодекс Японии/науч. ред. предисл. и перевод докт. юрид. наук, проф. А. И. Коробеева. СПб.: Юрид. центр Пресс, 2002. 226 с.

[33] Trestni zakonik. Zakon Ceske republiky ze dne 8 ledna 2009 № 40/2009. Sbirka zakonů Ceske republiky. 2009. Častka 11.

[34] УгОлОвный кодекс Польши/науч. ред. канд. юрид. наук, доц. А. И. Лукашов, докт. юрид. наук, проф. Н. Ф. Кузнецова; вступ. статья канд. юрид. наук, доц. А. И. Лукашова, канд. юрид. наук, проф. Э. А. Саркисовой; пер. с польск. Д. А. Барилович. СПб.: Юрид. центр Пресс, 2001. 234 с.

[35] Injury Center: Violence Prevention. U.S. Centers for Disease Control and Prevention. URL: http://www.cdc.gov/violenceprevention/sexualviolence/definitions.html.

In most countries of the Anglo-American legal family, and, accordingly, scientific sources, sexual violence is considered as sexual relations with juveniles within the framework of the *child sexual abuse* concept that encompasses a wider range of actions that fall under the category of sexual abuse[36]. For example, in U.S. criminal law, the *sexual abuse* term refers to sexual intercourse perpetrated using threats or violence, or when the victim is unable to resist. At the same time, the specific physiological nature of sexual abuse, whether natural or unnatural, does not affect its legal classification. American researchers define child sexual abuse (CSA) as any sexual experience between a child under the age of 16 (aged from 1 to 18 years) and an individual who is at least 5 years older. Also, child sexual abuse is viewed as a form of sexual violence when an adult or adolescent exploits a child for sexual arousal, stimulation, or gratification[37].

However, when describing the terms used abroad, it can be observed that the definition of child sexual abuse is conveyed through the terms: child abuse, child neglect, sexual abuse, and sexual harassment. The most common is the term child abuse: sexual relationship between an adult and a child that encompasses a range of features, including: a) inequality; b) one-sided authority of the adult over the child, meaning dominance-subordination relationships; c) limitations on a child's freedom and choice; d) primary motivation for such relationships is the adult's sexual gratification[38] [272, p. 304].

A. Baker and S. Duncan define the *child sexual abuse* concept as sexual acts (oral, vaginal, petting, anal) committed by adults against a young child or adolescent[39].

R. Sonnets introduces a general concept for *sexual encroachment* that includes any sexually oriented activities exceeding socially acceptable boundaries in relationships between adults and children. Sexual encroachment against a child includes sexual violence and sexual abuse. Sexual violence is defined as "satisfying sexual desires with a child against the child's will, in circumstances where the child is unable to refuse and protect themselves due to an inequality of emotional and physical strength". Sexual abuse entails the non-coercive exploitation of a child as a sexual object for one's own sexual satisfaction[40].

G. Kemp believes that child sexual abuse should be understood as inducing dependent, underdeveloped children and adolescents to engage in sexual activities that they are completely incapable of understanding or giving consent to[41].

If we consider Ukrainian legislation, it should be stressed that in 2017, the *sexual violence* concept was included in the Criminal Code of Ukraine (CCU) as stipulated in

[36] Violence and its impact on the right to health - Report of the Special Rapporteur on the right of everyone to the enjoyment of the highest attainable standard of physical and mental health, Tlaleng Mofokeng (A/HRC/50/28). URL: https://reliefweb.int/report/world/violence-and-its-impact-right-health-report-special-rapporteur-right-everyone-enjoyment.

[37] Martin J, Anderson J, Romans S, Mullen P, O'Shea M (1993). Asking about child sexual abuse: methodological implications of a two stage survey. Child Abuse & Neglect 17 (3): 383–92. PMID 8330225. https://doi.org/10.1016/0145-2134(93)90061-9.

[38] Lang R. A., Frenzel R. R. How sex offenders lure children. Annals of Research. 1988. № 1. P. 303–307.C. 304.

[39] Baker A. W. Child sexual abuse a study of prevalence in Great Britain/A. W. Baker, S. P. Duncan//Child Abuse and Neglect. 1985. Vol. 9. P. 457–467. C. 460.

[40] Соонетс Р. и др. Недостойное обращение с детьми. Тарту: АО Атлекс, 2000.С. 104.

[41] Kempe C. Henry. The Battered-Child Syndrome. 1961. 389 p. C. 59.

the Law of Ukraine *On Amendments to the Criminal and Criminal Procedure Codes of Ukraine for the Purpose of Implementing the Provisions of the Council of Europe Convention on Preventing and Combating Violence against Women and Domestic Violence* No. 2227-VIII dated December 6, 2017.

This Law was adopted to comply with the requirements of the Council of Europe Convention on Preventing and Combating Violence against Women and Domestic Violence. Therefore, in Part 1 of Article 153 of the Criminal Code of Ukraine (CCU), the following definition is provided: sexual violence is the commission of any violent acts of a sexual nature, not related to penetration into the body of another person, without the victim's voluntary consent)[42].

In addition to the Criminal Code, the *sexual violence* concept is contained in the Law of Ukraine *On Prevention and Combating Domestic Violence* dated December 7, 2017, which is understood as a form of domestic violence that includes any non-consensual sexual act committed against an adult or a child regardless of their consent, or in the presence of a child, coercion to a sexual act with a third party, as well as other offences against the sexual freedom or sexual integrity, including those committed against a child on in their presence[43]. According to national legislation, these definitions indicate that sexual violence includes all acts of violence of a sexual nature, which may encompass both acts involving penetration into a person's body and those that do not. In O. O. Dudorov's opinion, as a result of the aforementioned legislative step, violent acts of a sexual nature that do not involve penetration into the victim's body are recognized as distinct from sexual violence[44].

While the amendments introduced by the domestic legislator have addressed some issues related to regulating criminal liability for *unnatural satisfaction of sexual desire*, they have also resulted in the emergence of new problems regarding the regulation of criminal liability for offenses envisaged by Chapter IV of the Special Part of the CC. One of these problems is the issue of how the *sexual violence* concept in Part 1 of Article 153 of the CC correlates with other criminal encroachments on sexual freedom and sexual inviolability as well as with efficient international instruments ratified by our state. The *sexual violence* concept in the current CC is used only to denote the act stipulated in Article 153 of the CC, whereas rape and other sexual deviations committed against a person's will are not categorized as sexual violence.

If we study theoretical papers by Ukrainian researchers, it becomes evident that the *sexual violence* concept encompasses all possible forms of sexual deviations.

Before the inclusion of the *sexual violence* concept in the Criminal Code of Ukraine, O. M. Dzhuzha, the distinguished expert in criminal law, had systematized the forms of sexual violence in criminal law, taking into account the object of encroachment. The first group comprises of the Criminal Code of Ukraine rules that directly protect relationships in the area of sexual freedom and sexual inviolability of a person (Articles

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[42] ККУ. URL: https://zakon.rada.gov.ua/laws/show/2341-14?find=1&text=153#w1_5.

[43] ЗУ. URL: https://zakon.rada.gov.ua/laws/show/2229-19?find=1&text=сексуал#w1_2.

[44] Дудоров О.О. Злочини проти статевої свободи та статевої недоторканості особи (основні положення кримінально-правової характеристики): практ. порадник. МВС України, Луган. держ. ун-т внутр. справ ім. Е.О. Дідоренка. Сєвєродонецьк: РВВ ЛДУВС ім. Е.О. Дідоренка, 2018. 92 с. С. 20.

152–156 of the CC). The second group includes criminal law rules imposing liability for encroachments inflicting harm not only to protected relationships but also to sexual ones. These are the following types of crimes: 1) clause 10, Part 2, Article 115 *Murde*r; 2) Article 303 *Pimping or engaging person in prostitution.* The main objects of these offenses are both the life of a person and moral values of population. However, certain harm can also be inflicted on sexual relationships, serving as an additional object. This is very clearly observed when encroaching on a person's life. It is important to highlight that this institution includes crimes that are somewhat related to sexual violence: 1) Article 149 *Trafficking in human beings or any other illegal agreement concerning a person's transfer*; 2) Article 297 *Violation of graves*; 3) Article 301 *Importation, production, sale or distribution of pornographic items*; 4) Part 4, Article 302 *Creating or running brothels and procuring*[45].

O. M. Humin classifies sexual violence as combined (mixed) forms of violence and suggests distinguishing between: 1) sexual violence without physical interaction (exhibitionism: displaying naked genitalia; voyeurism: secretly observing individuals as they undress or engage in sexual activities; child pornography: using children as models for obscene materials; verbal abuse and indecent comments of a sexual nature, including through phone or the Internet); 2) sexual violence involving physical interaction (dissolute actions: violent petting or manipulation of the genitalia, or coercing the victim into touching someone's genitals against their will; incest: sexual acts with relatives; rape: forced sexual intercourse involving physical force or the threat of its use[46].

H. M. Fedoryshyn notes that sexual violence has various manifestations. It includes not only physical forms but also sexual abuse, such as indecent SMS messages or messages on social networks, seductive phone conversations, etc.[47].

In practical psychology, which provides research findings of significant importance for addressing criminological issues, two types of sexual violence, particularly concerning children, are singled out:

– sexual violence without physical contact: a) fondling, groping, kissing, including secretly touching intimate parts of the child's body (for example, during bathing); b) causing embarrassment and shyness in a child through glances, verbal insults, obscene remarks, statements, and sexual phrases; c) exhibitionism (demonstration of one's genitals to the child); d) examination of the child's genitals; e) voyeurism (systematically observing a child while they undress, bathe, or use the toilet); f) child pornography (using children as models for shooting obscene content); g) making dirty phone calls with sexual connotations; h) masturbation in the presence of a child.
– sexual violence with alleged physical contact: a) friction of the penis against a child's body; b) forcing a child to masturbate in the presence of an adult; c) forcing a child to manipulate an adult's genitals; d) groping or manipulating a child's genitals; e)

[45] Джужа О. М. Запобігання злочинам, пов'язаним із сексуальним насильством: монографія. К.: Атіка, 2009. 240 с., С. 19.

[46] Гумін О. М. Кримінальна насильницька поведінка особи: теоретико-прикладні аспекти: автореф. дис. на здобуття наук. Ступеня д-ра юрид. наук: спец. 12.00.08. Львів, 2011. 38 с., С. 14.

[47] Федоришин Г. М. Сексуальне насильство над дітьми як соціальна і психологічна проблема. Молодий вчений. 2017. № 8 (48). С. 186–190., С. 189.

dissolute actions (violent petting); f) imitation of sexual intercourse with the help of a finger; g) incest (sexual acts with relatives); h) coercion to vaginal intercourse; i) coercion to anal sex; j) coercion to oral sex[48].

The viewpoint of K. Hobbs is of particular scientific interest, as he believes that sexual violence against a child can only manifest in sexual abuse:

- intrafamily violence is associated with sexual offenses committed by close blood relatives (parents, siblings); persons who act as substitute parents (adoptive parents, guardians, caregivers); individuals performing parental functions (the husband or cohabitant of the mother, and the wife or cohabitant of the father); close relatives (uncles, aunts, grandparents, cousins), with whom the child lives together or frequently interacts. All of these adults are authoritative figures for the child, and the child is devoted to and in a strict dependence on them;
- extrafamily violence involves sexual abuse by adults well known to the child, such as family friends, neighbours, distant relatives, or teachers. Since the child is acquainted with these persons, he/she trusts them and does not perceive them as a likely source of danger;
- street violence refers to sexual offenses committed by strangers or occasional acquaintances. Street manifestations of sexual violence are characterized by sudden attacks, the use of physical force or threats to supress the child's resistance;
- institutional violence often refers to closed communities of children and involves sexual offenses that are manifestations of hazing, when sexual violence is used to demonstrate power and control, and to establish hierarchical relationships within the group[49].

According to S. V. Romantsova, sexual violence against children is defined as unlawful use of a child to satisfy sexual needs of the offender or other persons which inflicts harm to the child's physical and mental health, psychosexual development, and hinders their further socialization[50]. She lists the following main peculiarities that define the *sexual violence against children* concept:

- unlawful use of a child;
- committed to satisfy sexual desires or gain advantage;
- perpetrated using violence or the threat of its use against the victim or other persons or by exploiting the victim's vulnerable state;
- can be perpetrated through information and communication technologies;
- the very fact of sexual acts with a child;

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[48] Говорун Т., Кікіненді О. Стать та сексуальність: психологічний ракурс. Навчальний посібник. Тернопіль: Навчальна книга. Богдан, 1999. 384с.

[49] Hobbs C. J., Hanks H. G., Wynne J. M. Child abuse and neglect. A clinicans handbook. Longman Group. London. 1993.C. 118.

[50] Романцова С. В. Запобігання сексуальному насильству щодо дітей в Україні. Дис. канд. юрид. наук 12.00.08 – кримінальне право та кримінологія; кримінально-виконавче право. Львів. Національний університет «Львівська політехніка». 244 с. URI: https://old.lpnu.ua/sites/default/files/dissertation/2018/10869/dis_mukan_o.v.r.pdf. С. 64.

– both an adult and a juvenile can be guilty[51].

Considering the issue of sexual violence and child exploitation in Ukraine and abroad from another perspective, it is vital to take into account the mechanism of combating them.

Combating child sexual violence and exploitation.

As envisaged by Article 19 of the Convention on the Rights of the Child[52]: "…States Parties shall take all appropriate legislative, administrative, social and educational measures to protect the child from all forms of physical or mental violence, injury or abuse, neglect or negligent treatment, maltreatment or exploitation, including sexual abuse, while in the care of parent(s), legal guardian(s) or any other person who has the care of the child".

This protection is primarily achieved through violence prevention, but what do we mean by *preventing*? The World Health Organization (WHO)[53] offers a definition based on three levels of intervention:

- primary prevention includes a set of measures aimed at preventing the emergence of a problem, pathology, or symptom: informing the public, target groups, or particular persons (through health education or health promotion), vaccination…
- the second level of prevention focuses on early detection of disorders for their subsequent early-stage treatment.
- the third level of prevention is aimed at averting complications in individuals who already have an illness or condition.

The World Health Organization (WHO) employs an intersectoral approach, sometimes referred to as the *social health protection model*. This model is also applied in other sectors, bringing together several sectors. Within this approach, work is conducted with the aim of:

- preventing a situation from occurring;
- indentifying a problem and attempts to resolve it;
- minimizing negative long-term consequences.

In cases of child maltreatment and combating child sexual violence and exploitation, the method presupposes:

- implementation of preventive measures;
- identification of violence cases and timely intervention;

[51] Романцова С. В. Запобігання сексуальному насильству щодо дітей в Україні. Дис. канд. юрид. наук 12.00.08 – кримінальне право та кримінологія; кримінально-виконавче право. Львів. Національний університет «Львівська політехніка». 244 с. URI: https://old.lpnu.ua/sites/default/files/dissertation/2018/10869/dis_mukan_o.v.r.pdf. С. 65.

[52] КОНВЕНЦІЯ про права дитини (20 листопада 1989 року) (редакція зі змінами, схваленими резолюцією 50/155 Генеральної Асамблеї ООН від 21 грудня 1995 року). Конвенцію ратифіковано Постановою ВР № 789-XII від 27.02.91. URI: https://zakon.rada.gov.ua/laws/show/995_021#Text.

[53] Посібник INSPIRE. Дії для впровадження семи стратегій задля припинення насильства стосовно дітей. URI: https://apps.who.int/iris/bitstream/handle/10665/272996/9789241514095-ukr.pdf.

- ongoing care and assistance to violence victims and their families;
- prevention of the recurrence of violence cases.

Preventing violence involves teaching both children and adults not only to anticipate and protect themselves from dangerous situations but also to communicate openly about such incidents before they lead to psychological problems and emotional disorders. The law of silence inherent in violence situations makes it extremely difficult to maintain a dialogue. However, even if the victim does not speak about what happened, their behaviour, depending on their age, shows various signs and signals about events.

Combating also involves enabling professionals working with children to recognize these signals and signs.

Preventing means creating a safe and supportive environment, primarily within the family and the community. Consolidation of positive parenting, which is strengthening protective and educational functions within a family, is a cornerstone in the fight against child sexual violence and exploitation.

The Law of Ukraine *On the Prevention and Counteraction of Domestic Violence*[54] envisages that domestic violence prevention is a system of measures implemented by executive authorities, local self-government authorities, enterprises, institutions, and organizations, as well as by citizens of Ukraine, foreigners, and stateless persons residing in Ukraine on legal grounds. These measures are aimed at increasing public awareness of the forms, causes, and consequences of domestic violence, promoting an intolerant attitude toward violent behaviour in personal relationships, fostering empathy for the victims, especially children, eliminating discriminatory beliefs about the social roles and responsibilities of women and men, as well as any customs and traditions stemming from such beliefs. Sexual violence is a form of domestic violence that includes any actions of a sexual nature committed against an adult without their consent, or against a child regardless of their consent or in the presence of a child. It also involves coercing into sexual acts with a third party and other offenses against a person's sexual freedom or inviolability, including those committed against a child or in their presence.

While combating child sexual violence and exploitation, prevention primarily serves as a means to ensure the efficiency of actions. Effects and results of morality-based prevention are limited in comparison with the impact achieved through active violence prevention methods.

To be efficient, prevention should be viewed as a dynamic process that adapts to the conditions in which it is implemented. It is not about direct opposition to violence, which may seem entirely legitimate, but rather about creating a context-specific system that discourages the likelihood of violence. This tendency is implemented through reevaluating behaviour in the context of violent actions. The ultimate goal is not only to demonstrate how violence is dangerous and, therefore, wrong but rather to showcase the capabilities of every child to resist and avoid violent situations.

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[54] Про запобігання та протидію домашньому насильству. Закон України. Відомості Верховної Ради (ВВР), 2018, № 5, ст.35. URI: https://zakon.rada.gov.ua/laws/show/2229-19#Text Із змінами, внесеними згідно із Законами № 2671-VIII від 17.01.2019, ВВР, 2019, № 18, ст.73 № 2849-IX від 13.12.2022}.

Active prevention methods enable every child to realize that there are alternatives to cruelty and violence, and they can be manifested not through their direct implementation but through creating an environment that fosters their genuine comprehension.

It is not about providing a ready-made action plan but rather about creating conditions where a child can respond to and break the cycle of violence (victim/perpetrator) in order to find a way out of a difficult situation independently or with someone's help. Only by carefully observing and analysing real situations of violence, without distancing themselves or panicking at the sight of cruelty, can adults and adolescents test and evaluate their own boundaries and resilience, become aware of their vulnerabilities, and recognize their potential to resist child sexual violence and exploitation.

Thus, it is not just individuals but also society and the state as a whole that create a particular action plan, often referred to as *best practice*. But what does this concept entail?

The definition for the *best practice* concept varies. According to UNESCO, a best practice is a "creative, successful, and long-term method for addressing social problems related to poverty and social isolation". Following the European Commission's definition, it pertains to "efficient practice(s) aimed at solving specific situations or problems, achieving a set goal, and creating conditions for problem-solving or comprehensive solutions in combination with other methods". According to the Committee of the Regions of the European Union, a best practice is "local peculiarities, measures, and innovative projects that have been successfully implemented and can now be successfully disseminated".

All these definitions converge in the fact that best practice should be innovative, efficient, designed for the long term, and capable of replication. Furthermore, four elements can be identified that provide added value and ensure prevention efficiency: a resilient approach, a spiritual approach, a legal approach, and a community approach.

These four characteristics have formed the basis for the practices that we will further consider.

1. Resilient Approach.

Resilience is a quality inherent in every person that allows them to grow and develop while facing substantial challenges. Stefan Vanistendael[55] lists five factors that need to be considered in measures to strengthen the resilience of a child who has experienced trauma. All of these factors, in one way or another, stem from the child's interaction with those around them:

- accepting the child as a human being by at least one adult;
- possibility of discovering the meaning of life that is essential for the child through artistic creativity, concern for animals, religion, participation in team sports, educational programs, etc.;
- development of a child's sense of self-esteem;
- possibility of acquiring various skills from a professional, human, and social perspective;
- effective use of humour.

[55] Ваништендаль Стефан, Резильентность или оправданные надежды. Раненый, но не побежденный. Научные труды БИСЕ, Женева, 1998.

While combating child sexual violence and exploitation, it is essential that these factors are developed and taken into account in order to contribute to the overall development of the child and to enable them to strengthen their internal capabilities to resist potential acts of violence. Prevention of cases of violence based on a resilient approach is largely grounded on the development of life dynamics and so-called life skills, in conjunction with a supportive environment and adult guidance. All measures are built upon the strengths of children rather than their potential weaknesses and vulnerabilities.

2. Legal approach.

A legal approach means that everyone, both adults and children, knows their rights and can use them efficiently. Children should not only receive assistance but also become full-fledged participants in their own lives, knowing their rights and being able to exercise them.

In the program of combating child sexual violence and exploitation, this aspect is fundamental as the knowledge of their rights is the first step towards their implementation.

3. Spiritual approach.

The *spirituality* term is used in its broadest sense to encompass all aspects of a person's inner life. Spirituality is considered important because it adds vitality to a child's life. It allows children to transcend their "momentary" existence, move away from materialism, and discover a perspective that reveals life's deeper elements, which are sometimes obscured by everyday challenges. Spiritual strength helps to appreciate simple things like beauty, nature, and silence; it fosters empathy, commonality, kindness: all of which are essential for creating a safe and child-friendly environment.

4. Community approach.

A community approach is a social process in which specific groups united by common geographical location and shared needs strive to identify their problems and establish consensus-based, long-lasting solutions.

Drawing interim conclusions from the discussion of countering child sexual violence and exploitation, the following must be done:

Comprehensive and efficient national legislation is needed to protect children from all forms of sexual violence and exploitation in both the online and real world. This means not only criminalizing the actions of those who commit sexual offenses. Legislation must also ensure that law enforcement can identify the perpetrators of such actions, protect victims, and safeguard the rights of the victims. Internet service providers should provide a secure platform for the preview of online materials and reporting.

Legislation can rely on existing international laws or use them as a model, incorporate international standards and efficient child protection practices, and be based on security measures stipulated in the United Nations Convention on the Rights of the Child and its Optional Protocol on the sale of children, child prostitution and child pornography. In this Protocol, it is explicitly stated that States Parties, in order to achieve the objectives of the Convention on the Rights of the Child and fulfil its provisions, deem it advisable to

broaden the scope of measures aimed at ensuring the guaranteed protection of children from trafficking, prostitution, and pornography[56].

The results of the scientific and practical research outlined above allow us to talk about two main directions in combating child sexual violence: work focused on preventing episodes of sexual violence and measures aimed at overcoming the negative consequences of such episodes. Implementation of these directions is closely interrelated due to the realization of the psychological mechanism known as the *cycle of violence*, which ensures reccurrence of violence involving individuals who have experienced it and people related to it[57]. It is obvious that measures to prevent violence should be implemented by educational institutions, social services, national and international non-governmental organizations and associations, mass media, and law enforcement agencies.

As practice shows, business cooperation between law enforcement agencies and mass media often yields positive results. In today's crisis conditions characterized by a sharp increase in crime situation, interaction between the police and other law enforcement structures with mass media outlets demands immediate activation. But at the same time it is crucial that efforts need to be focused on particularly acute areas, employing the most effective forms and methods of collaboration, as mass media, given their vast daily audience, can make a significant contribution to combating and preventing crime[58].

Conducting legal education activities in the adolescent environment with the involvement of representatives of juvenile prevention and mass media necessitates careful planning, defining the purpose and content, identifying the target audience, and considering event co-executors, methods, forms of its implementation, expected outcomes, and establishing achievement indicators for the set goal[59].

One of the factors that combats sexual violence against children at the socio-cultural level is an efficient system of punishment for the perpetrators of such violence. Investigating these criminal cases and holding the perpetrators criminally liable is of particular importance for the psychological well-being of the victims, as it can be the basis for a child's belief in the restoration of justice, the overcoming of fear of the perpetrator and the restoration of the child's reputation in their community.

Investigating criminal proceedings initiated in cases of sexual violence is a complex task. The difficulties in establishing guilt are due to several reasons related to the nature of a crime: the presence of a longer or shorter time gap between the offense (which is often repetitive) and reporting it to law enforcement agencies; often the absence of physical

[56] Факультативний протокол до Конвенції про права дитини щодо торгівлі дітьми, дитячої проституції і дитячої порнографії. Ратифіковано Законом України N 716-IV (716-15) від 03.04.2003, ВВР, 2003, N 29, ст.226. URI: https://zakon.rada.gov.ua/laws/show/995_b09#Text.

[57] Сексуальне насильство над дітьми: причини, наслідки, профілактика: інформ.-метод. Посібник. Автори-упоряд. Цюман Т. П., Малієнко Ю. М.; За заг. ред. Цюман Т. П. Київ: ФОП Пономаренко Я.М. 2011. 76 с.

[58] Філіпенко Н. Є. Кримінологічна діяльність і питання правового виховання населення. Наше право. 2020. № 3., С. 146–151.

[59] Філіпенко Н. Є., Язан Н. С. Засоби масової інформації як складова кримінологічної діяльності підрозділів ювенальної превенції щодо правового виховання підлітків. Архів кримінології та судових наук: Науковий журнал. Вип. № 2. Харків ННЦ «ІСЕ ім. Засл. проф. М. С. Бокаріуса», 2023.

evidence and witnesses of a crime; the need to establish the truth based on the testimonies of the parties involved, whose versions of events may differ or be contradictory; a high risk of the victim changing their testimony as a result of influence from the suspect or their family; the need to establish the qualifying elements of a crime, which are often psychological facts. These phenomena include the need to assess a child's capacity to comprehend the meaning and nature of actions taken against them, their ability to resist such actions, the incomprehensibility of the child's behaviour by law enforcement officers. Conducting forensic psychological examination is valuable in accomplishing this task. In the Ukrainian legal system, expert conclusions serve as significant sources of evidence[60]. To address a wide range of the aforementioned tasks, including establishing the psychological basis for confirming legal criteria, law enforcement agencies order forensic psychological or multidisciplinary psycho-psychiatric examinations.

Currently, in Ukraine, a series of measures is being implemented to ensure that the justice system is designed to prevent re-traumatization of children, in particular, new standards for interrogating children during a criminal proceeding are being introduced[61]. At the same time, we encounter many cases of improper behaviour during child interrogations, where psychological traits of the child are not taken into account or are improperly considered[62].

The practice of carrying out psychological examinations on child victims in the Poltava Branch of National Scientific Center «Hon. Prof. M. S. Bokarius Forensic Science Institute» does not provide sufficient empirical data for statistical generalizations. However, it illustrates the data from the aforementioned sociological studies regarding the gender and age composition of victims of sexual offenses, sheds light on issues arising from sexual violence, offers new perspectives, highlights problems in the investigation of cases related to the infringement upon children's sexual inviolability, and presents ways to address them.

We have nineteen cases. In our practice, the victims are predominantly girls, and we have worked with only three boys. The majority of the victims are adolescents, with two being late adolescents, and two being preschoolers. In only four cases, the perpetrators were previously unknown to the child, and in two cases, other children were the offenders. Most cases of child sexual violence had been committed by relatives. A great number of

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[60] Кримінальний процесуальний кодекс України: Закон України від 13.04.2012 № 4651-VI. URL: http://zakon3.rada.gov.ua/laws/show/4651-17.

[61] Див. докладніше: Керівні принципи Комітету міністрів Ради Європи щодо правосуддя, дружнього до дітей, прийняті Комітетом міністрів Ради Європи 17 листопада 2010 року, і пояснювальна записка. Видавництво Ради Європи. URL: http://book.coe.int; Особливості опитування неповнолітнього потерпілого чи свідка злочину. Пам'ятка судді. URL: https://dejure.foundation/library/osoblyvosti-opytuvannia-nepovnolitnikh-pamyatka-prokuroru.

[62] Журавльова М. О. Помилки в опитуванні дитини. Актуальні питання судової експертизи і криміналістики: зб. матеріалів міжнар. наук.-практ. конф.-полілогу (м. Харків, 15—16 квіт. 2021 р.). Харків: Право, 2021. 320 с., С. 162-164.; Сліпець О О. До проблеми допиту неповнолітніх. Актуальні питання судової експертології, криміналістики та кримінального процесу: матеріали III міжнар. наук.-практ. конф. (м. Київ, 15 грудня 2021 р.)/за заг. ред. Н. В. Нестор; уклад. О. В. Баулін, О. І. Жеребко, Т. П. Кривак, О. О. Садченко, А. В. Старушкевич, О. В. Юдіна К.: Видавництво Ліра-К, 2021. Без нумерації сторінок.

children who experienced sexual violence were raised in families with a stepfather under conditions of inadequate supervision and emotional rejection. Two girls had conflicts with their mothers on the day of violence, and one stayed at her sister's house due to a conflict.

With this information, one can look at the phenomenon of high latency in crimes against sexual inviolability from a different perspective. Of all the cases we worked on, only in six of them did parents know about it immediately, and in five of them, the children cried, trembled, had physical injury marks, so not noticing these signs was extremely difficult. The reasons for the lack of disclosure by other children were feelings of shame and an inability to have the courage to speak, fear of threats from the perpetrator, and a lack of belief that they would be trusted. These fears are not always groundless. In four cases, mothers/guardians received information about sexual violence against a child and took no action to protect the child. In two cases, mothers implied to the child that their life would become more difficult if they took action against the child's stepfather; and in the other two cases, they stated that the girl was not telling the truth. In the latter case, caregivers and a psychologist at the kindergarten as well as the guardians of a family-style orphanages noticed that the child was drawing people with genitals, reacting specifically to scenes with sexual undertones; however, they believed the older ward who denied violence. Children often do not make the decision to report the abuse to their parents or law enforcement. Instead, other relatives (aunts, biological father who lives separately), peers, learn about it because children cannot bear the burden of negative experiences and are often afraid of revealing truth to parents.

Our observations point to the importance of adjusting conditions influenced by socio-cultural factors: conditions of child upbringing, quality of education, work of school psychologists and social workers, teaching them to recognize signals that may indicate possible sexual violence against children; educational work among children, for whom it is important to know what actions towards them are unacceptable, and that they are not responsible for any instances of sexual violence that may happen to them.

The situation of pre-trial investigation often "justifies" the worst expectations of children regarding challenges that await them after the disclosure of the fact of violence. In the course of pre-trial investigation, they are subjected to repeated traumatization due to the fact that their testimonies are called into question. During pre-trial investigation, suspects often deny committing sexual violence, point to the child's "fantasy" or state that the child himself/herself wanted sexual contact. There is a case where the stepfather claimed that his six-year-old stepdaughter seduced him and performed orogenital sexual acts with him.

Physical evidence of crimes against children's sexual inviolability is often absent or already missing at the time of investigation, there are usually no eyewitnesses to sexual violence, and teachers or parents do not notice signs of changes in children's behaviour. As a result, the investigator is in a situation where he has contradictory testimonies of an adult and a child and must evaluate them. In order to evaluate testimonies reasonably, psychological experts are asked the question of the child's ability to perceive and reproduce events, the presence or absence of the child's tendency to excessive fantasizing. According to the author's practice, such questions have been asked in fifteen cases. In five cases, children's testimonies were changed during pre-trial investigation, one girl

refused to testify about the violence she had suffered and then went back to it, another one faced pressure during trial. This information indicates the great importance of a qualitative interrogation of children. Some of these problems are solved by placing the child in a shelter, detaining the suspect, interrogating the child in trial at the stage of pre-trial investigation in accordance with Art. 225 of the Criminal Procedure Code of Ukraine. However, oftentimes the method of interrogating (interviewing) a child does not make it possible to meet the goals of this procedural action and inflicts harm to children.

All the children examined by us during forensic examinations had signs of mental trauma: acute or chronic. The specifics of mental trauma manifestation depends on the age of the child and mainly corresponds to the specifics of the reaction of children of a certain age to mental trauma which is manifested in: regression of cognitive skills, deformation of emotional and volitional development, formation or exacerbation of specific character traits (violations in the sphere of individuality), violation in the development of communicative competences, personality development disorder[63].

Most children say that their emotions have improved since they became aware of sexual violence. Our examinees attribute this improvement to a change in living conditions (moving to biological father, placement in a shelter, exclusion of the rapist from the family by the mother, etc.), lack of the need to stay vigilant.

At the same time, in the course of interrogation, we have not come across any cases when the child would have already received systematic psycho-corrective care during forensic examination. In addition, at the time of forensic examination, the children often had difficulty in explaining exactly what had been done to them. Meanwhile, most of our examinees had normal cognitive development, and those who were found to be lagging behind had sufficient competence to tell about the external side of events. Also, the use of known methods of talking to a child, which include respect for them and their personal boundaries, openness and honesty, balance, attention to the emotions and experiences of the child and compliance with other rules of conversation with such children, ensures obtaining valuable data and brings positive results for children. Thus, the experience of conducting forensic psychological examinations of children who have experienced sexual violence shows the importance of repeated remarks (especially those that are supposedly accidental) about the lack of the child's guilt for what happened and for the fact that they did not immediately tell about violence, as well as demonstrates the significance of discussion and provision of definition for a *dictionary* with the help of which one can talk about violence, using the simplest visualisation: pictures (especially in children's encyclopaedias) and dolls, consideration of possible options for the development of future events and ways of the child's behaviour in response. Observance of the above rules as well as an in-depth conversation about the child's life which is carried out in view of the mandatory use of the biographical method during forensic psychological examination is the reason why this conversation takes place: at the end of it, the children often have a smile on their faces, they themselves are more self-confident, although psycho-corrective effects are not the task of expert diagnostic interview.

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[63] Сліпець О.О. Психологічна експертиза неповнолітніх потерпілих як дослідження ушкодженого психічного розвитку. Теорія та практика судової експертизи і криміналістики: зб. наук. пр. Харків: Право, 2008. Вип.8. 651с. С. 605-610.

Our experience in performing forensic psychological examinations of children who have experienced sexual violence, which includes a thorough examination of their level of mental development, character traits, cognitive and communicative abilities, overall awareness and awareness of sexual relationships, helps us to expand our understanding of the child's individual risk factor. Thus, our research is consistent with the statement that active, brave teenagers who have a large circle of acquaintances, are open to new acquaintances and often realise late that they are in danger have a slightly increased risk of experiencing sexual violence. At the same time, most of the victimized children we have worked with are emotionally vulnerable, obedient, indecisive and insecure, willing to take on non-child responsibilities (care and protection of younger children, housekeeping, etc.) and feel guilty when things go wrong. Among the victimized children we have studied, the vast majority had a low level of knowledge about the sexual sphere. These observations are a valid reason for further development of educational work both among adults who work with children and among children themselves.

In addition to forensic psychological examinations, there is another type of research involving work with children. This is forensic examination of people's communicative activity which is recorded on video. Conducting such forensic examination does not presuppose discovering peculiarities of the child's individuality, but it provides answers about peculiarities of their interrogation (interview) by an investigator or judge, or about questioning during an unregulated interview. One of the main results of forensic examination is to determine if the child has experienced any mental pressure that might have affected their narrative. Establishing whether there has been an influence altering the child's narrative is crucial in understanding the child's decision to retract their testimony.

Out of the sixteen studies we conducted, eight involved interrogations conducted in an investigator's office or in a *Green Room.* Four studies took place during trial, and another four were performed during conversations between teachers and children. These studies reveal the most common mistakes made by investigators, teachers, and psychologists involved in the procedural action.

As previously discussed (11), our analysis of video recordings of interrogations and interviews points to mistakes made by adults during interviews. We will list the most common of these and provide comments on their impact on the child from the perspective of developmental psychology:

1. As for interview organization: uncomfortable conditions or the lack of privacy, including conducting interviews in a cramped room where the child sat next to their mother and educators, in outerwear, or under conditions of the *Green Room*, where the furniture is designed for younger children. Discomfort hinders optimal communication, and the invasion of privacy leads to mental tension;
2. At the stage of establishing psychological contact: excessively formalized appeal or flattery, addressing as if to an infant with imitation of *motherly language.* From a psychological perspective, such mistakes create conditions for the child to think that they are not of interest, that they are not understood, and that adults are insincere;
3. At the stage of discussing the child's life: formalized questions about school performance, clubs, etc. They may trigger negative associations in children who have experienced violence in educational institutions, evoke negative feelings in children with low academic performance or behavioural disorders, and create a sense of insincerity;

4. Regarding conversation style:
   - asking several questions in a row may lead to providing an answer only to the last question due to the difficulty of maintaining active attention and the need for a significant amount of short-term memory resources to keep all questions in mind;
   - asking questions containing information not previously mentioned or contradicting what the child has previously stated (referred to as suggestive questions) can lead to a change in the child's narrative and may result in the child retracting their own testimony;
   - providing evaluations addressed directly to the child regarding truthfulness of their testimonies, intellectual abilities, character and behaviour, create psychological tension, an understanding of the need to meet adult expectations, and sustain a feeling of guilt;
   - discussing the child with other interview participants increases mental tension, creating a feeling that the child is an object in whom no one is interested, leading to decreased self-esteem;
   - duration of the interview lasting over an hour creates discomfort and enhances subservience due to fatigue;
   - making promises, including those that the interviewee cannot fulfil.

Identification of errors in interrogations by a forensic expert, especially those that have led to changes in children's testimonies, helps law enforcement agencies understand the reasons for children retracting their testimonies. Establishing the presence in the child's testimony of the narrative about their direct bodily sensations, emotions, experiences, specific circumstances, their actions, and actions of the perpetrator, as well as determining the child's emotional involvement in their own narrative, allows the court to evaluate the child's testimony as a description of events that they have experienced.

4 Conclusions

Summing up the consideration of the issue of child sexual violence and exploitation in Ukraine and abroad, the following can be stated:

1. This is an increasingly complex and sensitive issue that requires in-depth cooperation between legal scholars, medical professionals, government institutions, and non-governmental organizations, as well as implementation of foreign countries' experience into Ukrainian legislation. It is particularly important in addressing the mentioned crimes because they pose a substantial public danger. These crimes not only harm social relationships, social and moral values, but also disrupt victims' social connections, creating challenges for their adaptation to society after experiencing moral and physical trauma and leading to the development of severe post-traumatic mental disorders.
2. Efficient legislation will enable law enforcement agencies to proactively investigate and prosecute persons committing crimes of a sexual nature against children, identify more victims, and protect them. This is particularly crucial when it comes to offenses on the Internet, where evidence regarding contact sexual violence is lacking. The issue of how the *sexual violence* concept, as defined in the context of Article 153,

Part 1 of the CC, relates to other offences that share elements of such sexual violence can be addressed through two alternative approaches. It appears advisable to create a separate section in the Special Part titled *Criminal Offenses Involving Sexual Violence* that would encompass all possible forms of sexual deviations committed against the victim's will. At the same time, the act that currently corresponds to the disposition of Art. 153 of the Criminal Code may be titled *Violent Acts of a Sexual Nature Not Involving Penetration into Another Person's Body*. Another approach could involve entirely removing the *sexual violence* term from the text of the Criminal Code while simultaneously presenting the title of Art. 153 of the CC as in the previous version. But such a proposal definitely needs further thorough research.

3. Data obtained during forensic psychological examinations illustrate and complement existing scientific data from developmental and crisis psychology concerning factors that contribute to a child ending up in a situation of sexual violence, assist in the efficient investigation of crimes against sexual inviolability, and reveal several issues related to interrogating children. Among individual factors that contribute to a child's vulnerability in such situations are personality traits and characteristics falling within the "inhibited" spectrum: obedience, deference to elders' authority, non-confrontational behaviour, indecisiveness, taking on responsibilities that are not age-appropriate (such as caring for younger children and housekeeping), a limited level of developed social competence, as well as a restricted understanding of matters related to sexual life. This stresses the importance of education and awareness-raising work among children for sexual violence prevention. Performing forensic psychological examinations involving direct examination of child victims provides the investigative and judicial authorities with required information on the psychologically justified actions of a child in a situation of sexual violence against them, enables to determine qualifying elements of the committed crime and contributes to the efficient mitigation of negative consequences experienced by the child. Conducting forensic psychological examinations of video recordings of child interrogations, appointed in criminal proceedings related to sexual violence crimes against children, helps the court properly evaluate children's testimonies.
4. Crimes involving child sexual violence and exploitation can transcend borders when the perpetrator resides in one country and the victim in another. In cases of child sexual exploitation, the service provider is often a resident of another state. Therefore, legal approaches to preventing and combating sexual violence and exploitation of children should be as coordinated and consistent as possible to prevent perpetrators committing sexual crimes against children from directing their efforts to those countries where children are more vulnerable, which is well-known to such individuals.
5. Ending violence against children requires both primary prevention and effective response. Primary prevention aims to address core beliefs, attitudes and behaviours, inequalities, risks and driving forces of violence at the level of an individual, family and relationships, community, organisation/institution and wider social and political context.
6. Developing and implementing effective strategies to end violence against children within the Ukrainian community should encompass all forms of violence, whether it be physical, emotional, psychological, or neglect. However, there is a need for special

coordinated attention to the issues of child sexual violence and exploitation. In addition, a support strategy for parents and caregivers may encompass general programs for all families, targeted programs for at-risk families, and/or individual programs for parents and caregivers whose children have experienced violence. Promotion of positive or nurturing parenting is a central element of support programs for parents and caregivers. These techniques assist mothers, fathers, and caregivers in managing children's behaviour and provide alternatives to physical punishment. Parental support also helps parents understand child development and enhance communication with their children, which are protective factors against physical and sexual violence. Many programs help parents teach their children skills such as emotional regulation, problem-solving, and social skills, which help children build resilience and avoid experiencing or perpetrating violence or bullying in the future. All efforts to create a safer environment benefit from active community involvement in planning and implementation to ensure the relevance and effectiveness of interventions aimed at expanding community participation.

7. Implementation of positive international experience in creating a safe environment for preventing child sexual violence and exploitation. For instance, the introduction of the *Breaking Boundaries* program. This is a school curriculum combining education on gender-based violence with situational crime prevention, interaction with offenders and victims. The school's curriculum focuses on the legal consequences of violence during dates, gender equality, and healthy relationships. The issues of combating child sexual violence and exploitation become particularly relevant during times of armed conflicts.

Bibliography

1. Baker, A.W.: Child sexual abuse a study of prevalence in Great Britain [Baker, A.W., Duncan, S.P.] Child Abuse Neglect **9**. 457–467 (1985)
2. Economist. Out of the Shadows: Shining the Light on the Response to Child Sexual Abuse and Exploitation: A 40 Country Benchmarking Index. Economist Intelligence Unit, London (2018)
3. Hobbs, C.J., Hanks, H.G., Wynne, J.M.: Child Abuse and Neglect. A Clinicans Handbook. Longman Group, London (1993)
4. Injury Center. Violence Prevention. U.S. Centers for Disease Control and Prevention. http://www.cdc.gov/violenceprevention/sexualviolence/definitions.html
5. INSPIRE Посібник з показників та матриці результатів. Нью-Йорк: ЮНІСЕФ (2018) рік
6. Kinder, K.G.g.: Bundesministerium für Familie, Senioren, 24 p. Frauen und Jugend, Bonn (1998)
7. Henry, K.C.: The Battered-Child Syndrome, 389 p. (1961)
8. Lang, R.A., Frenzel, R.R.: How sex offenders lure children. Annal. Res. **1**, 303–307 (1988)
9. Ligiero, D., Hart, C., Fulu, E., Thomas, A., Radford, L.: What works to prevent sexual violence against children: Evidence Review. Together for Girls (2019). www.togetherforgirls.org/svsolutions

10. Marcy, L., Messner, L., Duffy, M., Casto, J.: Зміцнення зв'язків між клінічними соціальними/громадськими послугами для дітей та підлітків, що зазнали сексуального насильства: супровідний посібник. Арлінгтон, Вірджинія: Проект «Зміцнення високоефективних інтервенцій для покоління без СНІД». 2016 рік (2016). https://aidsfree.usaid.gov/resources/prc-companion-guide
11. Martin, J., Anderson, J., Romans, S., Mullen, P., O'Shea, M.: Asking about child sexual abuse: methodological implications of a two stage survey. Child Abuse Neglect **17**(3), 383–92 (1993). PMID 8330225. https://doi.org/10.1016/0145-2134(93)90061-9
12. Stoltenborgh, M., van Ijzendoorn, M., Euser, E., Bakermans-Kranenburg, M.: A global perspective on child sexual abuse: meta-analysis of prevalence around the world. Child Maltreatment **16**(2), 79–101 (2011)
13. Hillis, S., Mercy, J., Amobi, A., Kress, H.: Global prevalence of past-year violence against children: a systematic review and minimum estimates. Pediatrics **137**(3). (2016). https://publications.aap.org/pediatrics/article-abstract/137/3/e20154079/81439/Global-Prevalence-of-Past-year-Violence-Against?redirectedFrom=fulltext
14. Trestni zakonik. Zakon Českе republiky ze dne 8 ledna 2009 № 40/2009. Sbirka zakonů Českе republiky. Častka 11. (2009)
15. UNICEF: A New Era for Girls: Taking Stock of 25 Years of Progress. UNICEF/UNWomen/Plan International, New York (2020)
16. Unicef.org. https://static1.squarespace.com/static/5630f48de4b00a75476ecf0a/t/5deecb0fc4c5ef23016423cf/1575930642519/FINAL+-+Global+Threat+Assessment.pdf
17. Violence and Its Impact on the Right to Health - Report of the Special Rapporteur on the right of everyone to the enjoyment of the highest attainable standard of physical and mental health, Tlaleng Mofokeng (A/HRC/50/28). https://reliefweb.int/report/world/violence-and-its-impact-right-health-report-special-rapporteur-right-everyone-enjoyment
18. Wager, N., Armitage, R., Christmann, R., Gallagher, B., et al.: Rapid evidence assessment: quantifying the extent of online-facilitated child sexual abuse: In: Report for the Independent Inquiry into Child Sexual Abuse. University of Huddersfield, Huddersfield (2018). https://www.iicsa.org.uk/document/rapid-evidence-assessment-quantifying-extent-onlinefacilitated-child-sexual-abuse
19. WHO. INSPIRE: Seven Strategies for Ending Violence Against Children. World Health Organisation, Geneva (2016); WHO. INSPIRE Handbook: Action for Implementing the Seven Strategies for Ending Violence Against Children. World Health Organisation, Geneva (2018)
20. WHO: Responding to Children and Adolescents Who Have Been Sexually Abused: WHO Clinical Guidelines. World Health Organisation, Geneva (2017)
21. Kolomiets, V.: Sexual Violence During War is a War Crime that has No Statute of Limitations (2023). https://minjust.gov.ua/news/ministry/valeriya-kolomiets-seksualne-nasilstvo-pid-chas-viyni-tse-voenniy-zlochin-yakiy-ne-mae-stroku-davnosti
22. Vanishtendal, S.: Resilience or Justifiable Hopes. Early, But Not Defeated. Scientific Works of the BISE, Geneva (1998)
23. Busel, V.T.K. (eds.): A Large Explanatory Dictionary of the Modern Ukrainian Language/Comp. and Goal, 1440p. VTF "Perun", Irpin (2003)
24. Govorun, T., Kikinendi, O.: Gender and Sexuality: A Psychological Course. Tutorial. Ternopil: Educational Book. Bohdan, 384p. (1999)
25. Humin, O.M.: Criminal Violent Behavior of a Person: Theoretical and Practical Aspects: Autoref. thesis for Obtaining Sciences. Doctor of Law degree. Sciences: specialist 12.00.08. Lviv. 38p. (2011)
26. Dzyzha, O.M.: Prevention of Crimes Related to Sectarian Targeting: Monograph. K.: Atika. 240c (2009)
27. Dzhuzha, A.O.: Alcohol intoxication as a victimogenic factor contributing to the commission of sexual crimes. Sci. Bullet. KNUVS **2**, 184–186 (2010)

28. Dzhuzha, A.O.: Criminal-Legal and Criminological Principles for the Prevention of Crimes Against the Sexual Integrity of a Child: Monograph/NAVS. K., 193p. (2013)
29. Herman, J.: Psychological Trauma and the Path to Recovery: The Consequences of Violence - From Domestic Abuse to Political Terror, p. 424. Stary Lev Publishing House, Lviv (2019)
30. Dudorov, O.O.: Crimes Against Sexual Freedom and Sexual Integrity of a Person (Main Provisions of Criminal Law Characteristics): Practice. Adviser. Ministry of Internal Affairs of Ukraine, Luhan. State University of Internal Affairs Named After E.O. Didoren-ka Severodonetsk: RVV LDUVS Named After E.O. Didorenko, 92p. (2018)
31. Zhuravlyova, M. O.: Errors in the survey of a child. In: Actual Issues of Forensic Examination and Criminology: Coll. Materials of International Science and Practice Polylogue Conference, Kharkov, 15–16 April 2021, 320p., pp. 162–164. Pravo, Kharkiv (2021)
32. Guidelines of the Committee of Ministers of the Council of Europe on child-friendly justice, adopted by the Committee of Ministers of the Council of Europe on 17 November 2010, and Explanatory Note. Publishing House of the Council of Europe. http://book.coe.int; Peculiarities of Interviewing a Minor Victim Or Witness of a Crime. Memo of the Judge. https://dejure.foundation/library/osoblyvosti-opytuvannia-nepovnolitnikh-pamyatka-prokuroru
33. Convention on the Rights of the Child. (as amended by UN General Assembly resolution 50/155 of December 21, 1995). The Convention was ratified by the Verkhovna Rada Resolution No. 789-XII dated 27.02.91 (November 20, 1989). https://zakon.rada.gov.ua/laws/show/995_021#Text
34. Council of Europe Convention on the Prevention of Violence against Women and Domestic Violence and Combating These Phenomena (Istanbul Convention) dated May 11, 2011. https://zakon.rada.gov.ua/laws/show/994_001-11#Text
35. Council of Europe Convention on the Protection of Children from Sexual Exploitation and Sexual Violence (the Convention was ratified with declarations by Law No. 4988-VI dated 20.06.2012). Official Translation. https://zakon.rada.gov.ua/laws/show/994_927#Text
36. Kostenko, S.S.: Victimological prevention of sexual crimes against minors: abstract of the thesis for the acquisition of sciences. Candidate Degree Legal Sciences, Specialty 12.00.08 - Criminal Law and Criminology, Criminal Executive Law, 20p. (2004)
37. Krasnokutskyi, M.I.: Some aspects of providing psychological assistance to children who have experienced violence. Probl. Extreme Crisis Psychol. **17** (2015)
38. Criminal Codex of Ukraine. https://zakon.rada.gov.ua/laws/show/2341-14?find=1&text=153#w1_5
39. Criminal Procedure Code of Ukraine: Law of Ukraine Dated 04.13.2012 No. 4651-VI. http://zakon3.rada.gov.ua/laws/show/4651-17
40. Measures to Stop Sexual Violence and Exploitation of Children. UNICEF (2020). Published by the UNICEF Child Protection Section, Program Unit 3, United Nations Plaza, New York 10017 Email: childprotection@unicef.org Website: www.unicef.org © United Nations Children's Fund (UNICEF), December, 2020, p. 2 (2020)
41. INSPIRE Guide. Actions to implement seven strategies to end violence against children. https://apps.who.int/iris/bitstream/handle/10665/272996/9789241514095-ukr.pdf
42. Explanatory report to the Council of Europe Convention on preventing and combating violence against women and domestic violence (Istanbul Convention) dated May 11 (2011). https://rm.coe.int/1680093d9e
43. About preventing and combating domestic violence. Law of Ukraine. Bullet. Verkhovna Rada (VVR) **5**, 35 (2018). https://zakon.rada.gov.ua/laws/show/2229-19#Text. As amended in accordance with Laws No. 2671-VIII dated 17.01.2019, VVR, 2019, **18**, 73 No. 2849-IX Dated 13.12.2022
44. Zimbabwe Intersectoral Sexual Abuse and Violence Management Protocol. Legal Services Committee; Harare (2012). http://www.togetherforgirls.org/wp-content/uploads/2017/10/Multi_Sectoral_Protocol_2012-Zimbabwe.pdf

45. Romantsova, S.V.: Prevention of Sexual Violence Against Children in Ukraine. Diss. Ph.D. law Sciences 12.00.08 – criminal law and criminology; criminal executive law. Lviv. Lviv Polytechnic National University. 244p (2018). https://old.lpnu.ua/sites/default/files/dissertation/2018/10869/dis_mukan_o.v.r.pdf
46. Tyuman, T.P., Malienko, Yu.M. (eds.): Sexual Violence Against Children: Causes, Consequences, Prevention: Information-Method. 76p. FOP Ponomarenko Y.M., Kyiv (2011)
47. Slipets, O.O.: Psychological examination of juvenile victims as a study of impaired mental development. In: Theory and Practice of Forensic Examination and Criminology: Collection of Science Kharkiv Ave.: Right. Issue 8, pp. 605–610, 651 (2008)
48. Slipets, O.O.: To the problem of interrogation of minors. In: Nestor, N.V., et al. (eds.): Current Issues of Forensic Expertise, Criminology and Criminal Process: Materials of the III International Science and Practice Conference, Kyiv, 15 December 2021. Lira-K Publishing House (2021)
49. Soonets, R.: Inappropriate Treatment of Children, p. 104. AO Atlex, Tartu (2000)
50. Sup, V.: Crimes against sexual freedom and sexual integrity of minors and juveniles: certain aspects of determining the legal nature and directions of prevention. In: Streltsova, E.L., Kozachenko, O.V., Musychenko, O.M. (eds.) Latest Criminal and Legal Researches – 2021: Almanac of Scientific Works, pp. 230–235. MIP NU "OYUA", Mykolaiv (2021). https://hdl.handle.net/11300/17612
51. Krylova, N.E. (ed.): Criminal Code of Austria/Scientific. [Trans. Serebrennikova, A.V., Zertsalo, M.], 144p (2001)
52. Lukashov, A.I., Kuznetsova, N.F., Sarkisova, E.A. (eds.): The Criminal Code of Poland. [Trans. from Polish Ba-rylovych, D. A.], 234p. Center Press, Jurist (2001)
53. Golovko, L.V., Krylova, N.E. (eds.): The Criminal Code of France [Trans. KrylovoiJury, N.E.]. 650p. Press Center (2002)
54. The Criminal Code of the Federal Republic of Germany. [Translation and translation. Serebrennikova, A.V.], 208p. Zertsalo (2000)
55. Kuznetsova, N.F., Belyaev, S.S. (eds.): The Criminal Code of Sweden [Trans. with English Belyaev, S.S.], 168p. Izd-vo Moscow University (2000)
56. The Criminal Code of Japan. Preposition and the Translation of A. I. Korobeeva, 226p. Law Center Press, St. Petersburg (2002)
57. Optional Protocol to the Convention on the Rights of the Child-on-Child Trafficking, Child Prostitution and Child Pornography. Ratified by the Law of Ukraine No. 716-IV (716-15) Dated 04.03.2003, VVR, 2003, vol. 29, p. 226 (2003). https://zakon.rada.gov.ua/laws/show/995_b09#Text
58. Fedoryshyn, G.M.: Sexual violence against children as a social and psychological problem. Young Scientist **8**(48), 186–190 (2017)
59. Filipenko, N.E.: Criminological activity and the issue of legal education of the population. Our Right **3**, 146–151 (2020)
60. Filipenko, N.E., Yazan, N.S.: Mass media as a component of the criminological activity of juvenile prevention units regarding the legal education of adolescents. Archiv. Criminol. Forens. Sci.: Sci. J. **2** (2023). Kharkiv NSC "ISE named after Ex. Prof. M. S. Bokarius", 2023
61. Shemshuchenko, Yu.S., et al. (eds.): Judith Encyclopedia: in 6 Volumes. Ukrainian Encyclopedia, T. 4: H–P. 720p (2002)

The Collective Agreement as an Institution of Labour Law and a Regulatory-Legal Agreement of Local Action: Historical and Legal Genesis, Current Status, Development Trends

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Abstract. The historical and legal genesis of the development of the collective agreement institution in foreign countries and Ukraine has been analyzed. The possibility and expediency of implementing collective bargaining relations within a democratic state's market economy have been determined. Conclusions have been drawn that the collective agreement is currently one of the most important forms of social dialogue used at the local level to agree upon production, labor, socio-economic issues between its parties (employees and employers), particularly in the aviation sector. The primary purpose of the collective agreement is to provide additional and effective incentives for hired employees. Therefore, the terms of the agreement should ensure more incentivizing working conditions for employees compared to standard labor legislation norms. The current state of legislation on collective bargaining regulation of labor relations has been analyzed. The position on the need for its further improvement, taking into account the challenges of current realities related to informatization of the state and society and virtualization of legal relations, including labor relations (remote work, use of artificial intelligence at work, etc.), has been determined.

Keywords: collective agreement · labor relations · collective bargaining relations · collective bargaining · social dialogue · employees · employers

1 Introduction

The collective agreement is a social guarantor of labor relations, a key institution of labor law, through which social partnership relations (social dialogue) are realized. This is because it is concluded with the purpose of harmonizing interests of employers and hired workers regarding regulation of production, labor, and socio-economic relations at the local level (enterprises, institutions, organizations); therefore, both parties of labor relations are equally interested in concluding a collective agreement. The collective agreement is aimed at performing important functions, such as: protecting the interests of both aforementioned parties of social and labor relations; organizing (arranging) social and labor relations; stabilizing social and labor relations.

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The collective agreement is an integral element of market relations because it is designed to incentivize work and ensure competitiveness of a specific legal person in the market, acting as a mediating link between economic entities. At the end of the 20th century and the beginning of the 21st century, in view of the intensification of the area of dispositive regulation of legal relations (specifically labor), the collective agreement gained importance as a universal social regulator in any area of social relations, particularly in aviation.

Today, the modern world faces challenges associated with the use of artificial intelligence technologies and the virtualization of labor relations. These challenges include such phenomena as 'telework', electronic exchanges, and international contractual telecommuting, necessitating transformations in the approaches to legal regulation in the labor field, including collective agreements should stipulate certain provisions aimed at shaping legal regulation of a new format of relations between hired employees and employers.

For the domestic legislator, it is essential to align Ukrainian labor legislation with the requirements of international legal standards in the field of labor, especially those outlined in European Union conventions, taking into account that Ukraine has ratified a significant number of them and will further implement the provisions of international labor law at the national level. This certainly applies to the development of social dialogue in the field of labor relations, which is represented by collective agreements of local action.

From the above it follows that the research topic of collective bargaining regulation is important and relevant for modern labor law science and the state in any field of activity, including aviation. In this context, we find it appropriate to analyze the historical and legal genesis of the collective agreement institution in Ukraine, given foreign experience of leading countries of the world and the current state of domestic legislation on collective agreements (especially under conditions of martial law in the state), as well as to identify prospects for its development.

2 Literature Review

As Ukrainian labor legislation is being reformed, the role of scientific research in the field of labor law is significantly increasing. The majority of domestic and foreign scientists have dedicated their research papers to studying the issue of improving legal regulation of collective bargaining relations, including such researchers as Yaroshenko O.M., Pylypenko P.D., Zhernakov V.V., Melnyk K.Iu., Chanysheva H.I., Hetmantseva N.D., Mutsynova N.D., Pasechnik O.V., Butynska R.Ia., Pokryshka V.O., Rybnytskyi H.V., Amelicheva L.P., etc. In foreign scientific literature, the specified problematics has been studied by Ford G.D., Kamakura Y., Fryer J.F., Fumerton N.B., Denmark L.O., J. de Givry, Morris A., Willman P., Visser J., Ebisui M., and others.

However, currently there are issues that provoke scientific interest and necessitate comprehensive research on the mentioned topic. These issues are primarily related to: the informatization of society and the virtualization of labor relations; the use of the latest technologies in the labor field, particularly the uncontrolled use of artificial intelligence technologies without considering workers' interests; the application of new methods to

protect workers' rights, for example, to counteract such negative phenomena as mobbing; and the prospects for the development of the collective agreement institution. Also, as of today, the scientific opinion regarding transformation of collective bargaining regulation under martial law conditions in Ukraine is a priority.

3 Main Content Presentation

In labor law science, the collective agreement is viewed as a labor law institution and a form of legal regulation with local action, containing legal norms intended to regulate socio-legal relations. As P. D. Pylypenko points out, the collective agreement in labor law is considered one of the main institutions of this field. It encompasses a significant number of legal norms at multiple levels, both centralized and local, through which a relatively independent group of labor relations is regulated. From the researcher's perspective, the legal science views the collective agreement that is adopted at a particular business, institution, or organization as a form of regulatory legal agreement [1, p. 132]. As H. I. Chanysheva notes, the formation and development of social partnership in Ukraine allows us to consider the collective agreement and collective bargaining as important forms of social partnership through which the interests of employees and employers are reconciled [2, p. 19]. As mentioned by H. I. Chanysheva, it is worth emphasizing the connection between the institution of social partnership and the institution of collective agreement as an important manifestation of it.

In turn, V. V. Zhernakov believes that global experience convincingly demonstrates that problems in economy and social life, including in the field of using hired labor, are optimally resolved if the focus is on achieving social harmony and coordinating interests of different social groups, rather than fostering confrontation [3, p. 330]. As O. I. Protsevskyi stressed, social partnership, as an institution of civil society and a principle of labor law, should shape a European social model in Ukraine, which would be based on high economic indicators, a high level of social protection, and social dialogue [4, p. 214].

Therefore, the institution of social partnership (social dialogue) is primarily built upon the collective bargaining method of regulating labor relations. This method is implemented through conclusion of collective agreements at the local level and agreements at the national, sectoral, and territorial levels. Such a method of labor regulation contains a certain system of forms and methods for implementing social partnership, which introduces specificity and novelty into the content of the legal regulation method in general [5, p. 85]. Collective agreements are concluded through the conduct of collective negotiations (essentially, through the implementation of social dialogue) between their parties. These parties are: the employer's side, whose subjects are the employer and/or the employer's authorized representatives, including representatives of separate divisions of a legal entity; and the employee's side, whose subjects are the primary trade-union organizations operating in the enterprise, institution, organization, or separate divisions of a legal entity, which unify the employees hired by a natural person employing labor and represent interests of the workers employed by this employer on the basis of employment contracts. In their absence, representatives are freely elected by employees for the conduct of collective negotiations (Part 1, Article 3 of the Law of Ukraine *On Collective Agreements and Contracts*) [6].

In our view, the legal nature of the collective agreement should be considered from the perspective of its historical development as an institution of labor law and its formation as a regulatory legal agreement of local action. Therefore, the first collective agreements were concluded at the end of the 18th century in England as a result of the formation of trade unions and the holding of active strikes by the working class, during which workers protested against low wage rates and harsh working conditions. Lockouts on the part of entrepreneurs did not help and they were forced to negotiate with trade unions, who acted as representatives of workers, mainly for higher wage rates, hence the first collective agreements were called *tariff agreements*. At the beginning of the 19th century, collective agreements appeared in the USA, France, and Germany. Their introduction into the area of labor relations provoked stiff resistance from entrepreneurs and the state. In the US, for example, the courts prohibited collective agreements from the 1870s. It wasn't until 1938 that they were legally recognized. In the first half of the 20th century, the right to conclude collective agreements began to be legally enshrined in European countries. For instance, specific norms regarding legal regulation of collective agreements were introduced to the Civil Code of Denmark in 1907, the Swiss Code of Obligations in 1911. Collective bargaining legislation emerged in Germany in 1918, and in France and Austria in 1919. Further, in the 1920s and 1930s, such legislation also appeared in Sweden and Finland, etc. [7, p. 261].

It should also be noted that at the beginning of the 20th century, scientific papers of economists dedicated to social dialogue, in particular collective agreements, began to be published. This is entirely logical as the topic of social partnership (social dialogue) and its forms is a relevant research direction not only for legal but also for economic science. These papers were the first to use such well-established terms in labor law as *collective bargaining* and *collective agreement* [8, p. 217; 9, p. 59].

After the legal recognition of collective agreements and their consolidation in the national legislation of leading countries around the world, a stage of international legal regulation regarding labor collective bargaining began. Much law-making work in this regard was carried out by the International Labor Organization (hereafter: the ILO). The ILO developed and adopted a significant number of regulatory acts, namely: Freedom of Association and Protection of the Right to Organise Convention, 1948 (No. 87), Right to Organise and Collective Bargaining Convention, 1949 (No. 98), Collective Bargaining Convention, 1981 (No. 154), Collective Agreements Recommendation, 1951 (No. 91), and Recommendation concerning Consultation and Co-operation between Employers and Workers at the Level of the Undertaking, 1952 (No. 94), etc. European countries have ratified these international legal regulations. Consequently, the specified normative provisions have been integrated into their national labor legislation and are mandatory to adhere to.

The mentioned conventions provide definitions of key categories in the field of collective bargaining labor regulation. Thus, according to Article 2 of Collective Bargaining Convention, 1981 (No. 154), collective bargaining extends to all negotiations which take place between an employer, a group of employers or one or more employers' organizations, on the one hand or more workers' organizations, on the other, for- (a) determining working conditions and terms of employment; and/or; (b) regulating relations between

employers and workers; and/or; (c) regulating relations between employers or their organizations and a workers' organization or workers' organizations [10]. In compliance with Collective Agreements Recommendation, 1951 (No. 91), collective agreements means all agreements in writing regarding working conditions and terms of employment concluded between an employer, a group of employers or one or more employers organizations, on the hand, and one or more representative workers organizations, or, in the absence of such organizations, the representatives of the works duly elected and authorized by them in accordance with national laws and regulations, on the other [11].

Accordingly, from an analysis of international experiences in forming the collective agreement institution, we can conclude that in most Western countries, including the USA, the development of a social partnership (or social dialogue) system was preceded by an extended period of legislative consolidation for regulating collective bargaining in labor relations. This was a manifestation of democratic principles in the labor field (industrial democracy). If we determine the relationship between the institution of social partnership (social dialogue) and the institution of collective agreement in labor law, the former certainly appears as a more substantive category and complex phenomenon involving a set of social and legal norms aimed at organizing social dialogue between its parties at all levels of labor relations (national, sectoral, territorial) in order to harmonize their interests with the help of various forms and methods. One of the efficient democratic forms of establishing a balance of interests between employers and employees at the local level is the collective agreement [12, p. 170].

The development of the collective agreement institution in Ukraine also has its own history, the study of which can reveal key points that should be considered for improving collective bargaining regulation in the state. Throughout the 19th and 20th centuries, the formation of the collective agreement institution in Ukraine had its peculiarities due to different economic conditions and principles that prevailed on its territory, as it was under the rule of two empires. Western Ukraine, which belonged to the Austro-Hungarian Empire, developed as an agricultural region. Therefore, the working class did not show much activity in fighting for labor rights because of their small number. Furthermore, there were virtually no trade unions that could represent workers in negotiations with entrepreneurs. Ukrainian lands under the protectorate of the Russian Empire were more economically developed. In the context of active strike struggle between 1894 and 1904 and the revolution of 1905–1907, trade unions were established, which were active subjects of collective bargaining regulation at that time. For example, in 1905, in the Kharkiv region, the first collective agreements in Ukraine were signed with the help of trade unions. These agreements had legal force and were called *Agreement Protocols* [13]. After the 1917 revolution, a rapid organization of trade unions of various levels (production, sectoral, central) took place in Ukraine, and owners' associations also emerged [14, p. 43].

In the early years of Soviet power, regulation of labor relations occurred at the state level. However, according to legal sources of that time, there was also an emergence of collective bargaining regulation for wages. This indicates that the collective agreement institution began to establish itself as a form of regulating relations between workers, factory owners and manufacturers in individual enterprises and even entire industrial sectors. The main and most essential condition set out in the collective agreement was

the condition for work remuneration, i.e., the establishment of a minimum wage, the so-called tariff, and some collective agreements were initially called tariff agreements, as in European countries. In July 1918, a Decree *On the Procedure for Approving Collective Agreements (Tariffs) that Establish Wage Rates and Working Conditions* was issued. This Decree did not oblige conclusion of collective agreements, but if such agreements were concluded, they needed to be approved by the People's Commissariat of Labor to become binding for both parties involved. Admittedly, collective agreements were not of great significance at that time. The era of war communism did not provide favorable conditions for the development of the practice of concluding collective agreements, and consequently, for the local regulation of wage payment and other working conditions [15].

The New Economic Policy (hereinafter: the NEP), which had been introduced following the era of war communism in 1921, substantially amended the labor law: abolition of labor service, change in labor standardization regulation, and revival of agreement-based principles. Particularly, on September 23, 1921, the Council of People's Commissars of the Ukrainian SSR adopted the Resolution *On Tariff and Financial Policy*, which played a significant role in organizing wage payment for workers and employees. The NEP envisaged the introduction of state accounting and private ownership activities within certain limits, which promoted the active development of collective bargaining relations. In this regard, on January 17, 1922, the Council of People's Commissars of the Ukrainian SSR adopted the Resolution *On Collective Agreements and Regulation of Working Conditions in Private and State Enterprises, Farms, Institutions, and Organizations* defining agreement-based regulation of labor relations [16, 17, pp. 84–85].

During the NEP period, the agreement-based method of regulating labor relations was prioritized, however, the state retained the right to establish forms and limits that had to be observed when setting working conditions. With the transition from the NEP to a command system in managing the national economy in the late 1920s and the first half of the 1930s, there was a shift from agreement-based regulation of labor to centralized regulation. As a result, collective agreements were not renewed and their legal significance was practically devalued during the period from 1934 to 1947.

Collective bargaining (local) regulation of labor relations was resumed in the 1950s after adoption of the Resolution of the Council of Ministers of the USSR dated 1947. From the second half of the 1960s, Ukraine began to implement an economic reform (from 1965) aimed at expanding the autonomy of enterprises. By that time, Freedom of Association and Protection of the Right to Organise Convention, 1948 (No. 87), and Right to Organise and Collective Bargaining Convention, 1949 (No. 98), had already been ratified.

As a result of the reform in the 1960s–70s, there was an expansion of enterprise rights, particularly regarding the establishment of working conditions, however, the centralized principles in labor regulation were practically not limited. This was the main contradiction of the 1965 reform. At the same time power structures tried to intensify two mutually exclusive processes: strengthen centralism in the economy and engage market economic regulators (profitability rate, profit, etc.).

An important stage in the development of collective bargaining regulation in the 1980s was the adoption of the USSR Law *On Labor Collectives and Increasing Their*

Role in the Management of Enterprises, Institutions, Organizations dated June 17, 1983, which envisaged a weakening of the command-administrative system of state management and intensification of local methods for labor regulation. According to this Law, labor collectives were granted a wide range of labor rights, but these innovations did not lead to significant results initially. However, during these periods of the Soviet era, the foundations for the legal regulation of collective bargaining were laid. These foundations further developed during the establishment of a market economy in Ukraine, not as a part of the USSR, but rather as an independent state [18, 19]. Considering the conducted analysis of the historical stages of the establishment of the collective agreement as an institution of labor law and a regulatory legal agreement of local action in the system of law during the Soviet times, it can be concluded that collective bargaining was introduced in the labor field when the development of a market economy took place in the country. There arose a need to incentivize the labor of hired workers and ensure both the profitability of an enterprise and its competitiveness as an economic entity in the market.

After the declaration of Ukraine's independence on August 24, 1991, there was an urgent need to adopt democratic laws that would regulate legal relations, including labor, at a new historical stage of the state's development (during its transition to a market economy). Thus, on April 24, 1993, the Decree of the President of Ukraine *On the National Council of Social Partnership* was adopted and the Law of Ukraine *On Collective Agreements and Contracts* (hereinafter: the Law) was passed on July 1, 1993, where the legal principles for the development, conclusion, and execution of collective agreements with the aim of assisting in the regulation of production, labor, socio-economic relations and reconciling the interests of employees and employers (Article 1 of the Law) were determined. In the Labor Code of Ukraine (hereinafter: the LC), which was adopted on 10.12.71 and remained valid in sovereign Ukraine, Chapter II was dedicated to collective agreements. Voluntariness of concluding collective agreements as stipulated in the Law and the LC corresponds to the provisions of *Right to Organize and Collective Bargaining* ILO Convention, 1.07.1949 (No. 98) [6, 20, 21].

Regulatory provisions of the collective agreement, which ensure the regulation of work standards, wages, guarantees, and remuneration, working hours, the organization of health and recreation, housing and cultural services, occupational safety, and gender equality of hired workers, etc., must comply with the norms of the current legislation and are mandatory. Thus, commenting on the topic of collective agreements and collective negotiations, Ann Morris notes: «In broad terms, a collective agreement is an agreement between an employer and employee representatives, setting out the agreed contractual terms and conditions following a "collective bargaining process". Issues commonly pursued through collective bargaining negotiations include pay increases and improved terms of employment and working conditions, such as working hours, holidays, pensions contributions or any other such matters that may be agreed between the parties» [22].

The primary purpose of the collective agreement is to additionally and efficiently incentivize work of hired workers. Consequently, the terms of the collective agreement should not only advocate for more humane working conditions than current labor legislation dictates but also ensure workers' participation in enterprise management and profit distribution. Such an approach in developing the content of a collective agreement is not formal. It is not only capable of stabilizing relations between hired workers and

employers but can also positively influence a creative approach to work, conscientiousness of employees, their patriotic attitude towards results of the enterprise's (institution's, organization's) operations. As a consequence, it leads to achieving high income status and sustained competitiveness in the market.

In this context, it makes sense to draw attention to the collective agreement provisions of the National Aerospace University "Kharkiv Aviation Institute", where paragraph 1.2 states that the collective agreement is a local regulation of the University. In accordance with the current legislation, it regulates labor and socio-economic relations between university administration and labor collective and guarantees protection of rights and interests of all employees. Compared to the current legislation, the Subject of the Collective Agreement includes both legislative and additional provisions concerning wage payments, social and household services for the University employees, as well as guarantees and remuneration [23].

However, unfortunately, local labor regulation often did not fulfill its intended purpose after its introduction in our country. When researching the issue of improving collective bargaining labor regulation, legal experts note that the collective agreement, which is one of the most important labor relations regulators, has been characterized by a formalistic attitude towards the development of agreement terms as well as some vagueness and uniformity. Moreover, the absence of collective agreements is typical for many enterprises. In particular, H. V. Rybnytskyi stressed that the lowest level of worker coverage by collective agreements is observed in non-production sectors: healthcare, education, culture, and within the apparatus of public administration bodies as well as in many enterprises that are privately owned. What is more, a significant shortcoming in collective agreement regulation is the non-fulfillment of obligations by the parties. Thus, an urgent issue is the improvement of the accountability mechanism for both employer representatives and worker representatives in the area of collective bargaining relations [24, p.150, 25, pp.1–2].

Considering all the shortcomings of local labor regulation, the Ukrainian legislator faced the challenge of improving legal regulation of collective bargaining relations with the aim of developing the institution of social partnership (social dialogue) in the field of labor relations. This was associated with Ukraine's choice of a European development vector. Classifying the stages of the establishment of the social partnership (social dialogue) institution in our country, L. P. Amelicheva notes its active development at the beginning of the 21st century and the introduction, with the support of the ILO, of the Decent Work Concept through the Decent Work Programs for 2008–2011, 2012–2015, and 2016–2019. In these programs, a further development of the aforementioned institution is consistently highlighted as one of the strategic directions which influenced Ukraine's choice of a new model for regulating collective bargaining relations [26, p. 172]. To legislatively consolidate this model, the Decree of the President of Ukraine *On the Development of Social Dialogue in Ukraine* dated December 29, 2005, was adopted. In 2007, The ILO Convention *Concerning Tripartite Consultations to Promote the Implementation of International Labor Standards* (No. 144) dated June 21, 1976 (Tripartite Consultation, 1976 No. 144), and Collective Bargaining Convention (No. 154) dated June 18, 1981, were ratified. Additionally, the Law *On Social Dialogue in*

Ukraine was passed on December 23, 2010, and the Decree of the President of Ukraine *On the National Tripartite Socio-Economic Council* dated April 2, 2011, was adopted.

In order to improve the collective bargaining procedure and effectively resolve labor disputes, the development and adoption of a new version of the Law of Ukraine *On Collective Agreements and Contracts* was planned according to the Decent Work Program for 2016–2019 [27].

Since the beginning of the Russian Federation's military aggression against Ukraine on February 24, 2022, our country has faced numerous social challenges. Occupation of territories, destruction of enterprises, exodus of skilled workforce abroad, reduced work efficiency due to the impossibility of working during air raid alarms, rolling and emergency power outages, and mass layoffs are just a fraction of the problems the Ukrainian people have encountered. Therefore, it is evident that after the establishment of peace in Ukraine there will be many tasks related to restoring a stable economic state in the country, and their resolution will directly depend on effective cooperation conditions between workers and employers in the post-war period.

Under martial law conditions, labor law reform in Ukraine did not stop and, as H. I. Chanysheva rightly points out, it is taking place in two directions: establishing certain restrictions and peculiarities of organizing labor relations while adhering to minimum labor guarantees on one hand, and strengthening the protection of workers' labor rights on the other. In the first case, it refers to provisions of the Law of Ukraine *On the Organization of Labor Relations under Martial Law* dated March 15, 2022. In the second, it pertains to the provisions of the Law of Ukraine *On Amendments to Certain Legislative Acts of Ukraine Regarding the Strengthening of Workers' Labor Rights Protection* dated May 12, 2022 [28, p. 504; 29, 30].

It should be emphasized that during martial law, collective agreements and collective contracts as acts of social dialogue are of particular importance, as they shape the protection of labor, social, and economic rights of workers. Agreements between the parties involved in social dialogue are reached through their conclusion. Accordingly, with regard to the development of the second reform direction, it was quite logical to introduce amendments to the Labor Code and the Law concerning the expansion of their application scope. Thus, according to labor legislation norms before its amendments, it was envisaged to conclude collective agreements in enterprises, institutions, organizations that have signs of a legal entity and employ hired labor. After introducing amendments, provisions about conclusion of collective agreements not only in an enterprise, institution, or organization, but also with a person who employs hired labor were set out (Part 1 of Article 2 of the Law, Part 1 of Article 11 of the Labor Code).

Recognizing the great importance of agreements and collective contracts as forms of social partnership (social dialogue), the Verkhovna Rada of Ukraine took the next step in reforming collective bargaining aimed at the European integration of labor's legal regulation. On February 23, 2023, the Draft Law of Ukraine *On Collective Agreements and Contracts* was adopted as the basis and signed by the President of Ukraine on April 11, 2023. Most provisions of the new Law come into effect 6 months after termination or cancellation of martial law, excluding clause 2 of the Final and Transitional Provisions, which enters into force the day following the date of the Law's publication. The law introduces legal regulation on a number of issues where legislative gaps previously

existed, specifically: it stipulates that at the enterprise (institution, organization) level, all employees and employers will have the right to enter into a collective agreement; it clarifies the scope of collective agreements and contracts; establishes a new mechanism for extending the effect of collective agreements to workers who are not trade union members; regulates the issue of forming a joint representative body of the party at any level of social dialogue; provides a rather flexible approach to mandatory content of the collective agreement (the agreement must specify its duration, control over implementation of its provisions, the ability to halt or suspend the effect of certain provisions of agreements and contracts, the ability for new parties to join, and a list of force majeure circumstances [uncontrollable events]. In the event of their occurrence, the effect of certain agreement provisions is suspended. On the other hand, provisions on organization of production and labor, labor standardization and wage payment, guarantees of trade union activities, and a number of other provisions that were mandatory, according to the new law, can be included in the collective agreement at the discretion of the parties, which means they aren't deemed essential to be part of the agreement). The changes affected the procedure for conducting collective negotiations, i.e., provisions regarding composition of participants in the negotiation process. What is more, regulations on the procedure for conciliation procedures and formation of conciliation commission to resolve discrepancies during collective negotiations have been eliminated, etc. [31].

Therefore, analyzing the content of the new Law that governs collective bargaining labor regulation indicates that it provides new opportunities for collective agreement parties to protect their labor rights and interests. However, we believe that the possibility (meaning it is not mandatory) of regulating wage payment, preventing mass layoffs, labor standardization, and other working conditions, as set out in the new Law *On Agreements and Collective Contracts*, should not imply neglecting agreements related to these matters in collective agreements. The more detailed and incentivizing local regulation of labor relations between workers and employers, the more conscientious and creative workers will be. This will undoubtedly influence the high profitability of an enterprise, institution, or organization. Moreover, in the context of collective agreements, we deem it essential to consider certain modern trends of current realities that also affect the labor field.

In particular, this refers to the emergence of new forms of work (for example, freelancing) in conditions of society's digitalization and the use of artificial intelligence to intensify and enhance working process efficiency. Extending collective bargaining labor regulation to self-employed freelance workers provides an opportunity to secure certain guarantees for the protection of their labor rights. For example, in Denmark, there is an experience of concluding a collective agreement that transforms *pseudo self-employed workers* into *employees with rights*. For the first time in the world, in August 2018, 450 workers of the Hilfr.dk Danish online platform, who worked as cleaners in private houses and provided services to 1,700 clients, received significant guarantees according to the new collective agreement (higher wages, pension contributions, leave allowance, and sick pay). One of the founders of Hilfr, Steffen Wegner Mortensen, stated that the agreement "raises the bar for the Gig Economy and demonstrates how we can all benefit from applying new technologies without violating labor rights." According to Torkild Holmbo-Heyaba, the collective agreement's author, such an agreement helps Hilfr

cleaners, who previously did not work under employment contracts, become workers protected by EU labor legislation and national labor laws. Lars Løkke Rasmussen, the Prime Minister of Denmark, was present during the signing ceremony of the collective agreement. He stressed that this agreement is a ground-breaking one that ensures human security and social responsibility [32]. Such experience is highly valuable for the further development of collective bargaining in Ukraine and other countries in the context of society and state informatization, as well as virtualization of social relations, including labor ones.

Regarding the use of artificial intelligence (AI) technologies in the labor field, aside from the positive outcomes of this usage, it's also worthwhile to consider certain negative trends that have been observed. In particular, The National Bureau of Economic Research (hereinafter: the NBER) in the USA has analyzed data from 1980 to 2020 and come to the following conclusions: technology either completely replaced those who were engaged in physical labor or reduced their wages. Earnings of a person without a degree are now 15 percent lower than in 1980; workers with higher education and "white-collars" have maintained their income level over the last 40 years: it has only increased; companies have automated tasks that were previously performed by people. Research and technology companies, analytical centers are publishing reports indicating that the use of artificial intelligence in the field of labor relations has resulted in an increased gap between rich and poor countries. They also promise that AI will soon replace many jobs, with 85 million jobs disappearing by 2025. First and foremost, AI, in terms of replacement, threatens those who perform routine, repetitive tasks (couriers, secretaries, employees of back-office, call centers, machine operators, fast-food chain workers, farmers, etc.). There might be fewer job positions in banks, insurance companies, and it is even conceivable that IT specialists could be at risk, especially after AI has been taught to write code [33].

Given the mentioned recent trend, which has both positive and negative aspects, it would be expedient to employ a collective agreement as a form of social partnership (social dialogue) at the local level. This agreement should be seen as a mechanism for humanization of labor relations capable of protecting labor rights of hired workers and human labor and adhering to the ethics of the use of AI, under the strict supervision of workers' and employers' representatives, all for the benefit of a human being.

We also believe that the collective agreement content should provide legal formulas to prevent mobbing as a negative phenomenon, which unfortunately often takes place in the realm of labor relations. The concept of mobbing (bullying) is outlined in Part 1 of Article 2^{-2} of the Labor Code where it is defined as systematic (repeated) prolonged intentional actions or inaction by an employer, individual workers, or a group of employees, aimed at undermining honor and dignity of an employee, his/her professional reputation, including actions with the intent of affecting the employee's acquisition, alteration, or termination of labor rights and obligations. This manifests itself in the form of psychological and/or economic pressure, particularly through the use of electronic communication means, creating a tense, hostile, and offensive environment towards the worker, including one that makes him underestimate his professional suitability. It should be noted that the collective agreement itself can be a means of prevention and timely response to any manifestations of mobbing within the working team and can envisage accountability for actions which fall within the scope of this concept [20, 34, p. 428].

In conclusion, we deem it essential to stress findings of the ILO in *Social Dialogue Report* 2022 which reviews collective bargaining practices in 80 countries with varying levels of economic development as well as regulatory framework of 125 countries worldwide. The report emphasizes a great importance of collective agreements in social dialogue: «Collective bargaining can advance equality and foster, the higher the coverage of emloyees by collective agreements. The lower the wage differences. Collective bargaining can effectively reduce wage inequality, whether in an enterprise, sector or industry and contribute to narrowing the gender pay gap. According to the report, over third of employees (35 per cent) in 98 countries have their wages, working time and other condition of work set by autonomous collective negotiations between a trade union and an employer or employers' organization. Collective agreements have played an important role in mitigating the impact of the COVID-19 crisis. Collective bargaining helping to cushion some of effects on inequality while reinforcing the resilience of enterprises and labour markets by supporting the continuity of economic activity [35].

4 Conclusions

To conclude, given the importance of the collective agreement across all areas of social relations, especially in the aviation sector, it's worth emphasizing that it acts as a stabilizer of labor relations as one of the forms of social dialogue. In the current context, it takes on particular significance given Ukraine's choice of a European integration development vector, which provides new impulses for further improvement of this institution. This has conditioned the present scientific research and the following conclusions have been drawn based on its results:

– the collective agreement is a regulatory legal agreement of local action, which fulfills the task of enhancing motivation of employees in performing their labor functions. Specifically, considering its democratic principles as an institution of labor law, it serves as a guarantee for protection of workers' labor rights and improvement of their working conditions in contrast to the standards of current labor legislation
– if one defines the relationship between the social partnership (social dialogue) institution in labor law and the collective agreement institution, the former is certainly viewed as a more substantive category. It encompasses a set of socio-legal norms aimed at organizing social dialogue between the subjects of labor relations regarding alignment of their interests through various forms and methods at all levels of their regulation (national, sectoral, territorial). Meanwhile, the collective agreement acts as the primary form of social dialogue at the local level (enterprises, institutions, organizations);
– the analysis of foreign experience regarding the establishment of collective agreements indicates that in most Western countries, including the USA, the development of a social partnership system was preceded by an extended period of legislative efforts to consolidate collective bargaining of labor relations. This was a manifestation of democratic principles in the labor field (production democracy);
– considering the conducted analysis of the historical and legal genesis of the collective agreement as an institution of labor law in Ukraine within the legal system of the Soviet era, it can be assumed that collective bargaining relations developed in the labor field

when the country was experiencing a period of market economy development. It was necessary to incentivize work of hired employees, ensure profitability of enterprises, and enhance their competitiveness in the market as economic entities;

– after the declaration of Ukraine's independence on August 24, 1991, a regulatory framework was established for collective bargaining regulation of labor relations as the state transitioned to a market-based economy. Thus, on April 24, 1993, the President of Ukraine issued a Decree titled *On the National Council of Social Partnership.* Subsequently, the Law of Ukraine *On Collective Agreements and Contracts* was adopted on July 1, 1993. These defined the legal principles for the development, conclusion, and execution of collective agreements with the aim of facilitating regulation of production, labor, socio-economic relations, and aligning the interests of employees and employers;
– given the evident shortcomings of local labor regulation at the end of the 1990s (a formalistic approach to developing agreement terms, their vagueness and uniformity, the absence of collective agreements within enterprises, institutions, and organizations, and the lack of clear definition of accountability for performance of collective agreement terms). At the end of the 1990s, Ukrainian legislators faced the challenge of improving legal regulation of collective bargaining relations. The aim was to develop the institution of social partnership (social dialogue) in the field of labor relations, in line with Ukraine's choice of a European direction for development. Thus, at the beginning of the 21st century, the implementation of the decent work concept began with the support of the ILO. In the Decent Work Programs for specific periods, further development of the collective agreement institution is viewed as one of the strategic directions. This influenced Ukraine's choice of a new model for regulating collective bargaining relations. To legislatively consolidate this model, a series of regulatory acts have been adopted, and ILO Conventions No. 144 and No. 154 have been ratified. With a view to improving the collective bargaining process and the effective resolution of labor disputes, the drafting and adoption of a new version of the Law of Ukraine *On Collective Agreements and Contracts* have been planned, as outlined in the Decent Work Programme for 2016–2019;
– during martial law, collective agreements and collective contracts as instruments of social dialogue are of particular importance since they manifest themselves as protective measures for the labor, social, and economic rights of workers, and therefore consensus is reached between social dialogue parties through their adoption. As a result, the Ukrainian legislator extended its activities towards labor law reform. Initially, the Law of Ukraine *On Amendments to Certain Legislative Acts of Ukraine Regarding the Strengthening of Workers' Labor Rights Protection*» was adopted on May 12, 22. This led to amending legislation concerning collective agreements. Subsequently, as the next step towards the European integration of labor law regulation, the Draft Law of Ukraine *On Collective Agreements and Contracts* was approved on February 23, 2023. On April 11, 2023, this law was signed by the President of Ukraine. The majority of the provisions of the new law will come into effect 6 months after termination or repeal of martial law;
– analysis of the content of the new Law which will regulate collective bargaining in labor relations allows us to conclude that it provides new opportunities for the collective agreement parties to protect their labor rights and interests. However, we believe

that the provision about the possibility (i.e., optionality) of regulating wage payment, preventing mass layoffs, standardization, as stipulated in the new Law, should not mean ignoring agreements on these issues in collective agreements/contracts. The more detailed and incentivizing the local regulation of labor relations between workers and employers, the more conscientious and creative workers will be. This will undoubtedly affect the high profitability and competitiveness of an enterprise, institution, or organization;

– to further improve local labor relations regulation within the framework of collective agreements, it is advisable to consider certain current trends in today's world that also affect the labor field. In particular, provisions should be made for thorough oversight of further implementation of AI technologies in the labor field to preserve jobs and not devalue human labor. It is reasonable to consider the digitalization processes in society and the state, and as a result, virtualization of legal relations, including labor relations. The scope of collective agreements should be expanded, for instance, to include workers who find employment through digital platforms. This is done to ensure their labor rights are protected under both EU legislation and national labor laws.

References

1. Pylypenko, P.D.: Problema rehuliuvannia sotsialnoho pertnerstva u proekti Trudovoho kodeksu Ukrainy. Kodyfikatsiia trudovoho zakonodavstva Ukrainy: stan i perspektyvy. Kharkiv: Vyd-vo Nats. un-tu vnutr. sprav., pp. 28–30 (2004). [in Ukrainian]
2. Chanysheva, H.I.: Kolektyvni dohovory y uhody yak forma sotsialnoho partnerstva. Nauk. visnyk Nats. akademii vnutr. sprav Ukrainy. **1**, 19–26 (2001). [in Ukrainian]
3. Zhernakov, V.V.: Teoretychni ta praktychni pytannia instytutu zakhystu prav liudyny u sferi pratsi. Aktualni problemy derzhavy i prava. Seriia «Iurydychni i polytychni nauky». Vyp. **32,** 329–335 (2005). [in Ukrainian]
4. Protsevskyi, O.I.: Metodolohichni zasady trudovoho prava: monohrafiia. Kharkiv: KhNADU 260 (2014). [in Ukrainian]
5. Hetmantseva, N.: Sotsialne partnerstvo yak sposib intehratsii interesiv subiektiv sotsialno-trudovykh vidnosyn. Pidpryiemstvo, hospodarstvo i pravo. **3**, 82–86 (2016). [in Ukrainian]
6. Pro kolektyvni dohovory i uhody: Zakon Ukrainy vid 1.07.1993 r u red. 11.12.2022 r. № 2759-IKh. https://zacon.rada.gov.ua/laws/show/3356-12#Text. [in Ukrainian]
7. Hetmantseva, N.D., Kozub, I.H.: Trudove pravo Ukrainy (Zahalna chastyna): navch. posib. Chernivtsi: Chernivetskyi nats. un-t., p. 312 (2013). [in Ukrainian]
8. Potter, B.: The co-operative movement in Great Britian. New York: Charles Scribners Sons., p. 290 (1904). https://archive.org/details/cooperativeemovem00webbuoft [in English]
9. Webb, B.: The Letters of Sidney and Beatrice Webb/ B. Webb, S. Webb; ed. Norman MacKenzie, vol. 1, Apprenticeships, pp. 1873–1892. Cambridge University Press in co-operative with the London School of Economics and Political Science, p. 428 (2008). [in English]
10. Collective Bargaining Convention, 1981 (No. 154). https://www.ilo.org/legacy/english/inwork/cb-policy-guide/collectivebargainingconvention1981No154.pdf [in English]
11. Collective Agreements Recommendation, 19 (No. 91). https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUD:12100:0::NO::P12100_ILO_CODE:R091
12. Hordeiuk, A.O., Spitsina, H.O.: Zarubizhnyi dosvid rozvytku instytutu sotsialnoho partnerstva u sferi trudovykh vidnosyn. Naukovyi visnyk Dnipropetrovskoho derzhavnoho un-tu vnutrishnikh sprav. **4**. 168–178 (2022). [in Ukrainian]

13. Potushynska, O.P.: Istoryko-pravovyi henezys profisiinykh spilok v Ukraini ta sviti. Derzhavnyi naukovo-doslidnyi instytut mytnoi spravy (2019) http://dndims.com/nevidome/data/entry/300
14. Hromadska, N.A.: Sotsialnyi dialoh: posib. vydannia ChDU im. Petra Mohyly. (2012). http://lib.chdu.edu.ua/index.php?m=2&b=337
15. Pro taryfnu i finansovu polityku: postanova RNK URSR vid 21.09.1921 r. ZU URSR 19. St. 548 (1921)
16. Pro kolektyvni dohovory ta rehuliuvannia umov pratsi na pryvatnykh i suspilnykh pidpryiemstvakh, u hospodarstvakh i orhanizatsiiakh: post. RNK URSR vid 17.01.1922 r. № 30. ZU URSR 1. St. 33 (1922)
17. Khlebnikov, D.: Nachatky trudovoho prava URSR. Kharkiv: Yuryd. vyd-vo NKIu URSR, p. 270 (1930)
18. Kondratiev, R. I.: Lokalne pravove rehuliuvannia trudovykh vidnosyn v SRSR: dys. d-ra yuryd. nauk: 12.00.05. Lviv., p. 358 (1978)
19. Kondratiev, R.I.: Ponovlennia prohalyn trudovoho prava lokalnymy normamy. Derzhava i Pravo. No **3**, 58–65 (1977)
20. Kodeks Zakoniv Ukrainy pro pratsiu vid 10.12.1971 r. № 322-VII. Vidomosti Verkhovnoi Rady URSR, № 50. St. 375 (1971). (iz zmin. ta dopov.)
21. Right Organize and Collective Bargaining Convention (No. 98) (1949). http://ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILOCODE:CO98
22. Morris, A.: Collective Bargaining & Agreements (2022). https://www.davidsonmorris.com/collective-bargaining/
23. Kolektyvnyi dohovir mizh rektorom i trudovym kolektyvom v osobi holovy profspilkovoi orhanizatsii Natsionalnoho aerokosmichnoho universytetu im. M. Ye. Zhukovskoho «Kharkivskyi aviatsiinyi instytut» na 2017–2020 rr. : zatv. konf. trudovoho kolektyvu NAU «KhAI», protokol № 4 vid 24.03.2017 r.; zareiestr. Upravlinniam pratsi ta sotsialnoho zakhystu naselennia administratsii Kyivskoho r-nu Kharkivskoi miskoi rady, reiestr. № 81, vid. 03.04.2017 r.; rishennia pro prodovzhennia dii poperednoi redaktsii vid 26.08.22 r. do zakinchennia periodu voiennoho stanu v Ukraini. http://khai.edu/ua/
24. Valetska, O. V.: Udoskonalennia kolektyvno-dohovirnoho rehuliuvannia pratsi v suchasnykh umovakh. Universytetski naukovi zapysky. Chasopys. Khmelnytskyi: Vyd-vo Khmelnytskoho un-tu upravlinnia ta prava. Vyp 1 (25), pp. 144–150 (2008). [in Ukrainian]
25. Rybnytskyi, H.V.: Kolektyvnyi dohovir v umovakh rynkovoi ekonomiky: avtoref. dys. na zdobuttia nauk. stupenia kand. yuryd. nauk : spets. 12.00.05 «Trudove pravo; pravo sotsialnoho zabezpechennia». Kharkiv, p. 18. (2005). [in Ukrainian]
26. Amelicheva, L.P.: Istoriia formuvannia ta rozvytku instytutu sotsialnoho dialohu v trudovomu pravi. Universytetski naukovi zapysky Donetskoho natsionalnoho un-tu (m. Vinnytsia), № 59, 165–176 (2016). [in Ukrainian]
27. Memorandum pro vzaiemorozuminnia shchodo realizatsii Prohramy hidnoi pratsi MOP dlia Ukrainy na period 2016–2019 rr. vid 07.04.2016 r. Ministerstvo sotsialnoi polityky Ukrainy. http://www.mlsp.gov.ua/labour/control/uk/publish/article?art_id=187817&cat_id=107177
28. Chanysheva, H. I.: Shchodo ukladannia ta dii kolektyvnykh dohovoriv, uhod v umovakh voiennoho stanu. Yevropeiskyi vybir Ukrainy, rozvytok nauky ta natsionalna bezpeka v realiiakh masshtabnoi viiskovoi ahresii ta hlobalnykh vyklykiv KhKhI stolittia: u 2 t: Materialy Mizhnar. nauk.-prakt. konf. (m. Odesa, 17 chervnia 2022 r.). Odesa : Vydavnychyi dim «Helvetyka». T. 1., pp. 504–508 (2022). [in Ukrainian]
29. Pro orhanizatsiiu trudovykh vidnosyn v umovakh voiennoho stanu : Zakon Ukrainy vid 15.03.2022 r. № 2136-IKh. https://zacon.rada.gov.ua/laws/show/2136-20#Text [in Ukrainian]
30. Pro vnesennia zmin do deiakykh zakonodavchykh aktiv Ukrainy shchodo posylennia zakhystu trudovykh prav pratsivnykiv: Zakon Ukrainy vid 12.05.2022 r. № 2253-IKh. https://zacon.rada.gov.ua/laws/show/2253-20#Text

31. Pro kolektyvni uhody ta dohovory : Zakon Ukrainy vid 23.02.2023 r. № 2937-IX. https://zakon.rada.gov.ua/laws/show/2937-20#Text [in Ukrainian]
32. In Denmark, a historic collective agreement is turning the "bogus self-employed" into "workers with rights". http://equatimes.org/in-denmark-a-historic-collective?lang=tn
33. Shtuchnyi intelekt zminyt (i uzhe zminiuie) rynok pratsi. https://zaborons.com/shuchnyj-intelect-zminyt-i-uzhe-zminyuye-rynok-praczi/
34. Kornilov, D.: Mobinh yak nehatyvne yavyshche u sferi pratsi ta shliakhy yoho podalannia cherez kolektyvno-dohovirne rehuliuvannia trudovykh vidnosyn. Naukovyi visnyk Dnipropetrovskoho derzhavnoho un-tu vnutr. sprav (DDUVS). **1**, 425–431 (2023)
35. Collective agreements contribute to fighting, says ILO. http://ilo.org/global/about-the-ilo/newsroom/lang-en/index.htm

The Concept of Comprehensive Security for Higher Educational Institutions: Ukrainian and European Experience

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Abstract. The report studies principal issues of ensuring security at higher educational institutions and provision of equal, proper and safe conditions for obtaining education and organization of a safe educational environment, which is especially relevant in view of the military aggression of the Russian Federation against Ukraine.

Keywords: security · higher educational institutions · armed aggression · security protocols · safe physical space for stay · training

1 Introduction

Security is the essential condition for the functioning of a state, directly affecting the development of all social institutions. Like any other field, education suffers from the consequences of natural disasters, man-made catastrophes, fires, environmental and other problems.

However, the most serious and dangerous challenge today is to resist Russia's armed attack on Ukraine. According to the Ministry of Education and Science of Ukraine, as of August 18, 2022, 2300 education institutions have been damaged due to bombings and shelling, of which 286 have been completely destroyed [1]. The combination of these and other factors exacerbates extreme and emergency situations of a humanitarian and social nature (for example, threats to the lives and health of students and employees of higher educational institutions due to fire, building collapse during/after bombing, bodily injuries, sexual violence by invaders, kidnappings, torture, robberies, drug spread, emergence of terrorist threats, etc.).

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As Oksen Lisovyi, the Minister of Education and Science of Ukraine, rightly pointed out, due to the current state of war, the educational process is dependent on the security situation and takes place offline, online, or in a blended format. Educators continue to hold their ground resiliently. A painstaking work of restoring emotional state of teachers and students and adjusting the educational process lies ahead. But most importantly, education needs to be safe. Every child in Ukraine deserves the guarantee of receiving quality education, and every educator must feel valued and supported [2].

The issue requiring resolution is insufficient level of security in educational institutions and organization of a safe educational environment in Ukraine, which are consequences of such factors as: insufficient number of facilities in the civil protection facility fund; a low level of compliance of these facilities to the requirements for necessary capacity and the number of evacuation exits; availability of water supply, drainage, ventilation, heating, lighting, communication and Internet facilities, means of providing medical aid; accessibility for people with limited mobility, as well as the possibility of organizing educational process in such civil protection facilities; educational institutions have a low level of compliance with fire and man-made safety legislation; outdated regulatory framework in civil protection field, specifically pertaining to the creation of safe conditions for students, teaching staff, scientific-pedagogical workers, administration, and other employees in educational institutions; lack of established procedure for organizing protection of educational institutions, including with involvement of security police officers (setting up an emergency alarm system connected to centralized observation and response points); the lack of proper organization of access control (fencing, stationary metal detectors, access control system) and the lack of indoor and outdoor video surveillance; inaccessibility for people with disabilities and for other limited mobility population groups; insufficient implementation of measures aimed at preventing and deterring commission of offenses by preventive police services; a lack of knowledge among educational participants about their rights, obligations and responsibilities, safe daily behaviour and traffic rules, and about how to avoid cyber threats and behave safely online; unpreparedness of education process participants for actions in emergency situations, hostilities; educational institution staff members lack necessary skills to provide first aid, ensure psychological support for learners; limited access to mental health care and psychosocial support services for educational process participants during study and work, taking into account the impact of military aggression on their mental health; lack of comprehensive infrastructure to provide psycho-emotional and psychological support to those involved in the educational process; lack of conditions for providing inclusive education and support for learners who need it, in accordance with new security conditions [3].

The comprehensive security of higher educational institutions (hereinafter: HEIs) is achieved through implementation of a specially developed and currently modified system of legal, organizational, technical, personnel, financial, and anti-terrorist measures, intended to prevent and minimize risks of emergency situations.

Therefore, the analysis of these threats and careful planning on its basis of thought-out measures to ensure reliable security of higher educational institutions is an urgent requirement of our time.

1.1 Literature Review

Specific aspects of domestic and international practice in ensuring security of higher educational institutions have been studied in research papers by such domestic and foreign researchers as Burov O. Yu., Zhelibo Ye. P., Kuznetsov V. O., Mukhyn V. V., Podolianchuk S. V., Sahaidak I. S., Serdiuk O. O., Shtepa T. V., and others.

The range of scientific developments on this problematics is quite broad. However, not all problematic issues of ensuring security of higher educational institutions have been resolved: some of them have only been mentioned, and some still remain debatable and almost undeveloped. Moreover, Ukrainian higher educational institutions have faced a threat that has been unknown for almost eighty years: open armed aggression.

Therefore, without in any way diminishing scientific and practical value of published research papers on the issue under consideration, let's note that the issue of ensuring security in higher educational institutions requires a comprehensive coverage, taking into account provisions of current Ukrainian and foreign legislations, professional theoretical research, practical issues, and European experience implementation.

2 Main Content Presentation

An educational institution is a complex mechanism that independently resolves difficult, multidimensional issues of comprehensively supporting its activities (operation of buildings and structures, utilities, ventilation systems, lighting, power supply, bomb shelters, early warning systems, etc.).

When analyzing dangers to a higher educational institution, it can be concluded that ensuring its security consists in creating conditions for safe living and working of employees, higher education seekers, and visitors in everyday activities and in various emergency situations (for example, bombardment or territory seizure by enemy raiding forces, a terrorist act or hostage-taking), resolving issues of preserving people's lives and health, property and material assets in educational institution, as well as ensuring safe operation of buildings and structures.

At the same time, the majority of authors tend to view security primarily as creation of fire safety system and protection against acts of terrorism [4, 5]. Such approaches significantly narrow the problem, make its resolution one-sided, and do not allow to see and address other issues of vital activity safety in a higher educational institution.

First and foremost, in our view, it is necessary to equip employees and higher education seekers with knowledge in vital activity safety and counteraction to military threats. It is also necessary to solve the task of creating comfortable and safe working and learning conditions, and this task encompasses a whole range of actions related to training heads of structural departments and all employees on how to behave in emergency situations, protection of life and health of employees and higher education seekers, creating a safe educational environment and ensuring consistent learning, for example, through blended learning, certification of workplaces in terms of working conditions, organization and implementation of production control over observance of sanitary rules and execution of sanitary and epidemiological (preventive) measures, as well as adjusting a system for investigating and recording accidents at work, addressing the tasks of fire, radiation, and chemical safety while carrying out educational and scientific activities

within an educational institution, regular medical examinations of employees and care for their health, control over compliance with security measures during various types of work, construction and equipping of bomb shelters and other safety-providing facilities, etc. It is also vital to implement measures ensuring safe operation of buildings and structures used by an educational institution (especially after they've been struck by rockets, bombs, or other explosive objects) as well as to carry out demining operations within the territory of a higher educational institution, etc.

Finally, it is essential to resolve the task of protecting the lives and health of employees and students from various threats, preserving property of an educational institution, etc. In other words, this is about creating a safe educational environment.

Having studied opinions of domestic and foreign researchers and practitioners, it can be asserted that the educational environment is a characteristic of life within an educational institution, a system of influences and conditions for personality formation, a system of opportunities for personal development in social and subject-spatial environments.

Under current rapidly changing conditions, the educational environment of higher educational institutions does not exist in isolation from external and internal influences, which can either lead to positive results or carry destructive threats, dangers, and risks. To counteract these factors, it's crucial for the educational environment to be protected and safe. Hence, a safe educational environment ensures: the availability of safe conditions for learning and working; comfortable interpersonal interaction contributing to the emotional well-being of higher education seekers, educators, and higher educational institution staff; the absence of any manifestations of violence and the presence of sufficient resources to prevent it, as well as adherence to the rights and norms of physical, psychological, informational, and social security by every participant in the educational process.

All of the above allows us to conclude that the problems of ensuring security of a person and an educational institution where they work (study) must be addressed comprehensively, using scientific developments in this field. This requires the development and implementation of the *Concept of security for a higher educational institution.* Certainly its provisions closely resonate with the requirements of the *Concept of security for higher educational institutions* approved by Ukrainian Government. It is a comprehensive strategic vision of creating a safe educational environment and organizing equal, appropriate, and safe conditions for education and teaching within educational institutions.

The Concept of security for higher educational institutions (hereinafter: the Concept) is a system of views, guiding ideas, principles, adopted for solving tasks aimed at ensuring comprehensive and reliable security of the educational environment. It can be represented as a certain virtual model that helps to understand what the security system of an educational institution is, taking into account issues of its efficiency, reality, humanism, democracy, technical equipment, economic feasibility, etc.

An effectively working Concept of security for higher educational institutions should clearly demonstrate the nature of emerging dangers and threats, identify specific parameters of the security system components for higher education seekers and staff of

higher educational institutions, mechanisms, ways and means of protecting them from potentially dangerous and emergency situations.

In accordance with the requirements of current Ukrainian legislation, the first principle of any security system must be legality. This principle implies that all actions related to ensuring security must be lawful and in no way restrict rights and freedoms of citizens. The Constitution of Ukraine states: "Constitutional human and citizens' rights and freedoms shall not be restricted, except in cases envisaged by the Constitution of Ukraine. Under conditions of martial law or a state of emergency, specific restrictions on rights and freedoms may be established with the indication of the period of effectiveness of these restrictions (Art. 64) [CU]." For example, the following actions can be implemented: 1) introduction of a curfew (prohibition to be on the streets and in other public places without specially issued passes and ID cards at set hours of the day); 2) checking citizens' documents, and in necessary cases: conducting personal searches, inspection of belongings, vehicles, baggage and cargo, office premises, and citizens' homes; 3) conscripts and personnel liable for military service are prohibited to change their place of residence without informing a relevant military commissariat, etc.

The principle of humanity, which prioritizes the interests of individuals — especially higher education seekers— over other factors, plays an important role in providing protection from hazards and emergencies of various origins, thus ensuring the security of an educational institution. The main rule here is to alert students about potential dangers as frequently as possible and develop algorithms for overcoming them. However, it is also essential to remember: the best way to teach higher education seekers safe behaviour is through personal example of teachers and all educational institution staff; while teaching learners safe behaviour rules, it is crucial not to intimidate them.

When developing security system for an educational institution, it is impossible to ignore such principles as: democracy, which takes into account opinions of higher education seekers, higher educational institution staff, law enforcement agencies, parents; close interaction with professionals and various security services; rationality and cost effectiveness; organization; continuity; planning; control; foreseeing and prevention; systematic and holistic approaches involving a comprehensive coverage of all components of the institution's security system as a whole.

All the indicated principles of ensuring security in educational institutions are not speculative rules made up in offices and classrooms, but crucial components of the requirements of current legislation and its application practice, regulating security in various areas of life. The significance of these principles lies in the fact that they provide a framework with the help of which even a teacher or other higher educational institution staff members who are not specifically prepared can quickly understand the suitability of one or another decision regarding protection of higher education seekers from dangers and threats. These principles become the criteria for choosing one or another option related to ensuring security or a specific component of its system.

Along with these principles, purposes of security provision hold an important place for higher education seekers and other persons. The main ones are: protection of higher education seekers, teachers, staff, their rights and interests as well as property from dangerous influences; ensuring a normal educational process and operation of an educational institution; reducing damage from negative consequences of emergencies; improving the

quality of life and security for higher education seekers, teachers, staff (unacceptability of death, reduction of injuries, strengthening occupational safety and health, environmental protection, property preservation, etc.).

The defined purposes give rise to the tasks of ensuring security in a higher educational institution: preparing the staff, teachers, and higher education seekers for dangerous and emergency situations and for countering them, which is achieved by learning about types of dangers and understanding the ways to overcome them; early detection of signs and causes of dangerous and emergency situations, their prevention, and elimination of their causes; providing conditions and opportunities for self-defense, rescue, and protection of others; legal, organizational, and technical support for security system; development of safety behaviour skills in case of dangerous and emergency situations; security culture formation among higher education seekers, teachers, and all staff of a higher educational institution.

The importance of the above-mentioned principles, purposes, and tasks of ensuring security in a higher educational institution is the fact that, when correctly worded and understood, they become a mindset for teachers, staff, and higher education seekers, serving as a certain guarantee of their adequate safety actions. Having studied principles, purposes, and tasks of ensuring security in educational institutions from the conceptual perspective, let us move on to the content and functioning mechanism of their security system.

Security system of a higher educational institution has a certain set of components, including dangers and threats, objects and subjects of security, regulatory documents, resources, organization, means of protection, techniques and skills of safe behaviour, etc.

As mentioned before, various factors of military, social, man-made, and natural environments can be *sources* of potential threats to higher educational institutions. Knowledge about possible dangerous and emergency situations, methods of their early detection and counteraction, is the essential condition for the efficiency of higher educational institution security system.

Security objects are: higher education seekers, teachers, staff, as well as material, intellectual, spiritual values, and the environment, without which normal educational process and life activities of a higher educational institution are impossible.

Security subjects at a higher educational institution include: leadership, staff, security personnel, various life support services, rescue and assistance, parents, higher education seekers, military-civil administrations of a district, city, law enforcement agencies, education authorities, health authorities, and others.

Financial, personnel, information, energy, and other resources ensuring security of a higher educational institution, as well as technical means for detecting and eliminating dangerous and emergency situations and their consequences, are of significant importance.

Organizational measures play a substantial role, including distribution of functional duties for ensuring security both under normal circumstances and in dangerous and emergency situations. For instance, in a case of emergency situations, experts believe that administration and higher education teachers should take the following measures: strengthen the access control at the entrance to the territory; install alarm systems, audio

and video recording systems; conduct daily patrols of the educational institution's territory; periodically inspect warehouses and utility rooms; carefully select and vet staff; regularly hold briefings and practical training on actions during emergency situations jointly with law enforcement agencies; in case of detection of suspicious objects, immediately report them to the law enforcement agencies via the phone numbers of territorial subdivisions of any law enforcement and defense agencies or by dialing the universal emergency number 112; do not allow independent disarming of explosive devices; evacuate people according to the existing plan if necessary, etc.

Safe behaviour skills in dangerous and emergency situations are of fundamental importance. This is the crucial component of the security system of a higher educational institution, the very human factor, without which this system is non-functional. Putting this human factor into practice implies a serious attitude of higher education seekers and all subjects of higher educational institution security towards security issues.

Methods and forms of developing safe behaviour skills may be diverse. Certainly they should primarily be implemented during vital activity safety classes. However, it is important to remember that the safety of higher education seekers is the task of all higher educational institution subjects (teachers, staff, parents, law enforcement and other agencies, including the seekers themselves). Safety should be a focus during every class and event at the institution.

Classes in tactical medicine, survival psychology in various extreme situations, physical training, and even simply trustful conversations on various security issues (military, mine, domestic, transportation) are of great importance. All of this requires high financial, energy, intellectual expenditures. The key here is an adequate attitude towards security issues from all teachers (without exception) and educational institution staff.

Therefore, minimization of the likelihood and consequences of a threat to higher educational institution security can currently be carried out in several main directions, which are interconnected and coordinated with each other.

The first, general, direction involves preparing all objects of a higher educational institution, employees, and higher education seekers for actions in the event of an emergency or any other event leading to a deviation from the normal state or process. The basis of this direction is the development of action plans in case of security threats, for the creation of which detailed scenarios of actions in the event of possible accidents, man-made or natural disasters, and other disruptions to the daily life of an educational institution are required. In order to do this, it is necessary to have experimental and statistical data on physical and chemical properties of hazardous substances (for example, chemical, biological, or nuclear threats) that constitute a possible emergency situation; to predict the size and degree of damage to objects when exposed to harmful factors of various types, etc.

In the developed action plan of an educational institution for prevention and elimination of natural and man-made emergencies, a description of a higher educational institution and a brief assessment of possible situation in the event of accidents, disasters, and natural disasters are provided, the order in which rescue operations are to be carried out in the event of the threat and occurrence of major accidents, disasters and natural catastrophes is determined, as is the procedure for organizing interaction and managing the measures taken, the issue of the availability of personnel and financial

resources for carrying out emergency rescue operations and other urgent tasks, as well as for implementing measures to protect employees, higher education seekers, and material assets, is resolved.

Based on the developed action plans and considering measures contained in them, all employees and students are trained in security issues.

The second direction involves the development of technical and organizational measures reducing the likelihood of fulfilling a dangerously impressive potential of modern technical systems, including those introduced from the outside. Within this direction, protective devices are incorporated into technical systems and objects: technical equipment with means of explosion and fire protection, electric and lightning protection, localization and extinguishing of fires, equipment of protective structures (bomb shelters), etc.

Proceeding from this, we believe that the main components of the Comprehensive Security Assurance Program in an educational institution are of the following content:

– planning actions to prevent and eliminate natural or man-made emergency situations and other threats within an educational institution;
– creating a system for training staff and students on security issues;
– implementation of a set of organizational and technical measures to ensure security.

In turn, security training system should be subdivided into student training, training of employees who are part of emergency rescue units recommended to be established in educational institutions, and training of other employees. It is necessary to note that throughout a person's active life, they can acquire knowledge, skills, and abilities in the field of vital activity safety, and this can and should be fully utilized. The most general consideration of the patterns of technological progress allows us to note that circumstances contributing to the occurrence of accidents and emergencies arise from completely objective reasons:

1. With the development of tools, the range of human influence on the surrounding world has expanded both in diversity and intensity. The achievements of science enable to make the development of technologies less dangerous, to create relevant means of protection from danger, to choose courses of action considering potential risks, etc. However, despite these preventive measures, as technology develops, the danger is growing faster than counteraction to it.
2. With the increasing danger in work and life environments, the consequences of mistakes are becoming more severe. Nowadays, people more often die from high voltage electricity, get injured while using increasingly powerful means of transport, fall from multi-story buildings or dormitories where higher education seekers usually reside.
3. Human habituation to danger. While enjoying the benefits provided by technology and getting used to them, people often forget that technology is usually also a source of high danger, and its intensive use increases the likelihood of dangerous events (for example, accidents, fires). Nowadays, a local resident tends to fear domestic animals more than an oncoming car. Constant interaction with dangerous equipment and and a lack of awareness of the frequency of accidents mean that people stop being afraid of what is actually very dangerous. Fortunately, not every violation leads to an accident. But this "fortunately" also has a downside. People who have previously broken rules

without facing consequences and have benefitted in some small way from doing so repeat such violations. Gradually, people both adapt to danger and develop a habit of rule-breaking.

In addition to common causes many diverse, purely individual factors, mainly of a psychological nature, are revealed that contribute to deliberate violations of occupational/study safety rules and an increase in the number of accidents (show-off bravery, lack of discipline, risk taking, etc.). Therefore, relying solely on technical measures is not sufficient to address the problem of ensuring security. Moreover, with the improvement of technology and the enhancement of its reliability and safety, the shortcomings of the human factor become more noticeable, as human errors gain more significance in the overall mass of events. That is why it is essential to teach safe behaviour to every person throughout their life (and especially in an educational institution).

Organizational and technical issues of ensuring security can also be divided into two main groups: ensuring security of a higher educational institution in daily activities and ensuring its security in emergency situations.

It's worth pointing out that components of the Comprehensive Security Assurance Program are interrelated. Is is impossible to successfully implement one component without setting up necessary conditions for the others, and vice versa. For instance, without planning the course of action in certain situations, it's impossible to properly organize training for all employees and students on how to act in these conditions; without organizing drills for responding to appropriate emergency situations, one cannot be assured of the adequacy of applied technical methods and means of protection, etc.

The availability of the Comprehensive Security Assurance Program in a higher educational institution and appropriate development of all its components will allow addressing various security issues.

Firstly, the Comprehensive Program is designed to equip specialists with competence in vital activity safety, cultivating in them a character predisposed to safe practices. This can also guarantee a higher level of safety for society in general.

Secondly, the Comprehensive Program makes it possible to foreseen consequences of any abnormalities or deviations in the educational institution's normal activities, facilitating timely development of appropriate preventive measures to avert these problems.

Thirdly, the Comprehensive Program thoroughly prepares all staff and students to handle emergency situations, including potential criminal incidents within and outside an educational institution. It also helps them acquire necessary physical responses for these situations.

The Comprehensive Program ensures timely and full resolution of the issues concerning occupational safety and environmental protection at all stages of a higher educational institution's operation.

3 Conclusions

Ensuring security requires significant effort and involves considerable costs. However, those who do not want to pay for security will end up paying for not taking timely measures. The cost for inaction can be substantial, or even disproportionately higher. At

the same time, optimal organization of security tasks and rational use of funds can both increase the efficiency of ensuring the security of a higher educational institution and ultimately reduce the load on its budget.

Thus, the development of the Comprehensive Security Assurance Program for an educational institution requires a comprehensive analysis of the institution's state, its level of preparedness and security at the current stage of development. In light of the above, it requires theoretical development of unresolved issues and their practical implementation.

Therefore, with the aim of protecting and ensuring the security of a higher educational institution and the entire educational environment, we propose the following:

1. Create a safe physical space for higher education seekers and staff of an institution (when using a blended learning format, it is essential to minimize the clutter of the institution's premises with irrelevant items, furniture, flammable materials, and other objects that could hinder evacuation).
2. Implement clear procedures for behaviour and response in emergency situations in an educational institution, with the development of explicit security protocols.[1]
3. Conduct regular online and in-person learning/trainings with higher education seekers on how to behave in dangerous situations. It would be beneficial to invite relevant specialists to these meetings: bomb disposal experts, specialists of the State Emergency Service of Ukraine, tactical medicine doctors, psychologists, conflictologists, etc.
4. Develop uniform requirements for administrative and teaching staff of higher educational institutions on the improvement of their knowledge in the field of personal security, health and life preservation of higher education seekers, rules of action to prevent emergency situations, and protection measures in case of their occurrence.
5. Implement foreign experience for integrating new security technologies.
6. Develop/update anti-bullying measures, which is especially important in mixed-type teams (in the presence of individuals who have IDP status).
7. Update the database of higher education seekers who require special social attention and support.
8. Update civil defense siren, security and fire alarm systems.
9. Build/update bomb shelters and other security structures.
10. Develop a clear algorithm for interaction between the leadership of higher educational institutions and territorial subdivisions of the National Police, the State Emergency Service, the Civil-Military Administrations, etc.

Finally, it is especially important to note that the comprehensive security assurance system of a higher educational institution must fulfill its main function: to create a safe and comfortable educational environment.

[1] The safety protocol is a certain set of rules and procedures that should be followed by university employees and students of higher education in relation to a certain dangerous situation. Given the security risks, the institution should have several such protocols, in particular regarding actions during air alarms and evacuations, staying in shelter, behavior during online classes, etc.

References

1. Safe educational environment: new dimensions of security. https://sqe.gov.ua/bezpechne-osvitnie-seredovishhe-novi-vim/
2. The government adopted the concept of security of educational institutions. https://mon.gov.ua/ua/news/uryad-uhvaliv-koncepciyu-bezpeki-zakladiv-osviti
3. Concept of security of educational institutions. Approved by the order of the Cabinet of Ministers of Ukraine dated April 7, No. 301 (2023)
4. Zhelibo, E.P., Sahaydak, I.S.: Life safety: education. Manual Kyiv, p. 200 (2011)
5. Shtepa T.V.: Fire safety. Labor protection in the field of education: theoretical and technological aspects: materials. In: Vseukr Science and Practice Conference Poltava: PNPU, pp. 152–159 (2014)

Theoretical and Practical Significance Identification of Objects of Preventive Influence in Criminology and Law Enforcement

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Abstract. Under today's conditions, humanity and all social and state formations, including Ukraine, as part of the world order, is experiencing many changes: we are in a radically new political, economic, spiritual and ideological situation compared to the end of the twentieth century; its main features are socio-economic stagnation, political, cultural, educational and moral-psychological uncertainty, activation of old and the emergence of new stressors at the level of both individual and group (and even mass) consciousness. The complexity and contradictions of socio-economic and political development of our country necessitate the theoretical understanding and development of scientifically sound tools with which to make more effective the process of social interaction, non-criminogenic development of society, crime prevention and counteraction. Without theoretical knowledge that directly serves a specific state-building practice, it is impossible to fulfill a strategic task—to build a democratic state and civil society in Ukraine. Scientists rightly point out that the current criminal situation is characterized by new types of crime, dynamism of development, unpredictability of changes, spread of organized forms and professionalism and the inability of the state to resist corruption necessitates the effectiveness of the fight against crime.

Keywords: criminal law · criminology · crime prevention · corruption prevention · victim prevention · objects of prevention

1 Introduction

The current period of development of legal science in Ukraine is associated with the need to solve a number of problems, among which a significant place is occupied by issues of study and creative analysis of scientific developments, ways to use scientific

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and technical achievements, identifying promising areas of research and more [1]. The law, which was brought to the perfection of a computer system at the end of the twentieth century, is lagging behind the problems of mankind, so the methodology of legal science should systematically respond to the challenges of today, using philosophical and scientific achievements [2]. Reforms of political and economic life exacerbated contradictions in modern Ukrainian society and led to a significant increase in criminal violence. These processes are accompanied by social tension and the decline of morality. In addition, modern crime acquires fundamentally new qualities and transforms from national into international threats to criminological security, transferring them to the category of global, international cooperation in the field of crime prevention and corruption at the transnational and cross-border levels is gaining relevance. Therefore, the lack of a single model of the strategy for ensuring the criminological security of the state causes particular anxiety, because it will serve as a guarantor of the observance of value norms and attitudes that determine the content and orientation of public consciousness and socio-political thought [3]. Crime and illegal behavior is determined by a complex of negative phenomena and processes of various origins, which become objects of preventive influence. Theory and practice of crime prevention and law enforcement activity shows that from the correct definition of the object preventive influence and its choice depends on the effectiveness of the preventive activity Such activity is carried out by various entities with a purpose neutralization of criminogenic factors and destruction and neutralization influence of determinative complexes of crime and individual types crimes [4, p. 189].

The purpose of this article is to study the objects of crime and corruption prevention, to determine their essential characteristics and to separate them from other objects of social reality.

1.1 Methods

The methodological basis of the work is the dialectical method, the application of which allows to study the object and subject of research in their epistemological unity, relationship, as well as differences. The technique used in writing the article consists of several basic methods of scientific knowledge. Using the historical method, historical and general theoretical questions of the essence of the object of crime prevention and corruption are clarified. The use of methods of analysis and synthesis made it possible to separate the objects of prevention from other objects of social reality—this was also facilitated by the use of the structural-functional method. These methods also allowed to investigate the theoretical views on the nature and elements of the object of crime and corruption prevention. The logical-semantic method was used to determine the relationships and mutual influences of crime prevention and corruption objects with other objects. Scientific abstraction and generalization of scientific and theoretical information as a process of establishing general properties and signs, allowed to reach and formulate final conclusions on the subject of research.

2 Main Body

Traditionally, in the doctrine of the science of criminology, the object of crime prevention includes: shortcomings and contradictions in the system of social relations, which affect the process of moral and psychological formation of an individual and his law-abidingness; negative social phenomena associated with certain forms of social pathology (drunkenness, drug addiction, prostitution, etc.); individual persons or contingents of persons characterized by illegal behavior; negative phenomena and processes that determine the commission of specific types and groups of crimes; places of concentration of persons with antisocial orientation; specific criminogenic situations.

In the literature, the object of crime prevention is also defined as a separate or interconnected set of negative phenomena and processes of real reality of a material and spiritual nature, different in genesis, sphere of being and consciousness, forms and degree of intensity of manifestations of their properties, the existence of which leads to reproduction on at the social level of crime as a social phenomenon, and at the group and individual level - to the emergence of mass destructive behavior of people, criminal motivation, intention, decision-making to commit crimes and their implementation [5].

Relying on the general theoretical doctrinal views of criminological scientists, the majority of modern scientists, when studying one or another issue in a narrow context, defined as the objects of crime prevention precisely those social relations that they studied.

It should be noted that in modern criminology such a definition of the object of prevention has been fixed, according to which the objects of preventive influence are understood as negative phenomena and processes of real reality of a material or spiritual nature, which lead to the emergence of causes and conditions that contribute to the commission of crimes. The following properties are characteristic of an individual object: criminogenicity (it is this that distinguishes it from the set of negative phenomena); dynamism, which causes constant variability of its quantitative and qualitative indicators; potentiality - it explains the fact that certain phenomena can quickly reach a high degree of criminogenicity; latency—criminogenicity that is hidden from the observer-researcher [6].

The problem of preventing crime of any nature or direction is related to certain social groups, individuals, personalities and life situations into which they fall. In this sense, prevention is a targeted act aimed at certain categories of people. Crime prevention is a specific social system. Its holistic vision and perception as an object of appropriate organizational regulating influence helps to get rid of the absolutization of the internal regularities of its functioning and development, the replacement of efficiency and its criteria with the problems of structural and functional perturbations, and leads to a significantly new level of clarifying the degree of conformity of the system's influence on causes and conditions crimes is her task.

As already mentioned, the correct choice of the object of preventive influence is of great importance for preventive activities. In the criminological literature, there is a difference of opinion on this issue, because different authors call the same phenomenon either an object or a subject, and some consider the object and subject as identical, categories that have unprincipled terminological differences. On this basis, a situation has developed when, for example, contradictions in social relations are called an object,

and the consequences of these contradictions—criminogenic factors—an object of crime prevention. We consider this situation to be clearly defined.

The object of crime prevention is the criminogenic factors to which the activities of the relevant entities are directed. In other words, it is something that is directly influenced by the subjects in order to reduce the number of offenses, prevent a specific, realistically possible crime, prevent it or stop its commission. In our opinion, crime prevention as a type of social practice and social value reflects social relations on the occasion of and in connection with the prevention of crime, therefore it is they (relationships), and not their shortcomings, that are its object.

A special object is potential victims of criminal encroachments. This is about the so-called victimological aspect of crime prevention. Victimological crime prevention is carried out at the same levels and directions as crime prevention, namely: general social victimological prevention; special victimological prevention, which, just like its criminological counterpart described above, consists of victimological prevention, diversion and termination of victimization of persons; individual victimological prevention of victim behavior.

At the same time, the object of victimological influence covers information sources of various origins, which testify to the origins of mass, group, individual victimization and the presence of dangerous victimhood at these levels, to which the theory and practice of victimological crime prevention is directed. Special objects of victimological prevention are social and psychological factors of victimization and victimhood as objects of preventive victimological influence at the individual level.

When studying the objects of preventive influence, it is impossible to ignore such a specific phenomenon of the existence of society as corruption, because it poses a real threat to many social relations and the world order in general. It is noted in the literature that the objects of corruption prevention include: 1) corruption factors; 2) corruption risks in the activities of authorities, local self-government, legal entities under public and private law and their officials; 3) illegal behavior of officials and officials of state authorities and local self-government [7]. Corruption-inducing factors are systemic problems that lead to corruption and contribute to its spread. Most of these problems are of an institutional, normative-legal and moral-psychological nature.

Institutional corruption-causing factors are caused by contradictions between the purpose, main tasks of state bodies and the actual focus of their activities. This also includes deficiencies in legal regulation and public administration.

Corruptogenic factors of legal regulation include a separate provision of a normative legal act or a set of legal norms that may contribute to the commission of corruption offenses or offenses connected with corruption. The specified factors are contained in normative legal acts and draft normative legal acts, in particular in the laws of Ukraine, acts of the President of Ukraine, the Cabinet of Ministers of Ukraine and central executive authorities. They are revealed by conducting an anti-corruption examination of normative legal acts and their drafts. Corruption-inducing factors of legal regulation may consist in unsettled or insufficiently settled social relations in certain spheres; gaps in legislation, legal conflicts in normative legal acts, as well as unclear definition of functions, rights, duties and responsibilities of state and local self-government bodies and

persons authorized to perform state or local self-government functions. Corruptionogenic factors of a moral and psychological nature include defects of legal awareness and corruption-oriented behavior of persons authorized to perform the functions of the state or local self-government, and persons equated to them. The mentioned factors consist in non-acceptance of ethical standards, anti-corruption restrictions and prohibitions, disregard for the interests of the civil service, dishonesty of officials, etc. The cumulative effect of the listed factors forms the motives for criminal behavior and causes internal readiness for corrupt actions. As a corruption-inducing factor, the social environment forms defects in legal awareness, determines the corrupt nature of official and non-official relations, and stimulates officials to commit corruption offenses [7].

3 Conclusion

Summarising the above, it should be noted that nowadays, during the rapid development of society, active globalisation processes, and the emergence of new forms of criminal manifestations, the doctrine of the object of crime prevention is becoming increasingly relevant for criminology in general and crime prevention theory in particular. It can be definitely pointed out that the opinions on the object of prevention discussed in this article are far from being limited to those expressed in the criminological literature, although it can be stated that most scholars, presenting their own vision of the object of crime prevention, are to some extent identical in their views, because in one way or another they understand the object of crime prevention as destructive influences on social relations, negative social phenomena, persons characterised by unlawful or deviant behaviour, negative phenomena and processes that determine the commission of crimes, etc.

The challenges facing Ukraine at the present stage of the historical development of the state make the rethinking of the essence of the state mechanism and promising and urgent problems arising from its improvement and functioning extremely topical. Therefore, for the Ukrainian society, the need for the latest methodological foundations of comprehensive interdisciplinary studies of social life, as well as progressive methods that would become the theoretical basis for constructive social shifts in general and in the field of preventing and counteracting the existence of certain types of crimes in particular, which will help reduce the general criminalization of society, is obvious [8].

In general, determining the essence of the object of prevention is a prerequisite for the correct choice of measures to prevent crime and its individual types and for determining the range and competence of the subjects of such prevention. Based on the considerations presented in the article, several of the most important conclusions can be noted. Firstly, the objects of preventive influence in relation to the prevention of crime and corruption are understood as negative phenomena and processes of real reality of a material or spiritual nature, which lead to the emergence of causes and conditions that contribute to the commission of crimes. At the same time, one should keep in mind the properties that are common to such objects, namely: criminogenicity; dynamism; potentiality; latency. Secondly, separate objects are the objects of victimological influence, which cover information sources of various origins, which testify to the origins of mass, group, individual victimization and the presence of dangerous victimhood at these levels, to which the theory and practice of victimological crime prevention is directed,

especially the objects of victimological prevention are social and psychological factors of victimization and victimhood as objects of preventive victimological influence at the individual level. Thirdly, specific objects are the objects of influence in the prevention of corruption, which include: corruptionogenic factors; corruption risks in the activities of authorities, local self-government, legal entities under public and private law and their officials; illegal behavior of officials and officials of state authorities and local self-government.

It is also worth noting the following fundamental conclusions drawn in the course of the study. Firstly, when classifying crime prevention actors by the types of objects of preventive influence, it is necessary to take into account their functional interrelationships and lack of subordination. Secondly, from the point of view of the hierarchy of crime prevention objects, the main purpose of specialised crime prevention actors is to fight crime as a type of social practice (law enforcement). The nature and content of this activity necessitates that it be based on the system of state institutions. Thirdly, given the properties of the objects of influence, crime prevention is the antithesis of crime control. It is characterised by less aggressive, more social forms of counteraction. Contributing to the implementation of security functions indirectly and over a longer period of time, it is the mainstream of social practice that should develop adequately with the development of the law enforcement system. The basis of this activity is social institutions and relevant measures, and priority should be given to broad public involvement in preventive procedures.

Crime prevention is a complex socially determined activity aimed at ensuring integrity of the state, strengthening the law and order in society, and protecting the rights and freedoms of a person and a citizen [9]. Therefore, a deep and comprehensive knowledge of the nature of criminogenic objects, their scientific, historical and epistemological research will serve as a basis for understanding the danger of this social phenomenon and finding appropriate effective methods, means and measures to influence it. The state should carry out crime prevention by influencing certain criminogenic objects, which by their very nature will constitute the object of crime and corruption prevention at various levels of preventive activity - general social, special criminological, individual, as well as when implementing victimological prevention measures.

References

1. Filipenko, N., Spitsyna, H.: Criminological Activity of Forensic Science Institutions: the Concept of Implementation in Ukraine//Teisė. 2022. T. 124. P. 67–80 (2022). [in English]. https://www.zurnalai.vu.lt/teise/article/view/29446
2. Lukashevych, S.Y., Salaeva, K.A.: Paradyhmalni zrushennia v metodolohii suchasnoi kryminolohii. Omul, Criminologia, Ştiinta: Conferința științifică internațională: ediția a II-a (Chişinău, 24 martie 2023). Chişinău, 2023. Vol. 1. P. 197–201 (2022). [in Ukrainian]. https://ibn.idsi.md/sites/default/files/imag_file/197-201_20.pdf
3. Lukashevych, S.Y.: Modeliuvannia trendiv zlochynnosti. Visnyk Chernivetskoho fakultetu Natsionalnoho universytetu «Odeska yurydychna akademiia». № 3. S. 103–111 (2018). [in Ukrainian]
4. Police activity in Ukraine and European countries: modern standards and unification options: Collective monograph. Riga, Latvia: "Baltija Publishing", 2021, pp. 600 (2021). [in Ukrainian]. http://baltijapublishing.lv/omp/index.php/bp/catalog/book/190

5. Holina, V.V.: Obiekt zapobizhnoho vplyvu: poniattia, oznaky, znachennia. Aktualni problemy kryminalnoho prava ta kryminolohii u svitli reformuvannia kryminalnoi yustytsii : zbirnyk materialiv Mizhnarodnoi naukovo-praktychnoi konferentsii [22 travnia 2015 roku, m. Kharkiv] / MVS Ukrainy ; Kharkivskyi nats. un-t vnutr. sprav ; Kryminolohichna asotsiatsiia Ukrainy. Kh. : KhNUVS. S. 104–105 (2015). [in Ukrainian]
6. Kryminolohiia: pidruchnyk/B.M. Holovkin, V.V. Holina, O.V. Lysodied ta in.; za red. B.M. Holovkina. Kharkiv : Pravo. 2020. 384 s. [in Ukrainian]
7. Zapobihannia koruptsii : pidruchnyk/B.M. Holovkin, V.F. Obolentsev, M.V. Romanov ta in.; za zah. red. B. M. Holovkina. Kharkiv: Pravo, 2019. 296 s. [in Ukrainian]
8. Lukashevych, S., Obolentsev, V., Ponomarenko, Y.: Systematic transformation processes of crime in the financial and economic spheres and the prevention of criminal leadership. In: 6th International Conference on Social, economic, and academic leadership (ICSEAL-6–2019). Atlantis Press, 2020, pp. 149–154 (2019). [in English]. https://www.atlantis-press.com/proceedings/icseal-6-19/125940981
9. Lytvynov, O., Spitsyna, H., Butenko, V.: Modern view of system of crime prevention subjects. Electron. Sci. J. Law Socrates **3**(24), 11–20 (2022). [in English]. https://doi.org/10.25143/socr.24.2022.3.011-020

Forming Core Values in Youth with the Usage of Media Materials

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Abstract. This article reveals the need of raising the level of media literacy in youth and the impact of media materials in educational and personality shaping processes, especially forming core and moral values. The importance of preparatory selection of media materials and its appropriate usage is underlined. The problem of youth lacking in media literacy competencies substantiates the expediency of its research. The peculiarities of student volunteer team training with the usage of media materials as a pedagogical technology are described. The description is concentrating on its step-by-step preparation, on the principles and core values of the suggested program or curriculum.

The analysis of the shaping youth' character with the usage of media materials in the works of domestic and foreign scientists from different scientific fields has been proceeding. A few sets of problems prevented or solved by such methods have been identified. The conducted research that used preparatory program with presented in it media materials meet the requirements of a pedagogical tool that effectively facilitated our activity. It is proved that combined features of applied professional technologies of thoroughly planned materials, including media texts, as well as effective engagement of youth in active volunteering, brings the shaping of core and moral values in youth as the result.

The opportunities and challenges for researchers working with the problem of developing media literacy as a conductor for bettering the educational processes and as a result, the behavioral patterns in the society in the country are outlined by the authors.

Keywords: Media literacy in volunteering · Youth' media literacy · Core values · Forming values · Transformation in society

1 Introduction

Modern society is moving forward with dynamism, the rapid innovative development of technology, characterized by continuous socio-economic changes that widely influenced by the multiplicity of ubiquitous media. The increased pace of these changes brings up the need to reform some of the educational and pedagogical processes, used methods and technologies, including the application of media materials and raising the level of

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media literacy with the goal to improve the ability of modern specialists to organize, plan and conduct their activities at the appropriate level. The shaping of the individuality, personal growth, forming and influencing their core life values is ever present issue of humanistic reflections of modern thought, and as a result, often the subject of philosophical, pedagogical, educational, historical, ethical, and sociological sciences and of other various researches.

Given this, the **objective of this paper** is specific methods and conditions where the core values ate formed in youth. It should be noted that the area of interconnection of media literacy and forming of values are, in general, one of the primary concerns of such studies and observations nowadays. The concern of parties involved in nurturing children and youth is notably growing with every new generation.

This study contributes to the existing literature by being the first to use a per cent approach to analyse inner and outer motivation of children‘s project volunteers; the direct and indirect impact of the media materials usage in the processes of preparing volunteers for participation in a complex project and its effectiveness; and as a result, forming core values in youth. As an example of a case for our research we are going to describe and analyze one of our many volunteer projects. The project (2015 – 2016) was organized mainly for children (6 – 16 years old) from temporarily internally displaced persons (IDPs) in the format of summer and winter camps.

2 Analysis of Recent Research and Publications

In the middle of the last century, the problem of forming of personal and societal life core values, including the moral and humanistic values, became a noted fragment of world knowledge in psychology, sociology and pedagogy. A significant contribution to the study of human values and motivation was made by A. Maslow, a famous American clinical psychologist (the 50s of the XX century), widely known by the Hierarchy of Needs. In the works devoted mainly to the personal development, the scientist emphasized the fact that choices and decisions of a person made by them are based on the combination of inner and outer motivation (“drives”) and their core life values. We fully agree with his conviction that “there are many determinants of behavior other than the needs and desires. Perhaps, more important than all these exceptions are the ones that involve ideals, high social standards, high values and the like”. “Classic economic theory, based as it is on an inadequate theory of human motivation, could be revolutionized by accepting the reality of higher human needs, including the impulse to self-actualization and the love for the highest values” [1].

Unfortunately, understanding all the advantages of modern technology, we have to realize the danger of possible manipulative influence of capitalistic and materialistic mentality, especially through usage of media materials for advertising purposes on social network platforms, as illustration shows (Fig. 1). It is fairly easy to access and analyze the personal preferences of users and “to examine several characteristics of the social media (but not limited to LBSN) data analytics such as users’ online activity and movement patterns, check-in behavior, city boundary definitions, and point-of-interest recommendations” [2].

Borisenko R. explains media culture as a constantly evolving form which is able to store, replenish and broadcast a huge amount of information, leaving the possibility

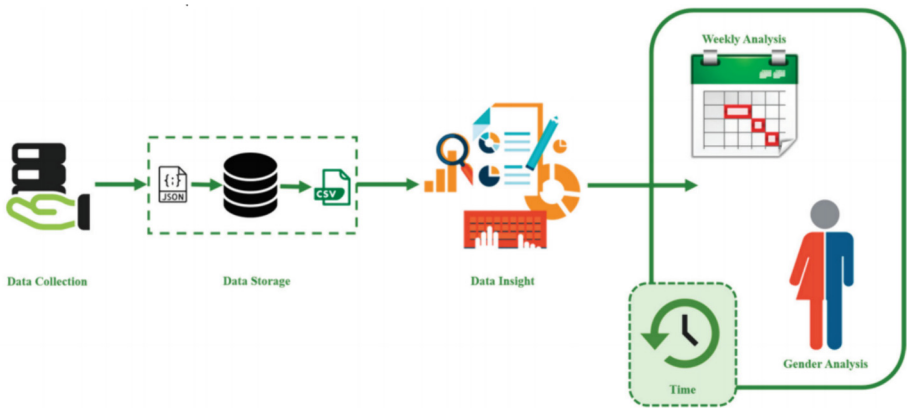

Fig. 1. Check-in behavior analytics framework [2]

of individual comprehension of information. Semiotic nature of media culture allows to define more effective technical means of implementations that preserve information accessibility and imaginative perception of it in the transmitting process of images and symbols [3].

In her monograph in the theory of mass communications Zhilavskaya I.V. considers the sphere of media education as technologies of interaction of mass media with an audience and analyses different ways of how to measure the efficiency of media educational activity surrounding mass-media [4].

According to the results done by the group of scientists from Netherlands Organization for Applied Scientific Research the forming of the core values is absolutely necessary for "The first value cluster is characterized by a positive attitude toward people and their "being"; it comprises the core values of interconnectedness, participation, and trust. The second value cluster is relevant for the organizational and individual "doing", for actions planned or undertaken, and comprises justice and responsibility. The third value cluster is relevant for "becoming" and is characterized by the alignment of personal and organizational development; it comprises the values of growth and resilience" [5].

Both "doing" and "becoming" are incorporated in learning activities. Learning processes are out most successful when they capture full attention of the students (true for any age) and engage all senses and emotions. That's why for centuries, games for children and adults were universal forms of learning and socializing. Janusz Korczak, a known Polish educator of WWII period, wrote: "A game (by author: in modern times could be different type of engaging activity) is not so much the child's medium as the only sphere in which he is allowed to display more or less initiative. When participating in a game, the child feels to some degree independent" [6]. The appropriate (non-virtual) games and "live" tactile activities are still an absolute must in a daily life of a child or teenager of any age and must be included into every educational syllabus. Regrettably, the world (of live face-to-face interaction) is not the same anymore. With the rapid development of world technology and daily presence of ubiquitous media materials, the society, and educators as a leading force, must learn their positive effects and include them into educational and pedagogical processes.

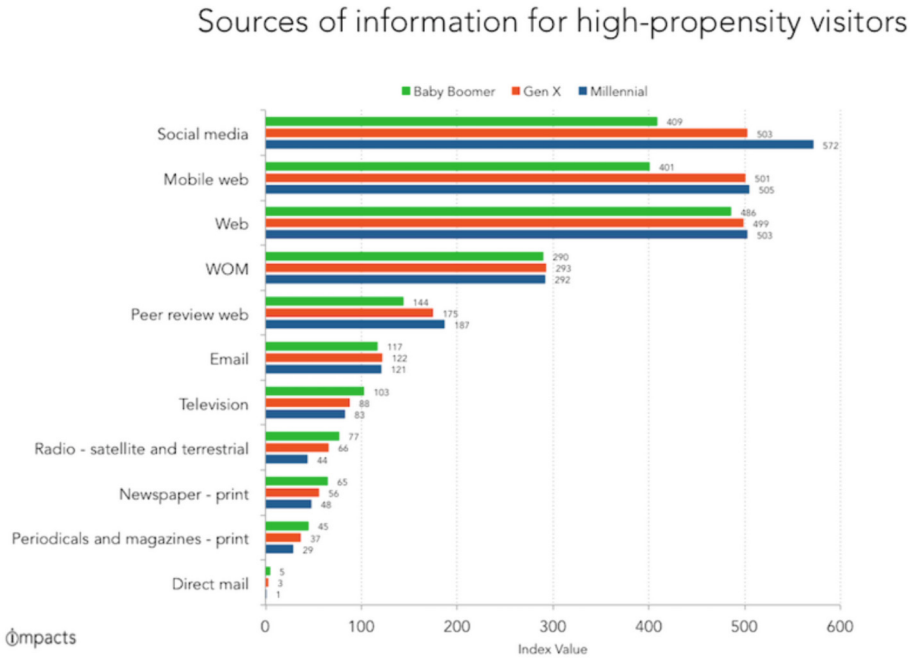

Fig. 2. Top Information Sources for Likely Visitors [7]

Various activities that include interaction with media materials, such as viewing films, video clips, browsing social networks and playing video games, became an indispensable part of their lives. Their trust in these materials is alarming, as we see on the scheme (Fig. 2). The world of online activity expands by the day, including schooling and entertainment. That is why educators of all levels, pedagogy, special stuff of any educational institution and also volunteers (which group is in focus of our research) for children's activities must be appropriately prepared and motivated [8].

Methodology Forming highest core life values is an ultimate goal of pedagogy and educational system, and of course, everyone who is concerned about the future.

The state of the world and modern technology is such that the amount of time children and youth spend with the "screen" is far above the appropriate, increased by every decade. Representatives of formal, informal, alternative and life-long types of education, alarmed by the decrease of the general knowledge, interests, involvement and morals, use various forms, methods, technologies and activities that could influence forming and deepening children's and youth' values, consequently, affect their character, and, therefore, their future.

As an example of a case for our research we are going to analyze and describe one of our many volunteer projects. Clearly understanding stated the above, the group of volunteers led by an NGO, organized the project for the children and teenagers from IDPs families from Donetsk region affected by the political unrest.

This article is concentrated mainly on the preparation of volunteers for hosting and assisting at various children's activities especially, their full-time (24/7) engagement

and conducting processes and features, on the sample of children's (winter – 5 days, or summer – 10 days) camps.

The training period, forming the content of the training program and conducting all of the camp events, included different activities, in which media materials were constantly and actively used. The process could be divided into three segments: 1) training the team of volunteers during a few months preparatory process; 2) morning briefings and motivational evening meetings for the administrative and youth leaders team during camp sessions and in between them, 3) during camp sessions, in day to day program, when scheduled, for training, education and entertainment of the participants (children). The project was prepared and conducted by the NGO "Let's Love", which is one of the active participants in the development and promotion of the volunteer movement in Eastern Ukraine.

The project (2015–2016) was organized mainly for children (6–16 years old) from temporarily internally displaced persons (IDPs) in the format of summer and winter camps. This paper is describes the preparation and conducting processes, especially, engagement and preparation of volunteers via various formats: training, exercises, presentation – via media and verbal, reviewing and discussion of required (mostly in various media formats) materials, skits, role games, singing with motions and more.

Being convinced Christians, keeping Christ's commandments to care for "your neighbor" all NGO members were involved in helping the IDPs in one way or another. Instead of wasting time focusing on the past and losses, often living in disadvantageous conditions, volunteers provided free housing on their church premises to those in need, delivered balanced food packages, provided warm clothes and blankets, conducted thematic seminars and work-shops, helped financially and practically, supporting others physically, spiritually and emotionally. They consider it a duty, doing everything, working "willingly at whatever they do, as though they were working for the Lord rather than for people" [9, Col. 3:23].

3 Research Results

3.1 The Expected Knowledge and Competencies from Media Education

Specialists working in the field of media education in formal setting, especially with high school and higher education students, along with the aim to uplift core life values via media materials, pursue the goal of preparing them for their professional path, for example, forming critical thinking skills in the heads of representatives of their corresponding audience.

This could be done by performing following tasks:

- forming theoretical knowledge of media literacy basics and practical skills of effective and safe dealing with obtained from media sources information, including taking into account the usage of modern information and communication technologies in everyday practical activities, including educational and cognitive;
- learning to perceive and process information transmitted through the media (in a broad interpretation), the development of critical thinking, the ability to understand the hidden content of a message, to resist the manipulation of individual consciousness by the media;

– forming skills to find, prepare, convey and receive information, including using various media resources.

The expected result is the students‘ obtainment of the following competencies.

1. *Ethical and pedagogical* (possession of life core values; knowledge of pedagogical ethics, the ability to adhere to its norms and rules in their own professional activities, communication and relationships).
2. *Cultural* (knowledge of the most significant achievements in theory and practice, respect for national and foreign special heritage; the ability to aestheticize their own activities, to show humane attitude to people with disabilities; culture of pedagogical and corrective interaction).
3. *Professionalism and creativity* (knowledge of advanced experience; the ability to creatively use innovations in their own work; the ability to generate new ideas and implement them in practice; the desire to transform reality according to the laws of humanity, tolerance, respect and harmony).
4. *Worldview* competence (possession of a scientific worldview; knowledge of basic theories, concepts, doctrines that form the scientific picture of the world; the ability to defend their own scientific views).
5. *Leadership* competence (ability to develop their own strategy and tactics of social behavior and professional activities taking into account the interests of the group (team); experience of productive diagnostic, rehabilitation and correctional work).
6. *Communicative* competence (knowledge of basic methods and means of interpersonal communication, speech styles, practical experience of communication in different languages; ability to constantly enrich their own speech, establish professional communication, apply information and communication technologies in professional and scientific activities).
7. *Cognitive* competence (ability to abstract thinking, analysis and synthesis; knowledge of cognitive processes and actions; ability to independently perform mental operations (analysis, synthesis, generalization, comparison, etc.) for cognitive purposes and in organizing the process).
8. *Research* competence (knowledge of basic methods of scientific research; ability to plan and organize research on applied topics (individual practical issues), summarize the results, design and present their own scientific achievements in accordance with current requirements).
9. Technological (knowledge of traditional and modern learning technologies; the ability to select technological support taking into account given tasks, prospects for their educational and professional growth; experience in organizing interactive learning etc.) [10].

The development of (any) competence can be expected as the result of training and preparation of students and teachers alike. [11, 12].

At times using the informal settings (in our case – the children‘s camp) could be more practical and successful for learning and obtaining certain qualifications and competencies, as some mentioned on the list above, such as: the ability to generate new ideas and implement them in practice, ability to abstract thinking, knowledge of basic methods and means of interpersonal communication, ability to develop their own strategy and tactics of social behavior, and especially, the forming of core values.

3.2 The Structure and Practical Aspects of the Presented Project

The project was prepared and conducted by the NGO "Let's Love", which is one of the active participants in the development and promotion of the volunteer movement in Eastern Ukraine. The NGO was formed by the post-protestant Christians of Donetsk and Donetsk region, who are believers with the active civil position. A group of student youth, at the initiative of a group of Christian enthusiasts, founded this organization to work with disadvantaged groups of the population. "Let's Love" was registered in 2007 in town Horlivka, where its original core team was formed. Due to the political unrest in Eastern Ukraine, most of the members of this NGO left the "hot spot" and moved to Kyiv, Kharkiv, Rivne, Sumy, Zaporizhia, Poltava and other regions of the country. The main office of the foundation was moved to Kyiv.

Since 2014, and one of the present projects of the NGO "Let's Love" is organizing and managing children's camps. Humanism, respect of a person and care for others are the leading themes of the program for such full week summer and winter camps, as well as short ones, when children are present only for a part of the day. The majority of the camp's staff: director, administrators, program director, sound system technician, youth counselors, youth leaders, pedagogy and their assistants were represented by active believers. Many of them were students and high school pupils. The entire team participated in the project on a volunteer basis [13].

Having their core and moral values shaped, they consider their participation in such activities as manifestation of their faith when they help physically and financially, caring for others. Their main inner motivation is the desire to behave according their convictions and principles, in agreement with their conscience and the calling of their heart. Participation in any volunteer activity is absolutely voluntary, but most Christians consider participation in it absolutely necessary, seeing it as service to God himself: "whatever you did for one of the least of these brothers and sisters of mine, you did for me" [9].

The volunteer project, which was scheduled for June – July 2016, involved permanent volunteers of the, NGO "Let's Love", students of the Ukrainian Bible Institute and several volunteers (partly students from Kharkiv Universities). The preparation of the program and organization of the team has begun six months prior to the camp. The composition of the main team responsible for administration, selection and training of volunteers, preparation of the camp program, schedule and activity was determined. At the same time, the recruitment phase began.

Selection was based on the criteria of 1) willingness to work with children, 2) assessment of readiness and 3) personal qualities and values of the volunteer; 4) experience in working with children and 5) professional orientation for older volunteers (There was a need in counselors, pedagogues, assistants; people who would lead sport activities in the camp; technicians; people who could conduct master classes, quests, educational classes for children, in particular, spiritual content); and of course, the availability of volunteers to allocate time for participation in the project. Also, the convictions and personal beliefs could be counted as one more criteria, though not a deciding one, but as additional, though very important: one of the goals of the camp was to instill in adolescents meaningful, moral and Christian values. Therefore, it was relevant that volunteers were at least tolerant to Christianity.

In the spring of 2016, three trainings in a format of seminars were held for project volunteers in Kyiv. For the most effective result, media materials were constantly used. There were few types of materials. Some, like thematic PowerPoint presentations, concentrated on pedagogical and behavioral aspects of volunteering at the camp. The pieces of famous cartoons or humorous short video clips were used to accentuate the point of the explanations.

There was also a row of slides, explaining in detail, for example, the daily routine schedule or the schedule of the evening duty shifts for pedagogues. Then, with the goal of teaching the adults how to do certain tasks (those that children would be required to perform at one of the activities at the camp), there were viewing and shooting video clips on a given topic. The number of photo images were shown to prepare the adults for children's photo competitions or participation in social media challenges. Other types also included watching and discussing videos and short films from the YouTube channel, learning the words of songs or dance movements using on-screen media files, recording videos of participants' charity events, and much more. Everything was conducted in an attempt to exclude the possibility of a volunteer (responsible for the children or certain event) not knowing how to handle the situation.

The trainings presented (mostly in different media formats) schedule and content of each session of the camp, lectures on the duties of counselors, educators; then the analysis in detail and exercises on the interaction of counselors, educators, assistants and administration with children; also, between themselves; rules of conduct; psychological features of relationships; possible force majeure, etc. The discussions, team building assignments, role-playing games were also held. For better understanding the practical side of the matter the attendees were asked to act out skits with possible difficult situations that may arise between volunteers and their future wards. The basic pedagogical techniques in working with children and adolescents were thoroughly explained.

At the trainings and meetings with volunteers, the goals of the project and the values that the volunteer should accept and share were clearly stated. The importance of mutual support, responsibility for themselves and children, care for their safety, the importance of personal example and volunteer's behavior in the presence of children were emphasized multiple times.

Owing to the enthusiasm and activism of administrative core of the team and properly prepared media materials, all volunteers both those who participated in them in person and those who for one reason or another were not present ¬ had the opportunity to have constant access to these materials, including media of different formats and themed content) and training videos via the Internet.

3.3 Data Analysis (Age, Gender, Location) on the Participants

Further some facts and figures about the composition of the team are presented. The ages of volunteers varied from 16 to 50 years old (See Fig. 3).

As it often happens at the similar projects, when the childcare, educational and correctional processes are included, there were more females than males in the team, 36 and 26 respectively (See Fig. 4).

As it was mentioned before, the composition of the team was diverse, what is recommended by the international experts [14–16]. The volunteers came from different regions

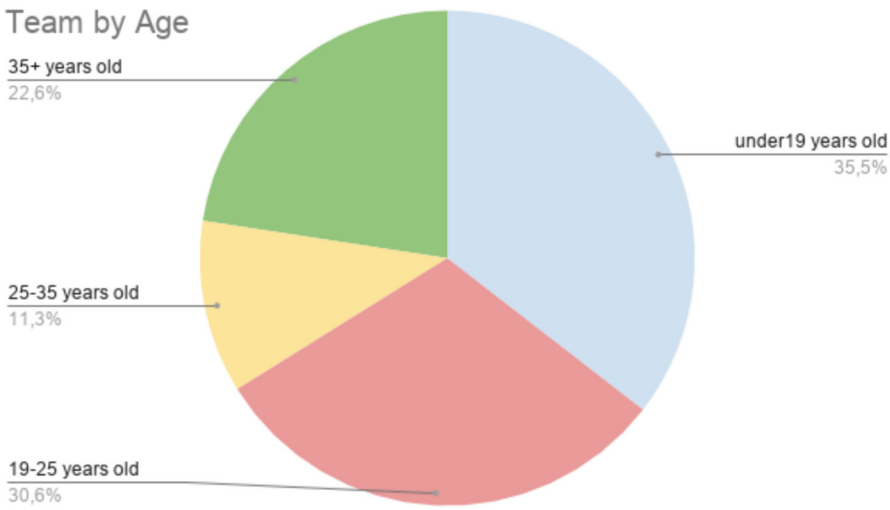

Fig. 3. Team (Volunteers) by Age

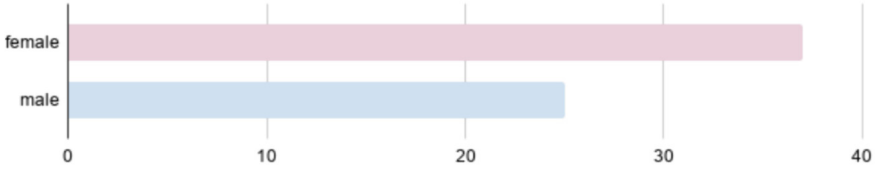

Fig. 4. Team (Volunteers) by Gender

of Ukraine, with the majority – 34% – were IDPs themselves. Due to the placement of the camp (outskirts of Kharkiv), the next prevailing amount of volunteers – 18% – came from Kharkiv. The third number – 13% – came from Kyiv, where the NGO's office is (See Fig. 5).

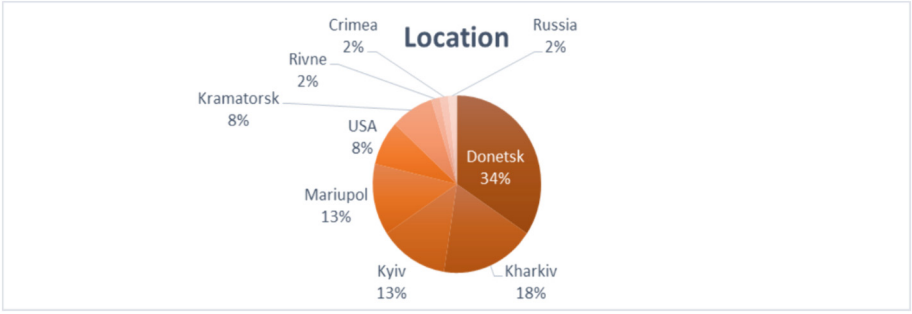

Fig. 5. Team (Volunteers) by Location

The project of our focus, the children's camp "Jump" was held in the summer of 2016, fully prepared and conducted by volunteers of the NGO "Let's Love". The camp was held in three stages:

The first session "Sport in Ukraine" lasted 12 days and was held for 120 children (6 to 16 years old) on a private territory, equipped for a children's camp, kindly provided by a couple of patrons from Kharkiv. They also provided security guards and the services of a doctor and a psychologist. Full meals three times a day were kindly offered by them as well. A team of 26 volunteers from the NGO "Let's Love" was responsible for the activities, sports, entertainment and full (24 h a day) engagement and safety of children. Of these: 8 people – the administration (including authors of the content and technical), and 18 people – youth counselors and pedagogues, three people per unit. Each unit consisted of 20 children.

The second session "My Ukraine", which lasted 10 days and covered 60 children, was held on the territory of the Training Center of the Operational and Rescue Service of Civil Protection of the SES of Ukraine in Novovodolazksk district, Kharkiv region. The children were housed in buildings converted into children's rooms. Meals were paid by the NGO "Let's Love". The camp employed 17 volunteers, 2 adults per squad of 15 children.

The third session of "CreAction" – 7 days of a day camp for 45 children – was fully funded by the American volunteers from the NGO "Let's Love" and held in Kharkiv on the premises of the Christian denomination. The session was dedicated to Christian values and principles based on biblical materials. Some programs were held in the small hall of the Cultural Center of the Theater of Musical Comedy with the assistance of the Playback Theater Group. The team consisted of 12 permanent volunteers who were present at all events of the camp and were responsible for the outcome of the project and the safety of the children, and 5–7 volunteers who participated partially in allocated segments of the program.

More than 85% of the children and adolescents who visited the Jump camp or volunteered in it were IDPs.

3.4 The Survey on the Motivation as the Product of Core Values

In September 2016, we conducted a survey among the volunteers of the NGO "Let's Love" to determine the source and nature of their motivation for participation in volunteering and their general attitude towards it. The survey included 62 people, as was mentioned in displaced earlier charts, aged 16 to 50 years old, who were permanent volunteers of the NGO or participated only in these projects, including the Christian camp in the summer.

Most of the respondents considered themselves Christians and are believers from the Christian post-protestant denominations. About half of the respondents (25 people) at the time of the survey were studying at the Ukrainian Bible Institute (in Kyiv, or were graduates of it earlier in Donetsk). 56 respondents said that they firmly believe in Jesus Christ and attend church gatherings, aka they are active believers.

As their strongest motivation, the volunteers of "Let's Love", (as was expected before the research) consider their service to Christ, a leading component of which is love for the neighbour, and therefore, ministering to others. This main motivation was indicated

in one way or another by 38 respondents in their answers. In addition, other motives for volunteering were also mentioned. The diagram below (See Fig. 6) shows the main motives for participating in volunteer work, indicated in the answers. For each person only one main motivation named by them was taken into consideration:

1) serving Christ, fulfilling His commandments to love people, opportunity to tell people about Christ, to glorify God – 38 people (61%);
2) giving people joy, make them happier – 8 people (13%);
3) desire to do good to people, to influence people's lives, to help – 5 people (8%);
4) spending time with children, teach, do something beneficial for children – 4 people (6.5%);
5) personal growth, self-improvement, obtaining and developing skills and abilities – 3 people (5%);
6) volunteering; opportunity to take part in an interesting volunteer project – 3 people (5%);
7) feeling needed and useful – 1 person (1.5%).

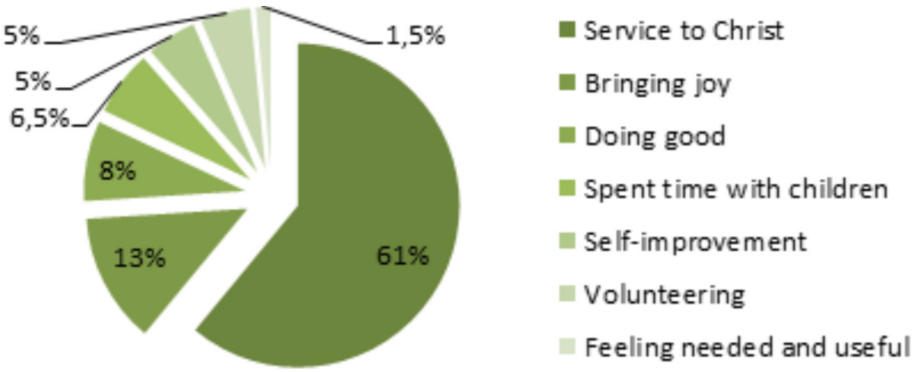

Fig. 6. Main Points of Motivation of Volunteers from NGO "Let's Love"

As sincere believers with an active life and Christian stance, many volunteers of NGO "Let's Love" are church ministers, who carefully study the Bible and other sources of Christian wisdom to regularly nourish their spirits and making their decisions and actions with right motivation. In order to better understand the depths of Scripture, the majority of "Let's Love" youth is studying at (or already graduated) from the Ukrainian Bible Institute.

4 Concluding Remarks

This research was conducted with a purpose to study the peculiarities of student volunteer team training with the usage of media materials as a pedagogical technology; and in an attempt to analyse the impact of it on the participants-volunteers and beneficiaries of the project.

Through this research it was found out that the majority of NGO‘s “Let‘s Love” members are Christian believers who regularly take part in some “service” or “ministry” (in other words, participate in volunteer projects) in Eastern Ukraine. Various activities organized by them after Euromaidan (2014) events are related to helping IDPs from Donetsk region, who presently live in Kyiv, Kharkiv, Rivne, Sumy, Zaporizhia, Poltava and other cities and their regions. Some of this volunteer work is organized and conducted with the focus on helping victims of hostilities in Eastern Ukraine in recent years, who at some point or another were the residents of the front line and migrants from at that time occupied territories. Ukrainian Bible Institute students who receive the necessary education in Christian core values, along with it get training about the opportunities and benefits of volunteering. Participation in meetings and events targeted for the development and cohesion of the volunteer team provides them with necessary skills and knowledge.

The analysis of the peculiarities of NGO “Let‘s Love” volunteer‘s preparation was carried out, in particular, on the basis of their participation in a volunteer project - a children’s camp aimed at educating children in Christian values. Volunteers received thorough well-planned training for carrying out the project in specially designed training sessions, which included team building, role-playing games, lectures and other forms of work. They also were continuously instructed on site and had on-going supervision and counselling by experienced in pedagogy and educational management volunteers who administered the camp. In general, the results of students’ participation in the project and data collected from interviews, online questionnaire and other types of feedback lead us to the conclusion that: 1) the level of their preparedness for volunteering was high; and 2) the effectiveness of training methods (including active and constant usage of media materials) both on the basis of the UBI and of NGO “Let‘s Love” proved by the on-going change in engaged youth.

In order to determine the main motivation of volunteers of the NGO “Let‘s Love” (almost half of whom were studying or have already completed their studies at UBI at the time of the study), the special survey was conducted. It showed that the main motive for volunteering for most participants is service to God. It is in accordance to His commandments, where loving other people (“our neighbours”) means caring for their well-being. They see their participation in volunteering mainly as helping and caring for others, as a physical, spiritual and material demonstration of their faith.

The core life values in youth‘ personality emerge faster and better developed with clearly put goals, with proper motivation, in well planned, thoroughly prepared and managed accordingly.

References

1. Maslow, A.H.: A theory of human motivation. Psychol. Rev. 50, 370–396 (1943). http://psychclassics.yorku.ca/Maslow/motivation.htm. Accessed 10 Mar 2021
2. Rizwan, M., Yaolong, Z., Fan, L.: Spatiotemporal analysis to observe gender based check-in behavior by using social media big data: a case study of Guangzhou, China. Sustainability, 11, 3392, the special issue big data research for social sciences and social impact (2019). https://www.mdpi.com/2071-1050/11/12/3392/htm. Accessed 14 Apr 2021

3. Borisenko, R.A.: Media culture as a universal form of transformation and preservation traditional symbols. Cult. Civilization. **4A**, 5–9 (2019). (in Russian)
4. Zhilavskaya, I.V.: Media education of a youth audience. Tomsk: TIIT, 322 (2019)
5. Zwetsloot, G.I., Van Scheppingen, A. R., Bos, E. H., Dijkman, A., Starren, A.: The core values that support health, safety, and well-being at work. Saf. Health Work **4**(4), 187–196 (2013). https://www.sciencedirect.com/science/article/pii/S2093791113000425. Accessed 1 Apr 2021
6. Korczak, J.: How to Love a Child. Vallentine Mitchell (2018)
7. Thought Fuel: Top information sources for likely visitors to cultural organizations by generation (DATA). Colleen Dilenschneider (2017). https://www.colleendilen.com/2017/10/11/top-sources-information-likely-visitors-cultural-organizations-generation-data/. Accessed 10 Mar 2021
8. Bondarenko, Z.P., Zhuravel, T.V., Liakh, T.L. et al.: Menedzhment volonterskykh hrup vid A do Ya: navch.-metod. posibnyk. Management of volunteer groups from A to Z: educational method. Manual. Verso-04, Kyiv (2012) (in Ukrainian) http://knowledge.org.ua/uk/file/menedzhment-volonterskih-grupp-ot-a-do-ya/. Accessed 19 Mar 2021
9. The Epistles of Paul the Apostle to the Colossians. The Bible Online. New Living Translation (2021). https://www.bible.com/bible/116/COL.3.NLT. Accessed 15 Mar 2021
10. Prykhodkina, N.: Medialiteracy. Syllabus of the university discipline. Special Education Program (2019
11. Pavliuk, R., Liakh, T.: Approaches to the development of the ICT competence standard in the system of research-based. In: Smyrnova-Trybulska, E., Kommers, P., Morze, N., Malach, J.(eds.) Critical Studies of Education. Training for the Future Specialist of Social Sphere in Ukraine. Universities in the Networked Society, vol. 10, pp. 201–222 (2019). https://doi.org/10.1007/978-3-030-05026-9_12
12. Diachenko-Bohun, M., Hrytsai, N., Grynova, M., Grygus, I., Zukow, W.: The readiness of future biology teachers for healthcare-safety technologies implementation in professional activity. Educ. Inf. Technol. **24**(1), 679–691 (2019). https://doi.org/10.1007/s10639-018-9799-y
13. Govorukha, N.: Social-pedagogical conditions for development of volunteering in Ukraine (1991–2014): monograph. Kharkiv (2020)
14. Study on volunteering in the European Union: final report. Brussels: GHK (2010). http://ec.europa.eu/citizenship/pdf/doc1018_en.pdf. Accessed 30 Mar 2021
15. World Giving Index: Charities Aid Foundation. https://www.cafonline.org/about-us/publications/2015-publications/caf-world-giving-index-2015/ultimate-charity-facts. Accessed 29 Mar 2021
16. World Heritage: Volunteers Initiative. https://whc.unesco.org/en/whvolunteers/. Accessed 22 Mar 2021

Smart Energy and Grids

Mobile Solar Power Plant "Pyramid" with a Kinetic Energy Storage

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Abstract. The purpose of the work is to research the energy efficiency of the developed solar power plant "Pyramid" depending on its design features, namely its execution in the form of a polyhedral geometric figure, inside of which a kinetic energy storage device is installed. First of all, the paper analyses the factors of influence on the energy efficiency of photovoltaic panels in the mobile power plant when they are located on the sides of the pyramid in the process of their operation. As theoretical methods of research of interrelation of factors of influence on quality and quantity of generated electric power by solar power plant were chosen methods of analysis on the basis of Ishikawa diagram and Paretto principle. Also, mathematical modelling of the processes of electricity generation by the Pyramid solar power station with regard to the increase in the capacity of the installation due to the application of an energy conservation system based on a kinetic energy storage device was carried out. The developed mathematical model of the solar power plant has indicators, maximally approached to the real conditions of operation taking into account the most significant factors that affect the energy efficiency of the solar power plant, namely, climatic environmental conditions, technical parameters of the design and operating conditions. Mass introduction of the proposed mobile solar power station "Pyramid" is a promising and energy-efficient solution for reliable and high-quality power supply to low-power consumers of both direct and alternating current, and also allows to solve the issues of energy independence and economic feasibility.

Keywords: Solar Power Plant · Photovoltaic Panel · Kinetic Energy Storage · Energy Efficiency of Solar Installation · Mathematical Model

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1 Prospects for the Introduction of Mobile Power Plants in Ukraine

Today, with the modern development of alternative energy, the issue of mobility of autonomous power supply to consumers is of particular importance. At this stage of development of the energy sector in many countries of the world, including Ukraine, meeting a wide range of consumer needs using autonomous generation sources is not only economically feasible, but in some cases the only way to ensure high-quality and reliable power supply, which contributes to the development of mobile energy supply technologies [1–5]. Trends in the introduction of mobile stand-alone power generation sources are becoming increasingly widespread, and therefore, the view that mobile autonomous power plants can only be used as backup or additional sources of electricity is no longer relevant in global practice. It should also be noted that the possibility of using this type of power plant in emergency situations is also a commonplace solution to the problem. It should be acknowledged that the introduction of mobile autonomous power plants has a very wide functional range of solutions to problems in the electricity sector and, accordingly, a great potential for the development of this power supply technology.

Thus, a number of researchers have devoted a lot of work to the development and construction of mobile power plants, and the main directions of development of this type of autonomous power plants are given in [1, 6, 7]. At the same time, manufacturers offer technical implementations of a wide range of mobile power plants. For such a large number of existing types of mobile power plants, there is practically no analysis of the comparative characteristics of energy efficiency of their use, depending on the design features and the principle of technology implementation, which practically does not allow the consumer to adequately assess the optimality of a particular design in order to ensure equality between the economically justified cost and technical capabilities of a mobile renewable energy source (RES) power plant, which guarantees reliable power supply [8].

Since 24 February 2022, Ukraine's energy sector has been constantly suffering from the destruction of power system facilities as a result of military operations, which leads to instability in its operation and complete disconnection of consumers from electricity supply for a long time. An effective solution in this situation is to increase the share of autonomous power supply through mobile power plants, which is actually a new round of development of the energy sector in emergency situations. In this case, we have the multifaceted functionality of mobile power plants, namely, they can be an additional source of energy both during rolling blackouts and when adjusting load schedules of various facilities, as well as the main source in cases of destruction of the general energy infrastructure, provided that it is impossible to restore the performance of electric networks.

In order to choose the design type of a mobile autonomous power plant, it is necessary to have an understanding of the variety of power generation technologies, as well as their capabilities and qualities, taking into account the advantages and disadvantages, which will ensure reliable power supply with the best energy efficiency indicators [8].

In order to determine the feasibility and prospects for the introduction of autonomous mobile power plants, we first present their classification, as shown in Fig. 1.

The classification of mobile power plants presented in Fig. 1 shows the diversity of energy generation technologies. The analysis of these technologies and the assessment

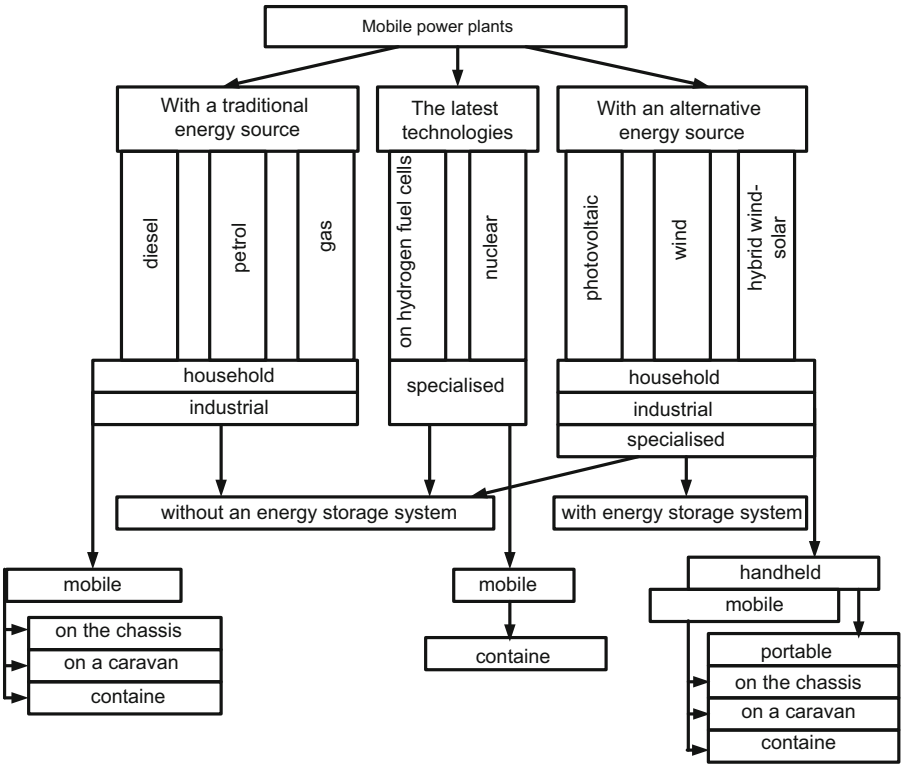

Fig. 1. Detailed classification of mobile power plants [8].

of the structure of RESs electricity producers (Fig. 2) allows us to conclude that mobile RESs power plants, namely mobile solar power plants (SPPs), have the greatest prospects for development and implementation.

2 Design Features of SPP "Pyramid"

Solar energy is currently the most developed renewable energy generation technology that is constantly being improved, so the development of new designs of mobile SPPs is a trendy issue. The developed design of the SPP "Pyramid" is a mobile autonomous source of alternative energy with a multifunctional purpose, which can be used to solve the problems of power supply for both industrial and domestic consumers. The dimensions of the plant depend on the required design capacity.

The design feature of such a SPP is, firstly, the location of photovoltaic panels (PV) on the faces of a polyhedral pyramid, and secondly, the presence of a kinetic energy storage (KES), which is mounted inside the installation and is unpretentious in operation. Also, it should be noted that this design has such advantages as compactness of location compared to in-line installation of PV modules and high wind resistance to overturning the installation due to the centrifugal action of the KES. The design and appearance of the SPP "Pyramid" is shown in Fig. 3.

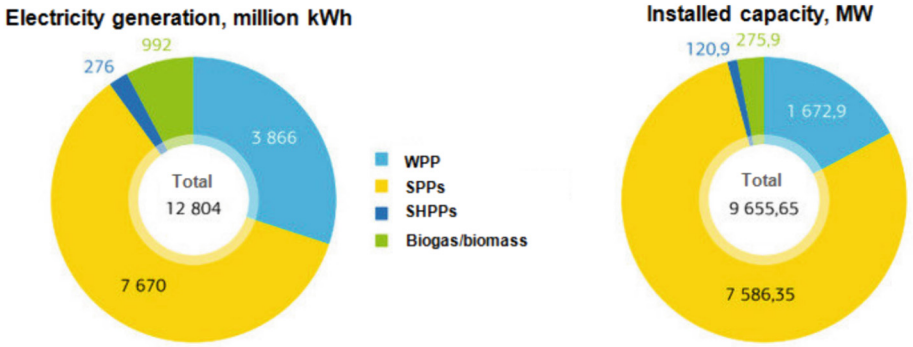

Fig. 2. Electricity generation and installed capacity of the RES sector in Ukraine, by type, as of the end of 2021 [9].

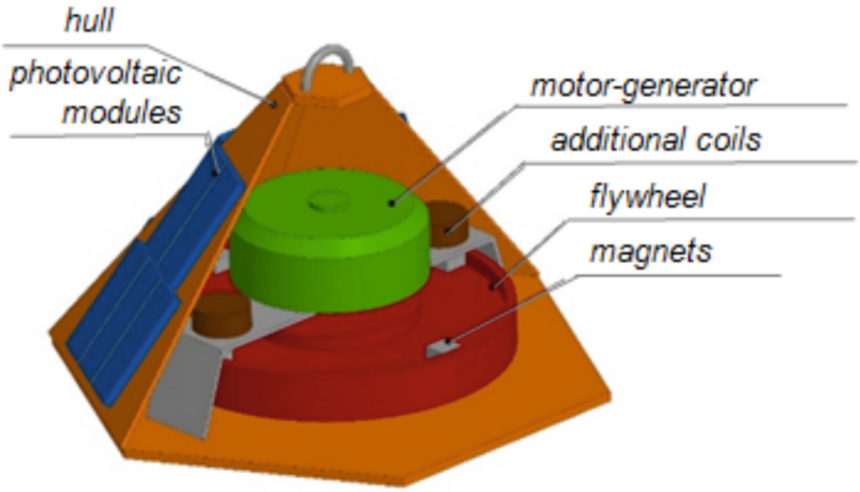

Fig. 3. The construction of the SPP "Pyramid" from KES.

Structurally, the SPP "Pyramid" shown in Fig. 3 consists of a hollow hexagonal cone-shaped casing with PV modules on it. In the middle of the hull there is a long-life fuel cell [10]. The principle of operation of the system is as follows: when PV modules are irradiated with solar energy, they generate electricity that can be supplied directly to the consumer through an inverter-type converter that will provide the type and value of current required by the consumer. In the event of excess energy, it will be stored in the KES in the form of kinetic energy from the rotation of a massive flywheel. The flywheel is driven by a brushless DC motor (BLDC). The motor is operated by a standard driver for such motors with a regenerative function. The charge level is controlled by an intelligent microcontroller-based system.

To extend the time of energy storage in the flywheel, a special system has been developed that consists of coils located on the drive body and permanent powerful rare

earth magnets located directly on the flywheel, as well as large-capacity electrolytic capacitors located in the unit body. As the flywheel with magnets rotates past the coils, an electric potential arises in the latter, which is accumulated in capacitors in the form of high-voltage electrical pulses according to a certain developed algorithm using an electronic control system and feedback sensors that monitor the position of the flywheel at certain intervals. The energy from the capacitors fuels the motor driver, keeping the system at a level of near self-rotation with a storage efficiency of about 90%, which is significantly higher than that of chemical batteries, and is also independent of ambient temperature.

If it is necessary to supply a large amount of energy to the consumer, which is greater than the PV system can currently provide, it is supplied by the flywheel through the motor-generator and its driver in the regenerative mode. It is possible to supply power to the consumer even in the complete absence of solar energy, but for efficient operation of the system, it is not recommended to discharge the flywheel below 30% of the nominal amount of energy it can store.

Installing the SPP “Pyramid” on a trailer ensures its mobility (Fig. 4). When transporting the system on a trailer, the KES must be stopped.

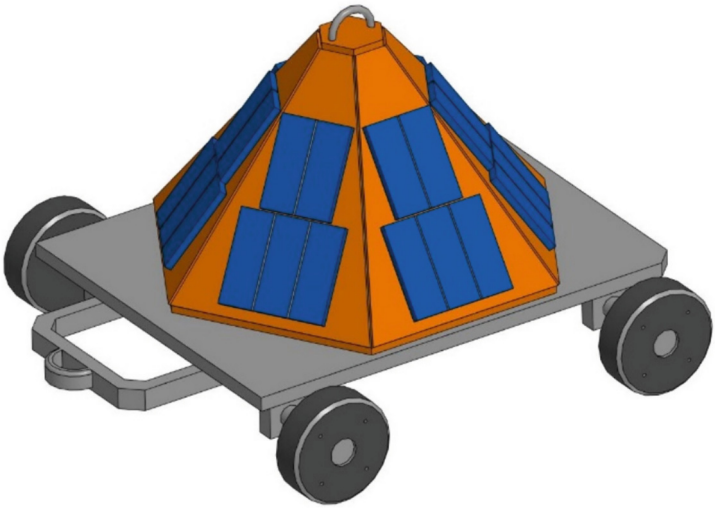

Fig. 4. Mobile SPP “Pyramid” on a trailer.

3 Analytical Analysis of the Factors Influencing the Energy Efficiency of the SPP “Pyramid”

The energy efficiency of a solar installation depends on the efficiency of its components, and in a particular case, on the operation of PV modules and KES. The analysis of the PV system efficiency is to fully identify the significant factors that influence the quality and

quantity of generated electricity during operation in order to minimise or eliminate them. The analysis of KES performance depends largely on the amount of energy stored, the amount of power losses and the performance of the charge-storage-discharge processes.

The classification of influence factors for assessing the efficiency of the SPP "Pyramid" is made in the form of an Ishikawa cause-and-effect diagram, which is shown in Fig. 5.

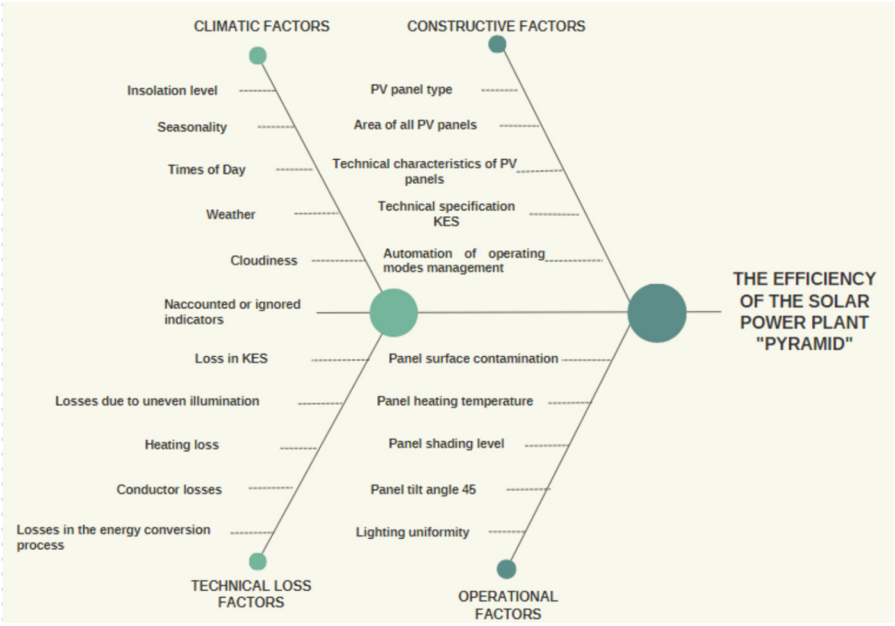

Fig. 5. Ishikawa diagram for analysing the factors influencing the energy efficiency of the SPP "Pyramid".

The diagram makes it possible to identify and record all the significant existing causes, i.e., the factors of influence that lead to a decrease in the efficiency of the installation [11, 12]. In fact, the main purpose of this diagram is to determine the most effective way to achieve maximum energy efficiency of the SPP "Pyramid", provided that the impact factors are eliminated or reduced, as well as to gain an in-depth understanding of the process under study and its management.

The advantage of an Ishikawa diagram is that it identifies the most important factors that give a clear picture of the solution to the problem at hand. The method of analysis used is an expert one and requires a ranking of the causes. Based on the results of the Ishikawa diagram analysis, the most significant factors affecting the efficiency of the developed SPP "Pyramid" were identified based on expert assessment. The list of the main factors that can be influenced is given in Table 1, and the factors that cannot be influenced are also recorded, so their analysis is meaningless.

Table 1. Ranking of factors that have an impact on the efficiency of a mobile solar power plant.

Influencing factors	Score in points (50 max)
PV panel type	50
Automation of process control	45
Technical characteristics of KES	43
Technical characteristics of the PV panel	38
The panel surface contamination	31
Lighting level	28
Shading level of the panels	25
Panel heating temperature	22
Losses in conductors	18
Losses in KES	16
Losses in the process of energy conversion	15

For further analysis of the importance of the factors of influence, a Pareto diagram is used [13, 14], which allows to visually distribute efforts to solve existing problems and record the main identified factors, which should be used to start the process of overcoming emerging problems. The diagram is actually a reflection of the interpretation of the Pareto law, i.e. the 80/20 principle, which perfectly shows the dependencies of the distribution of carefully identified resources or results across the entire large sample of the considered causes. The diagram is presented in Fig. 6.

The analysis of the diagram in Fig. 6 shows which factors have the greatest impact on the energy efficiency of the proposed SPP. The Pareto diagram gives a complete understanding that each most influential factor corresponds to a vertical bar of the histogram in accordance with the ranking in Table 1. At the same time, a separate graph in the form of a curve that grows until it crosses the 80% threshold and passes into the horizontal limit line shows the distribution of all factors into influential ones and vice versa.

Thus, the investigation of the energy efficiency of the proposed SPP design by combining the two above tools provides a complete understanding of which impact factors play the most important role and require attention and specific modern solutions when implementing the specified solar installation.

The solution to the issue of improving the energy efficiency of SPPs actually depends on the perfection of design factors, namely, attention should be paid to the use of modern technologies that reduce losses and increase the efficiency of the structure. Another special issue is the full automation of the management of the processes of generation, distribution and consumption of electricity in all modes of operation of the plant and the coordinated operation of all its components.

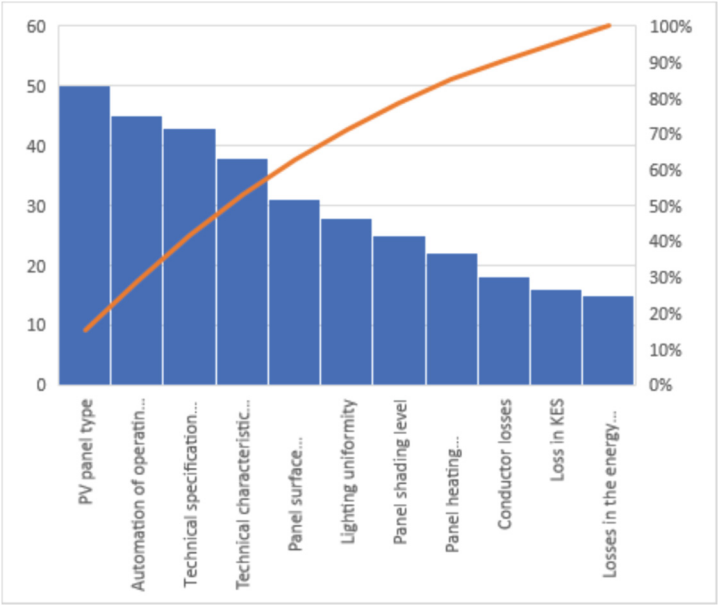

Fig. 6. Pareto diagram for the factors influencing the energy efficiency of the SPP "Pyramid".

4 Control Algorithm of SPP "Pyramid"

The control logic of the SPP "Pyramid" can be reduced to simple logical rules. In this case, the control algorithm can be conveniently represented in the form of Boolean algebra functions, which are given in tabular form and then described by logical expressions.

To understand the plant control processes, Fig. 7 illustrates the structural diagram of the SPP connection.

For the generation mode, the following values can be selected as independent variables [15]:

1. SPP generation capacity. The discrete value of $X1 = 1$ corresponds to the mode of excess SPP capacity over the current load power consumption, and $X1 = 0$ corresponds to the lack of generated energy.
2. Status of the battery: $X2 = 1$ if it is charged, $X2 = 0$ if it is discharged below the set level.

Control influences are also represented in the form of logical functions:

$U1 = 1$, $U1 = 0$, respectively, enables or disables the DC/DC operation mode of the inverter;
$U2 = 1$, $U2 = 0$ enables or disables the mains mode of operation of the DC/AC inverter;
$U3 = 1$, $U3 = 0$ switches on or off the CFC for charging or discharging.

The logic of the functioning of a mobile autonomous SPP depending on changes in the independent variables is given in Table 2.

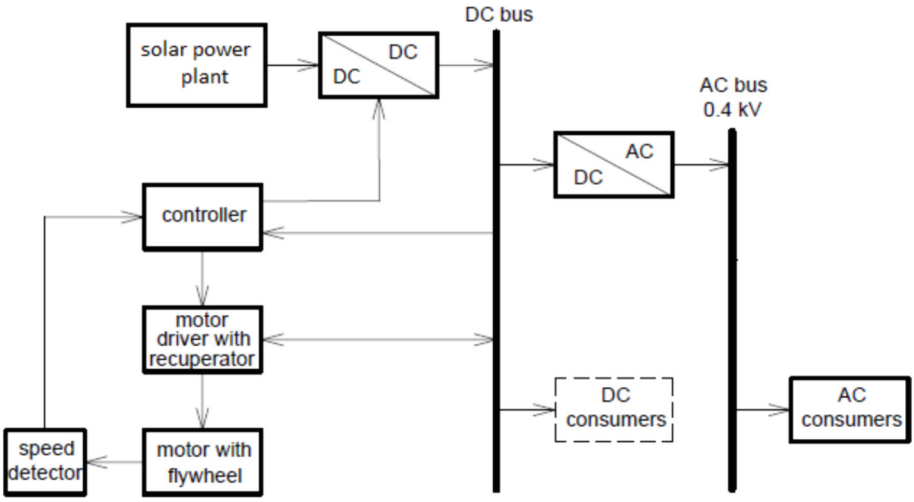

Fig. 7. A block diagram of the mobile SPP "Pyramid" connection.

Table2. The logic of the mobile autonomous SPP functioning.

X1	X2	Y1	Y2	Y3
0	0	0	0	0
0	1	1	1	0
1	0	1	1	1
1	1	1	1	1

The algorithm is formed in the form of functions of the algebra of logic [10]:

$$Y_1 = Y_2 = \overline{X}_1 \& X_2 \vee X_1 \& \overline{X}_2 \vee X_1 \& X_2 = \overline{X}_1 \& X_2 \vee X_1, \quad (1)$$

$$Y_3 = X_1 \& \overline{X}_2 \vee X_1 \& X_2 = X_1. \quad (2)$$

Thus, using the algorithm under consideration, it is possible to organise the intelligent control of an autonomous mobile SPP.

5 Mathematical Modelling of the Energy Characteristics of the SPP "Pyramid"

To solve many problems in the design, production and operation of modern SPPs, it is necessary to analyse their energy parameters [16–18]. For this purpose, we performed mathematical modelling of the main energy characteristics of the autonomous mobile SPP "Pyramid", taking into account the peculiarities of the structure and operation of

all components, as well as ensuring the required accuracy in determining the studied parameters. Since an essential and important factor in modelling SPPs is to ensure the maximum compliance of the studied installation with the conditions of its actual operation, as well as the possibility of taking into account the studied factors influencing the energy efficiency of SPPs, an improved mathematical model of the studied autonomous mobile SPP was created, which, in comparison with existing models [19–22], allows taking into account the most significant factors of influence, defined in accordance with Fig. 6.

The maximum output power of a PV power plant is determined by an expression that takes into account the type and technical parameters of the PV array and the level of shading of the PV module surface:

$$P_s = \sum_{i=1}^{N} \eta_i \cdot S_i \cdot G_{ti} \tag{3}$$

where N is the number of PV module sites operating under the same shading conditions; η_i is the solar module efficiency for site i operating under the same shading conditions; S_i is the total surface area of the illuminated PV modules of site i; G_{ti} is the quantitative flux of solar radiation on the surface of a PV module with the same shading level.

When determining the efficiency of PV panels, the lighting level, type and technical parameters of the PV panels, the heating temperature of the panel, and the amount of energy loss during conversion and in the PV system elements during operation are taken into account:

$$\eta_i = r_{SP} \cdot r_T \cdot r_G \cdot rI_A \cdot r_X \cdot \eta_{STCi} \tag{4}$$

where η_{STCi} is the efficiency of solar panels measured under standard conditions for the i-th section of PV modules; r_{SP} is a coefficient that takes into account the difference between the solar radiation spectrum and the AM 1.5 spectrum; r_T is a coefficient that takes into account the difference between the temperature at which the solar panel operates and the standard temperature; r_G is a coefficient that takes into account the difference between the solar radiation power and the standard power; rI_A is a coefficient that takes into account the angle of inclination of PV modules.

The value of the conversion efficiency for solar modules measured under standard conditions is defined by the expression:

$$\eta_{STCi} = \frac{\gamma \cdot I_r \cdot U_r}{G_{ti} \cdot S_i \cdot \sin\phi} \tag{5}$$

where I_r, U_r are the operating electric current and voltage of the PV modules; γ are the quantum efficiency and conductivity coefficients; $\sin\phi$ are the angle of incidence of the rays on the surface of the PV modules of the i-th section.

The total solar radiation on an arbitrarily oriented receiving surface in terms of angle and azimuth at time t for a solar module site operating under the same shading conditions is calculated by the expression:

$$G_{ti} = G_{dir\,ti} + G_{scat\,ti} + G_{ref\,ti} \tag{6}$$

where $G_{dir\,ti}$, $G_{scat\,ti}$, $G_{ref\,ti}$ are the values of direct, scattered from clouds and aerosols and reflected from the earth's surface radiation on an arbitrarily oriented surface in terms of inclination and azimuth, determined at time t for the solar module site and operating under the same shading conditions.

The values of direct, scattered and reflected solar radiation are determined by the geometry of the solar PV modules relative to the earth's surface and the activity of solar radiation. Their values can be determined in accordance with [23]. In this case, the expression for determining the total solar radiation takes the form:

$$G_{ti} = G^{\text{hor}}_{dir\,ti}\frac{\cos\theta}{\cos\theta_z} + \\ + G^{\text{hor}}_{scat\,ti}\frac{1+\cos\beta}{2} + \rho G^{\text{hor}}_{ref\,ti}\frac{1-\cos\beta}{2} \tag{7}$$

where $G^{\text{hor}}_{dir\,ti}$, $G^{\text{hor}}_{scat\,ti}$, $G^{\text{hor}}_{ref\,ti}$ are the values of direct, scattered from clouds and aerosols and reflected from the earth's surface radiation falling on a horizontal surface, determined at time t for the solar module area i and operating under the same shading conditions; θ is the angle between the direction of solar radiation flow to the surface and the normal to it; θ_z is the zenith angle of the Sun; β is the angle of inclination of the solar module surface; ρ is the albedo of the earth's surface.

The use of an automated process management system during the operation of the investigated SPP can significantly affect its performance, as control algorithms that are appropriately adapted to the specific conditions of the plant's operation allow to enhance or reduce certain characteristics of individual SPP elements.

The proposed mathematical model of the SPP "Pyramid" was developed in the MatLab/Simulink package. The general scheme of the autonomous SPP "Pyramid", which shows the peculiarity of connecting individual components of the installation, is presented in Fig. 8. Using this scheme, a simulation model of the SPP was developed to determine the energy characteristics and analyse the peculiarities of the operating modes of the SPP "Pyramid", which is illustrated in Fig. 9.

When specifying the parameters of the mathematical model blocks, the proposed mathematical expressions were used to determine the operating parameters and energy characteristics of the studied SPP, which makes it possible to take into account all the factors of influence on the SPP operating modes discussed above. The reliability of the modelling results is confirmed by the coincidence with analogues presented in the literature [24, 25].

In accordance with the proposed expressions, the energy characteristics of the SPP "Pyramid" were determined, taking into account the studied factors of influence, provided that it is located in the Kharkiv region for 15 April 2023, as represented in Fig. 10.

The modelling results show that the developed model well reflects the physical processes that take place during the operation of the investigated SPP. The climatic features of the SPP "Pyramid" operation determine the time and level of solar radiation reaching the Earth's surface, which coincides with the time intervals and the amount of total solar radiation reaching the surface of the PV modules.

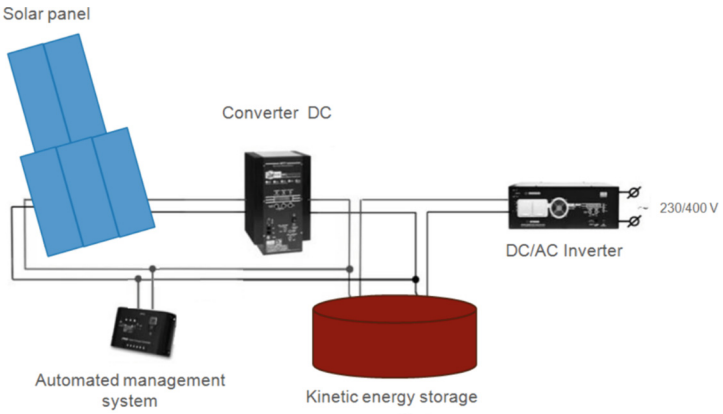

Fig. 8. Block diagram of the autonomous SPP "Pyramid" for model development in MatLab/Simulink package.

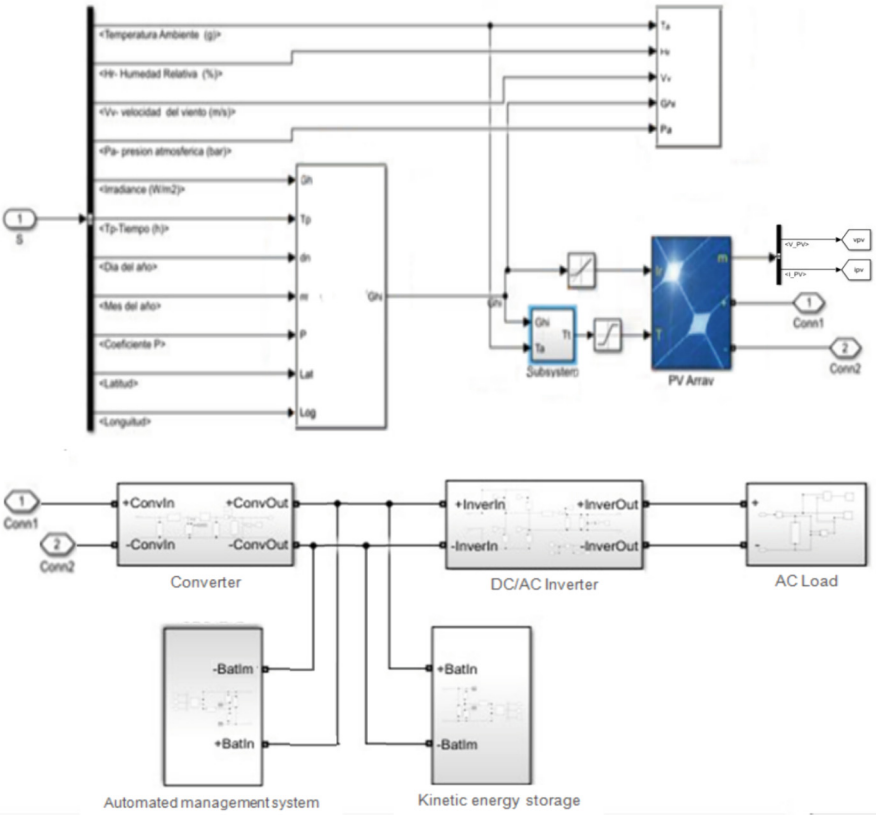

Fig. 9. Simulation model of autonomous SPP "Pyramid" in MatLab/Simulink package.

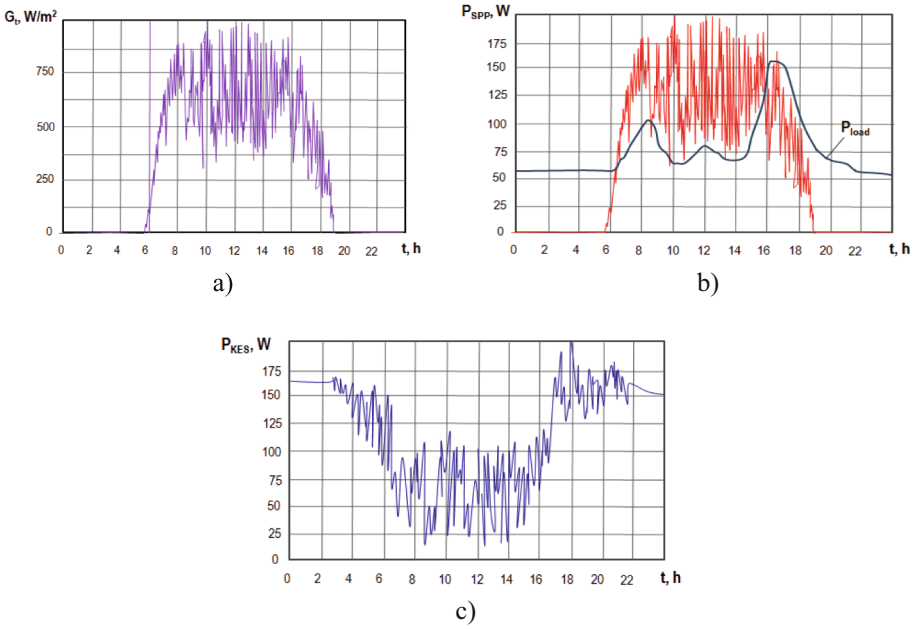

Fig. 10. Energy characteristics of SPP “Pyramid”: a) total solar radiation; b) power generated by SPP; c) power of KES.

Comparison of the graphs presented in Fig. 10, shows that with the adopted capacity ratio, the energy generated by the investigated SPP using KES is sufficient to fully cover the needs of the consumer load. When the SPP is located in the Kharkiv region, the energy accumulated by KES during daylight hours is sufficient to continuously supply consumers with electricity in the dark.

Thus, the analysis of the modelling results confirms that for the accepted operating conditions, the developed configuration of the autonomous mobile SPP “Pyramid” fully meets the requirements for its operation, providing uninterrupted power supply to the consumer with the maximum design load. This confirms the energy efficiency of the developed power plant.

6 Conclusions

The design of an autonomous mobile SPP “Pyramid” is proposed, the energy efficiency of which depends entirely on the design and technical parameters of its components, namely, PV modules and KES, and automation of control processes, which is confirmed by the analysis of Ishikawa and Pareto diagrams. A structural scheme for connecting the SPP to the consumer’s power supply system has been developed, on the basis of which an algorithm for intelligent control of the SPP operation based on the functions of logic algebra has been developed. The mathematical modelling of the SPP “Pyramid” operation was carried out, the results of which fully confirm the energy efficiency of the developed design.

References

1. Fedak, W., Anweiler, S., Ulbrich, R., Jarosz, B.: The concept of autonomous power supply system fed with renewable energy sources. J. Sustain. Dev. Energy Water Environ. Syst. **5**, 579–589 (2017)
2. Ginevičius, R., Trishch, R., Bilan, Y., Lis, M., Pěnčík, J.: Assessment of the economic efficiency of energy development in the industrial sector of the European Union area countries. Energies **15**, 3322 (2022)
3. Mohammad, N.H., Angga, N.R., Ferdian, R.: Feasibility analysis of a renewable autonomous power supply system at a coastal area in Indonesia. Int. J. Energy Econ. Policy **10**(3), 175–181 (2020)
4. Savchenko, N.P., Tretiak, A.V.: Prospects for the implementation of mobile autonomous power supply systems in the minds of the energy crisis. In: CONFERENCE 2022, Débats scientifiques et orientations prospectives du développement scientifique: collection de papiers scientifiques «ΛΌΓΟΣ» avec des matériaux de la IV conférence scientifique et pratique internationale, pp. 64–66. Paris-Vinnytsia: La Fedeltà & Plateforme scientifique européenne (2022)
5. Dovgalyuk, O., Bondarenko, R., Yakovenko, I., Dyakov, E., Syromyatnikova, T.: Efficiency increase of autonomous lighting complexes operation for Ukraine highways. In: Proceedings of the 2020 IEEE 4th International Conference on Intelligent Energy and Power Systems (IEPS), pp. 190–195. IEEE, Istanbul, Turkey (2020)
6. Litovchenko, V.G., et al.: Mobile solar power plants for use in field conditions. Bull. Natl. Acad. Sci. Ukraine **11**, 59–66 (2015)
7. Erdemir, G., Kuzucuoğlu, A., Selçuk, F.: A mobile wind turbine design for emergencies in rural areas. Renew. Energy **166**, 9–19 (2020)
8. Savchenko, N.P.: Analysis of the efficiency of the application of mobile autonomous power plants under critical conditions energy infrastructure. Scientific works of DonNTU. Series: Electr. Eng. Energy **2**(27), 15–19 (2022)
9. Ukraine's renewable energy sector before, during and after the war. https://razumkov.org.ua/en/articles/ukraines-renewable-energy-sector-before-during-and-after-the-war. Accessed 18 Aug 2023
10. Savchenko, N.P., Tretiak, A.V.: Conical photovoltaic installation with energy storage. Utility model patent № 148083, МПК (2021/01) H02L 31/00 – u202101368
11. Fishbone diagram (Ishikawa cause and effect). https://www.techtarget.com/whatis/definition/fishbone-diagram. Accessed 24 Aug 2023
12. Cause and effect (fishbone). https://www.england.nhs.uk/wp-content/uploads/2021/12/qsir-cause-and-effect-fishbone.pdf. Accessed 24 Aug 2023
13. Pareto Charts & 80/20 Rule Homepage. https://www.cec.health.nsw.gov.au/CEC-Academy/quality-improvement-tools/pareto-charts. Accessed 25 Aug 2023
14. Pareto Chart Homepage. https://qi.elft.nhs.uk/resource/pareto-charts/. Accessed 25 Aug 2023
15. Savchenko, N.P., Tretiak, A.V.: Analysis of the energy efficiency of buildings with a hybrid power supply system for intelligent generation and conservation of electricity. New Technol. Build. **37**, 63–68 (2020)
16. Makkiabadi, M., et al.: Performance evaluation of solar power plants: a review and a case study. Processes **9**(12), 2253 (2021)
17. Harrou, F., Kadri, F., Sun, Y.: Forecasting of photovoltaic solar power production using LSTM approach. Intech Open **2020**, 91248 (2020)
18. Soomar, A.M., Hakeem, A., Messaoudi, M., Musznicki, P., Iqbal, A., Czapp, S.: Solar photovoltaic energy optimization and challenges. Front. Energy Res. **10**, 879985 (2022)

19. Navada, H.G., Singh, S.V., Shubhanga, K.N.: Modelling of a solar photovoltaic power plant for power system studies. In: 2017 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES), pp. 1–6. IEEE, Kollam, India (2017)
20. Qawaqzeh, M., et al.: Development of algorithm for the operation of a combined power supply system with renewable sources. In: 2022 IEEE 3rd KhPI Week on Advanced Technology (KhPIWeek), pp. 456–459. IEEE, Kharkiv, Ukraine (2022)
21. Faiz, F., Shakoor, R., Raheem, A., Umer, F., Rasheed, N., Farhan, M.: Modeling and analysis of 3 MW solar photovoltaic plant using PVSyst at Islamia University of Bahawalpur, Pakistan. Int. J. Photoenergy **2021**, 1–14 (2021)
22. Shevchenko, S., Dovgalyuk, O., Danylchenko, D., Rubanenko, O., Fedorchuk, S., Potryvai, A.: Accounting for the effect of PV panel dustiness on system performance with correction for panel cleaning for Matlab Simulink. In: 2021 IEEE 3rd Ukraine Conference on Electrical and Computer Engineering (UKRCON), pp. 373–378. IEEE, Lviv, Ukraine (2021)
23. Duffie, J.A., Beckman, W.A.: Solar Engineering of Thermal Processes. Wiley, Hoboken (2013)
24. Shubham, K.S., Navada, H.G., Shubhanga, K.N.: Power flow analysis of power distribution system integrated with solar photovoltaic based distributed generation. In: 2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP), pp. 1–6. IEEE, Hyderabad, India (2022)
25. Salmi, M., Baci, A.B., Inc, M., Menni, Y., Lorenzini, G., Al-Douri, Y.: Desing and simulation of an autonomous 12.6 kW solar plant in the Algeria’s M’sila Region using PVsyst software. Optik **262**, 169294 (2022).

Improving the Quality and Energy Efficiency of Power Units of Thermal Power Plants by Optimizing the Operational Modes of Boiler Equipment

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Abstract. The article is devoted to optimizing the operation of the boiler equipment of Ukrainian power plants, which is relevant due to their physical and moral aging and is consistent with the concept of sustainable development of the United Nations. To solve the optimization problem by the criterion of minimum losses, it is proposed to use a combined approach based on the use of standard optimization methods and elements of heuristic analysis. The solution of the problem consists in finding the values of the parameters of the controlled values, at which the energy losses in the boiler will be minimal. For the practical implementation of a complex model, the division of the general technological process of the boiler into a number of conditionally independent processes, united by a common technological cycle, was carried out. The reliability of mathematical models is confirmed by the experiments carried out for the ТП-100 boiler of the 200MW power unit of Zmiiv Thermal Power Plant. The practical significance of the results obtained is substantiated by the construction of the static operational control characteristics of the boiler in the entire range of its normal operation and the determination of its optimal energy-saving operational modes.

Keywords: Optimization · Minimum Energy Loss Criterion · Boiler

1 Introduction

Steam boilers are the main elements of thermal power plants (TPPs), producing almost 40% of electrical and thermal energy in Ukraine [1]. However, TPP emissions are one of the largest environmental pollutants and affect the planet's climate change. According to the concept of sustainable development of the United Nations, it is necessary to take urgent measures to combat climate change and its consequences. It is also necessary to provide access to reliable and sustainable modern energy sources [2, 3, 3]. Currently, the state of the Ukrainian economy does not allow for a comprehensive modernization of power plants and improve the technical and economic performance of their main units [1, 3–5].

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Optimizing the operational parameters of the power units of power plants, taking into account their real physical condition, is especially relevant due to the depreciation of the existing equipment. The task is complicated because one has to deal with multi-parameter optimization under conditions of incomplete information.

Increasing the efficiency of the boiler unit and, as a consequence, the power unit and power plant as a whole lead to a reduction in fuel consumption and the cost of generating electrical energy. Lower fuel consumption leads to lower emissions of harmful substances and environmental pollution.

The minimum of total energy losses while maintaining the required parameters at a given level, due to the technological process and operational reliability indicators, can serve as an optimality criterion when creating an energy-saving automated process control system.

2 Literature Review

A literature review shows the presence of many studies devoted to various aspects of quality assessment [4–9]. Improving the quality and energy efficiency of power units at thermal power plants is an ongoing process that requires a combination of technological upgrades, operational improvements, and a commitment to sustainability.

The purpose of our study is to optimize the operation of boiler equipment according to the criterion of minimum energy losses on the example of Ukrainian thermal power plants. This is relevant due to their physical and moral aging, and is also consistent with the United Nations sustainable development goals.

To achieve the purpose, it is proposed to use a combined approach based on the use of standard optimization methods and elements of heuristic analysis to solve the optimization problem by the criterion of minimum losses.

The study does not imply replacement of boiler equipment. The article deals with a boiler control system based on minimizing energy losses through internal reserves, as well as changing their energy-efficient control modes.

The ТП-100 steam boiler of the 200 MW block of the Zmiiv TPP was selected as the object of the study. Control features typical for boilers are discussed in detail in [10–12]. Mathematical methods for solving control problems are successfully used, expanding the possibility of a scientific approach to their formalization [13–16].

Optimization of the combustion process is considered in [17–21]. In [20], the use of special additives of combustion activators (“anacloride”) is considered to improve the combustion of low-grade fuel.

The dynamics models used in control problems are most often formed using methods of decomposition for complex systems and methods of structural analysis, which make it possible to represent complex systems as a combination of simpler elements. During decomposition, heuristic methods are widely used, based on the results of experience and logic without a complete mathematical proof of the choice of the proposed actions [21].

Formalization of the control objective consists in the derivation and study of the features of the mathematical relationship between the control criterion (the indicator of control quality) and the parameters of the mathematical model. Often the objective of control is only to fulfill the specified restrictions on the initial values (parameters), i.e. ensuring the normal functioning of the object.

3 The General Problem of Optimization by Minimizing Losses

When evaluating the parameters of the equipment functioning and identifying the parameters, it is necessary to know how accurately the obtained solution corresponds to the actual values of the estimated values. To solve this problem, it is necessary to use the statistical method of analysis of observations. It is assumed that the measurements of the parameters were carried out independently of each other, obey the normal distribution law with given dispersions determined by the accuracy of the instruments, and mathematical expectations, which are taken as the optimal parameters.

The authors propose to use a combined approach based on standard methods such as static optimization, as well as methods of dynamic and experimental optimization. The latter is important for identifying the developed mathematical models, determining the operational parameters of the equipment and the characteristics of energy losses. This approach is widely used to solve problems of high complexity (which is the control of TPP power units).

As an optimality criterion when creating an energy-saving automated process control system can serve the minimum of total energy losses while maintaining the required parameters at a given level, due to the technological process, reliability indicators, etc.

Then the search for the optimal energy-saving mode can be carried out as a result of solving the following problem:

$$\begin{cases} \vec{V} = \min \Sigma \Delta N_{X_{input}^{reg},R}(\vec{X}_{input}, \vec{Y}_{output}, \vec{R}, \vec{H}, \vec{\xi}); \\ \vec{R}(\vec{X}_{input}, \vec{Y}_{output}, \vec{\xi}) \geq 0; \\ \vec{H}(\vec{X}_{input}, \vec{Y}_{ouyput}) = 0. \end{cases} \tag{1}$$

where V - the objective function;

$$\Delta\vec{N} = \{\Delta N_1 ... \Delta N_N\} \tag{2}$$

– The energy losses;

$$\vec{X}_{output} = \left\{x_{output1} ... x_{outputW}\right\} \tag{3}$$

– The output dependent optimization parameters;

$$\vec{X}_{input} = \left\{x_{input1} ... x_{inputM}\right\} \tag{4}$$

– The input dependent and independent optimized parameters (regulated);

$$\vec{\xi} = \{\xi_1 ... \xi_U\} \tag{5}$$

– The external disturbances;

$$\vec{R} = \left\{ r_1^{\min,\max} ... r_K^{\min,\max} \right\} \tag{6}$$

– The vector function of constraint-inequalities (includes constraints from below and from above on such dependent parameters as live steam flow to the turbine, electric power of the turbine unit, etc.);

$$\vec{H} = \{h_1 ... h_L\} \tag{7}$$

– The vector function of equality constraints, includes equations describing technological connections between circuit elements, energy and material balances of technological circuit elements, etc.

The basis of the mathematical model is the assumption that all variables, parameters, constraints and the objective function of the model are quantitatively measurable.

From the admissible area of the original problem, a subdomain is selected, which is a vicinity of the solution to the problem. Within the specified area, the values of the optimized parameters are generated, the constraints and the values of the measured output parameters are calculated. Points are selected at which: restrictions are met; the values of the output parameters are in the given vicinity of the solution; energy losses are minimal, i.e.:

$$\begin{cases} \vec{S} = \left\{ x_{input1}^{opt} ... x_{inputM}^{opt} \right\}; \\ \vec{V} = \min \Delta N_{\Sigma}; \\ \vec{X}_{output} = \vec{X}_{output} \cdot \vec{R}; \\ \vec{\xi} = \vec{\xi}\prime. \end{cases} \tag{8}$$

To solve the issue of energy-saving control, the mathematical model of the output parameters can be represented as the dependency:

$$\begin{aligned} \vec{X}_{output} &= \vec{H}_{(X_{output} - X_{input})} \vec{X}_{input} + \vec{H}_{(X_{output} - \xi)} \vec{\xi}; \\ \Delta N &= \vec{H}_{(\Delta N - X_{input})} \vec{X}_{input} + \vec{H}_{(\Delta N - \xi)} \vec{\xi}. \end{aligned} \tag{9}$$

4 Optimizing Equipment Operation According to the Criterion of Minimum Energy Losses on the Example of a Boiler Unit

The formalization of the optimization problem based on minimum energy losses will look like this:

– the energy losses and external disturbances (the transposed matrices):

$$\Delta\vec{N} = (B_f q_2 \; B_f q_3 \; B_f q_4 \;\; B_f q_5 \; B_f q_6 \;\; \Delta N_h \; \Delta N_{ad} \; \Delta N_{\Sigma})^T \tag{10}$$

where B_f - fuel consumption; $q_2 - q_6$ - thermal energy losses in the boiler (heat loss with flue gases, from chemical and mechanical incompleteness of fuel combustion, heat loss

to the environment, heat loss with slag); ΔN_h, ΔN_{ad}, ΔN_Σ - hydraulic, aerodynamic and total energy losses,

$$\xi = (k_f^{quan}\ k_f^{qual}\ T_{env}\ P_{env})^T, \tag{11}$$

where k_f^{quan}, k_f^{qual} - conditional indicators that take into account uncontrolled changes in the quantity and quality of fuel; T_{env}, P_{env} - temperature and pressure of the environment;

– The input and output parameters (the transposed matrices):

$$\vec{X}_{input} = (B_f\ G_{air}\ G_{fd.w}\ G_{inj}\ G_{act}\ G_{s.heat})^T, \tag{12}$$

$$\vec{X}_{output} = (\ G_{fl.g}\ D_{st}\ P_{st}\ T_{st}\ T_{furn}\ T_{\text{int}}\ S_{furn}\ G_{sl})^T$$

G_{air} - air flow rate; $G_{fd.w}$ - boiler feed water flow rate; G_{inj} - water injection flow rate; G_{act} - combustion activator consumption; $G_{s.heat}$ - steam flow rate for superheating; $G_{fl.g}$ - flue gas flow rate; D_{st}, P_{st}, T_{st} - flow rate, pressure and temperature of steam; T_{furn}- furnace temperature; T_{int} - steam temperature at the intermediate point of the path; S_{furn} - rarefaction in the furnace; G_{sl} - slag consumption;

– The restrictions on the input and output parameters:

$$\begin{pmatrix} B_f^{\min} \\ G_{air}^{\min} \\ G_{fd.w}^{\min} \\ G_{inj}^{\min} \\ 0 \\ G_{s.heat}^{\min} \end{pmatrix} \le \vec{R}_{X_{input}} \le \begin{pmatrix} B_f^{\max} \\ G_{air}^{\max} \\ G_{fd.w}^{\max} \\ G_{inj}^{\max} \\ G_{fl.g}^{\max} \\ G_{s.heat}^{\max} \end{pmatrix} \tag{13}$$

$$\begin{pmatrix} G_{fl.g}^{\min} \\ D_{st}^{\min} \\ P_{st}^{\min} \\ T_{st}^{\min} \\ T_{furn}^{\min} \\ T_{\text{int}}^{\min} \\ S_{furn}^{\min} \\ G_{sl}^{\min} \end{pmatrix} \le \vec{R}_{X_{output}} \le \begin{pmatrix} G_{fl.g}^{\max} \\ D_{st}^{\max} \\ P_{st}^{\max} \\ T_{st}^{\max} \\ T_{furn}^{\max} \\ T_{\text{int}}^{\max} \\ S_{furn}^{\max} \\ G_{sl}^{\max} \end{pmatrix} \tag{14}$$

– The relationship between input (and intermediate output) parameters, as well as the objective function:

$$\vec{H}_{(\Delta N - X_{input})} = \begin{pmatrix} A_{B_f}^{q_2} & A_{G_{air}}^{q_2} & 0 & 0 & A_{G_{act}}^{q_2} & 0 \\ A_{B_f}^{q_3} & A_{G_{air}}^{q_3} & A_{G_{fd.w}}^{q_3} & A_{G_{inj}}^{q_3} & A_{G_{act}}^{q_3} & 0 \\ A_{B_f}^{q_4} & A_{G_{air}}^{q_4} & A_{G_{fd.w}}^{q_4} & A_{G_{inj}}^{q_4} & A_{G_{act}}^{q_4} & 0 \\ 0 & 0 & 0 & 0 & 0 & A_{G_{s.heat}}^{q_5} \\ A_{B_f}^{q_6} & 0 & 0 & 0 & A_{G_{act}}^{q_6} & 0 \\ 0 & 0 & A_{G_{fd.wat}}^{\Delta N_h} & A_{G_{inj}}^{\Delta N_h} & 0 & 0 & A_{G_{s.heat}}^{\Delta N_h} \\ 0 & A_{G_{air}}^{\Delta N_{ad}} & 0 & 0 & 0 & 0 \\ A_{B_f}^{\Delta N} & A_{G_{air}}^{\Delta N} & A_{G_{fd.w}}^{\Delta N} & A_{G_{inj}}^{\Delta N} & A_{G_{act}}^{\Delta N} & A_{G_{s.heat}}^{\Delta N} \end{pmatrix} \tag{15}$$

– The relationship between input and output parameters:

$$\vec{H}_{(X_{output} - X_{input})} = \begin{pmatrix} A_{B_f}^{G_{fl.gas}} & A_{G_{air}}^{G_{fl.g}} & 0 & 0 & A_{G_{act}}^{G_{fl.g}} & 0 \\ 0 & 0 & A_{G_{fd.w}}^{D_{st}} & A_{G_{inj}}^{D_{st}} & 0 & A_{G_{s.heat}}^{D_{st}} \\ A_{B_f}^{P_{st}} & 0 & A_{G_{fd.w}}^{P_{st}} & A_{G_{inj}}^{P_{st}} & 0 & A_{G_{s.heat}}^{P_{st}} \\ A_{B_f}^{T_{st}} & 0 & A_{G_{fd.w}}^{T_{st}} & A_{G_w}^{T_{st}} & 0 & A_{G_{s.heat}}^{T_{st}} \\ A_{B_f}^{T_{furn}} & A_{G_{air}}^{T_{furn}} & A_{G_{fd.w}}^{T_{furn}} & 0 & A_{G_{act}}^{T_{furn}} & 0 \\ A_{B_f}^{T_{\text{int}}} & 0 & A_{G_{fd.w}}^{T_{\text{int}}} & A_{G_{inj}}^{T_{\text{int}}} & 0 & 0 \\ A_{B_f}^{S_{furn}} & A_{G_{air}}^{S_{furn}} & 0 & 0 & A_{G_{act}}^{S_{furn}} & 0 \\ A_{B_f}^{G_{sl}} & A_{G_{air}}^{G_{sl}} & 0 & 0 & A_{G_{act}}^{G_{sl}} & 0 \end{pmatrix} \tag{16}$$

– The relationship between the input parameters and the external disturbance:

$$\vec{H}_{(X_{output} - \xi)} = \begin{pmatrix} A_{quan}^{G_{fl.g}} & A_{qual}^{G_{fl.g}} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ A_{quan}^{P_{st}} & A_{qual}^{P_{st}} & 0 & 0 \\ A_{quan}^{T_{st}} & A_{qual}^{T_{st}} & 0 & 0 \\ A_{quan}^{T_{furn}} & A_{qual}^{T_{furn}} & 0 & 0 \\ A_{quan}^{T_{\text{int}}} & A_{qual}^{T_{\text{int}}} & 0 & 0 \\ A_{quan}^{S_{furn}} & A_{quan}^{S_{furn}} & A_{T_{env}}^{S_{furn}} & A_{P_{env}}^{S_{furn}} \\ A_{quan}^{G_{sl}} & A_{qual}^{G_{sl}} & 0 & 0 \end{pmatrix} \tag{17}$$

– The relationship between losses and external disturbance:

$$\vec{H}_{(\Delta N-\xi)} = \begin{pmatrix} 0\ 0\ A_{T_{env}}^{q_2}\ A_{P_{env}}^{q_2} \\ A_{quan}^{q_3}\ A_{qual}^{q_3}\ A_{T_{env}}^{q_3}\ 0 \\ A_{quan}^{q_4}\ A_{qual}^{q_4}\ A_{T_{env}}^{q_4}\ 0 \\ 0\ 0\ A_{T_{env}}^{q_5}\ 0 \\ A_{quan}^{q_6}\ A_{qual}^{q_6}\ 0\ 0 \\ 0\ 0\ 0\ 0 \\ 0\ 0\ A_{T_{env}}^{\Delta N_{ad}}\ A_{P_{env}}^{\Delta N_{ad}} \\ A_{quan}^{\Delta N}\ A_{qual}^{\Delta N}\ A_{T_{env}}^{\Delta N}\ A_{P_{env}}^{\Delta N} \end{pmatrix} \tag{18}$$

The relationship between steam boiler parameters and restrictions can be represented as a graph, as shown in Fig. 1.

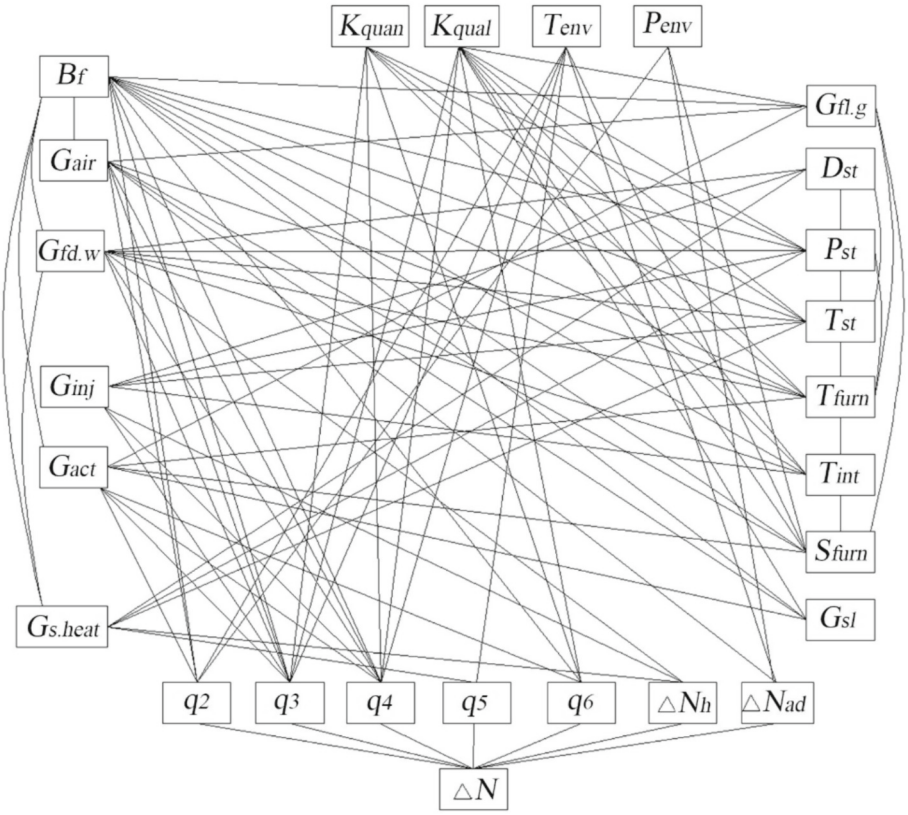

Fig. 1. The graph of relations between the boiler unit parameters.

The model is complex, and for its practical implementation it is necessary to divide the general technological process of the boiler into a number of conditionally independent processes, united by a common technological cycle or having a single physical nature.

The most adequate reduced model will be the model shown in Fig. 2.

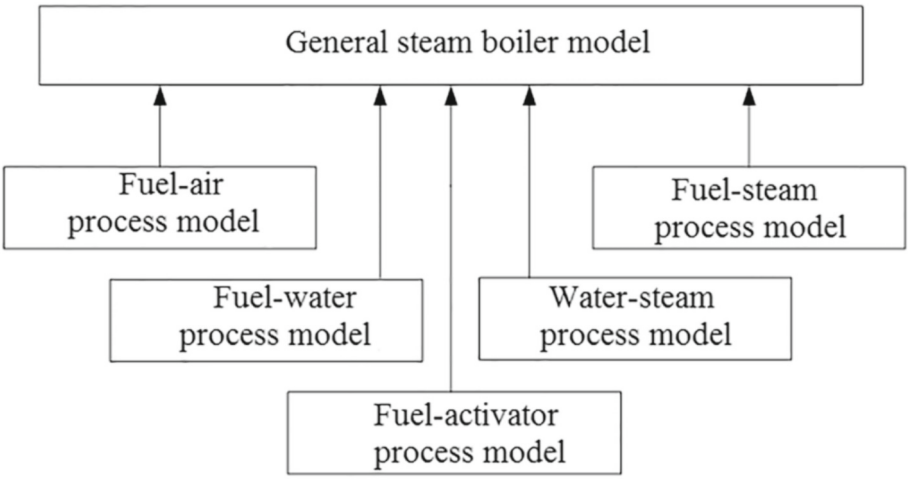

Fig. 2. The reduced model of the boiler according to the main technological processes.

5 Practical Results

Improving the quality and energy efficiency of power units in thermal power plants involves optimizing various operational aspects of boiler equipment.

The authors solved the practical task of optimizing the operation of the boiler by minimizing energy losses as finding the values of the parameters of the controlled values at which the energy losses in the boiler will be minimal (for a fixed value of the unit power, (Fig. 3, a), as well as constructing the static operational control characteristics of the boiler throughout range of its normal operation (Fig. 3, b).

Cycles of experimental research were carried out at 200 MW power units (the ТП-100 boiler) of Zmiiv TPP.

These dependencies should be used in microprocessor devices for automatic regulating the boiler plant and periodically updated in real time. This will make it possible to obtain minimal losses of energy and fuel resources in the boiler at the current values of the technical condition of the plant, fuel parameters, necessary process parameters and restrictions.

Implementing advanced control systems and automation can assist in achieving these optimized parameters. As a result of the conducted research, evaluations of the technical and economic efficiency of the proposed solutions have been performed. The expected values of the technical and economic indicators were determined through numerical experiments and theoretically based on developed mathematical models.

Implementing the proposed technical solutions during the control of boiler units at thermal power plants will allow to increase the boiler efficiency by up to 4% (under low-energy block loads and the use of low-grade fuel).

In monetary terms (based on the cost of electricity production at thermal power plants of approximately 6 UAH/kWh and considering a maximum usage of 4500 h), this could amount to up to 900 million UAH per year for every 1000 MW of installed capacity.

On a national scale within Ukraine (considering the installed capacity of Ukrainian thermal power plants at around 29,000 MW), the economic impact could reach nearly 26 billion UAH per year.

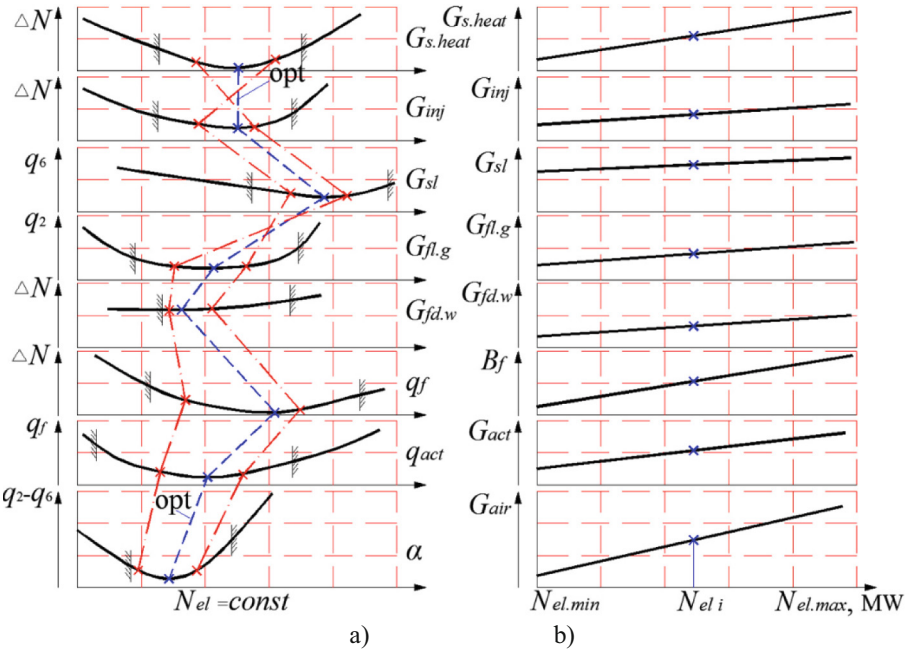

Fig. 3. Determination of optimal energy-saving boiler operational modes a) – the dependence of energy losses on the main control parameters at a fixed unit power and determination of a set of optimal parameters $\vec{S} = \left\{x_{reg1}^{opt} \ldots x_{regM}^{opt}\right\}$; б) – the static control characteristic of the boiler that is optimal in terms of minimum energy losses.

The relationships between the input, output, and internal parameters of the boiler equipment have been theoretically defined and substantiated by the results of statistical processing of experimental research.

6 Conclusions

Energy efficient boiler equipment is crucial for the overall performance, energy saving, and environmental impact of a thermal power plant. Optimization of operational modes and the implementation of advanced technologies are essential for improving the efficiency and reducing the environmental footprint of these power generation systems.

This is the first time that a mathematical problem has been formulated for optimizing the operational modes of steam boilers according to the criterion of minimum total energy losses. The objective functions, the constraint vector, and external disturbances are determined. The matrix relationship is established between the main input and output parameters, the control parameters, and the objective function, as well as the parameters of external influences.

The mathematical dependencies can be constructed for various types of boiler (different capacities and types of combustion chambers) and fuels. They can be used in the development of regulatory methods and technical conditions for creating energy-efficient automated control systems for power station boiler plants.

The principles of reducing the boiler unit complex model to a number of condition-independent mathematical models for separate control circuits of technological processes were improved.

The graph-analytical solution of the problem of energy-saving control for boiler plants is obtained. At a fixed power value, control parameters are determined at which the total energy and fuel losses in the boiler plant will be minimal (the optimal mode) and the optimal mode map is built for the entire power range.

References

1. Project of the Recovery Plan of Ukraine. Materials of the Energy Security working group [in Ukrainian]. https://www.kmu.gov.ua/storage/app/sites/1/recoveryrada/ua/energy-security.pdf. Accessed 08 Aug 2023
2. The Sustainable Development Goals. https://www.un.org/sustainabledevelopment/sdgs-framework-for-covid-19-recovery/. Accessed 08 Aug 2023
3. Contributing to the UN Sustainable Development Goals with ISO standards. https://www.iso.org/publication/PUB100429.html. Accessed 1 Apr 2023
4. Energy Community. https://www.energy-community.org/Ukraine/overview.html. Accessed 08 Aug 2023
5. Ginevičius, R., Trishch, R., Bilan, Yu., Lis, M.: Assessment of the economic efficiency of energy development in the industrial sector of the European union area countries. Energies **15**(9), 3322 (2022). https://doi.org/10.3390/en15093322
6. Trishch, R.M., Sichinava, A., Bartos, V., Stasiukynas, A., Schieg, M.: Comparative assessment of economic development in the countries of the European Union. J. Bus. Econ. Manag. **24**(1), 20–36 (2023). https://doi.org/10.3846/jbem.2023.18320
7. Trishch, R., Cherniak, O., Kupriyanov, O., Luniachek, V., Tsykhanovska, I.: Methodology for multi-criteria assessment of working conditions as an object of qualimetry. Eng. Manage. Prod. Serv. **13**(2), pp. 107–114 (2021). https://doi.org/10.2478/emj-2021-0016
8. Kupriyanov, O., Trishch, R., Dichev, D., Bondarenko, T.: Mathematical model of the general approach to tolerance control in quality assessment. Adv. Manuf. Process III, 415–423 (2022). https://doi.org/10.1007/978-3-030-91327-4_41
9. Ginevičius, R., Trišč, R., Remeikienė, R., Zielińska, R., Latušinskaja, S.: Evaluation of the condition of social processes based on qualimetric methods: the COVID-19 case. J. Int. Studies **15**(1), 230–249 (2022). https://doi.org/10.14254/2071-8330.2022/15-1/15
10. Ginevicius, R., Trishch, R., Remeikiene, R., Gaspareniene, L.: Complex evaluation of the negative variations in the development of Lithuanian municipalities. Transform. Bus. Econ. **20**(2A), 635–653 (2021). http://www.transformations.knf.vu.lt/53a. Accessed 11 Aug 2023

11. Valsalam, S.R.: Modelling, simulation and adaptive optimal control of a 210 MW boiler, PhD thesis, Anna University, Chennai (2003). https://shodhganga.inflibnet.ac.in:8443/jspui/handle/10603/77049. Accessed 11 Aug 2023
12. Darwish, S., Pertew, A., Elhaweet, W., Mokhtar, A.: Advanced boiler control system for steam power plants using modern control techniques. In: IEEE 28th International Symposium on Industrial Electronics (ISIE) (2019). https://doi.org/10.1109/ISIE.2019/8781481
13. Saccomanno, F.: Electric power systems: analysis and control. In: IEEE Press Ser. Power Eng. (2003). https://doi.org/10.1002/0471722901
14. Moon, U.-C., Lee, K.Y.: Step-response model development for dynamic matrix control of a drum-type boiler-turbine system. In IEEE Trans. on Energy Conv. **24**(2), 423–430 (2009). https://doi.org/10.1109/TEC.2009.2015986
15. Bujak, J.: Optimal control of energy losses in multi-boiler steam systems. Energy **34**(9), 1260–1270 (2009). https://doi.org/10.1016/j.energy.2009.05.005
16. Trojan, M.: Modeling of a steam boiler operation using the boiler nonlinear model. Energy **175**, 1194–1208 (2019). https://doi.org/10.1016/j.energy.2019.03.160
17. Wang, Z., Liu, M., Zhao, Y., Wang, Ch., Chong, D., Yan., J.: Flexibility and efficiency enhancement for double-reheat coal fired power plants by control optimization considering boiler heat storage. Energy, 201 (2020). https://doi.org/10.1016/j.energy.2020.117594
18. Wang, Y., Li, X., Mao, T., Hu, P., Li, X., Wang, G.: Mechanism modeling of optimal excess air coefficient for operating in coal fired boiler. Energy. Part A. (2022). https://doi.org/10.1016/j.energy.2022.125128
19. Ion, I., Stanciu, I.: Effect of energy modernization of a steam boiler on the economic efficiency. In: Annual conference of the University of Rousse, Ruse, Bulgaria, vol. 52 (2013). https://conf.uni-ruse.bg/bg/docs/cp13/1.2/1.2-4.pdf. Accessed 11 Aug 2023
20. Kapustianskyi, A.O.: Increasing the energy and environmental efficiency of boiler plants when burning non-design types of fuel. PhD thesis, National Technical University of Ukraine Igor Sikorsky Kyiv Polytechnic Institute, Kyiv (2016). In Ukrainian. https://ela.kpi.ua/bitstream/123456789/25683/1/Kapustianskyi_diss.pdf. Accessed 11 Aug 2023
21. Research report under contract with Research and Production Association "Adioz" LLC № 11–10 Processing and analysis of the results of the TP-100 boiler thermal balance tests of the 200 MW power unit of Zmiiv TPP. Ukrainian Engineering Pedagogics Academy (2012). (in Ukrainian)
22. Kozioł, J., Czubala, J.: An optimization strategy using probabilistic and heuristic input data for fuel feeding boilers with regards to the trading effects at CO_2 allowances. Energy **62**, 82–87 (2013). https://doi.org/10.1016/j.energy.2013.03.079

Software Engineering and IT-Infrastructure

Advantages of Automated Testing of Medical Applications and Information Systems Using Gherkin and Behavior-Driven Development

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Abstract. This research delves into the realm of automated testing for medical applications and information systems by employing Gherkin syntax and Behavior-Driven Development (BDD) principles. Behavior-Driven Development, an evolution of Test-Driven Development and Acceptance Test-Driven Development, fosters collaboration among various stakeholders in Agile software development projects. This approach accentuates the identification of desired feature behavior and focuses on establishing scenarios composed of inputs, actions, and outcomes. The study elucidates the rationale for adopting BDD, explains the roles of Cucumber and Gherkin in automated testing, and delineates the testing methodology undertaken in the context of medical software development. Through systematic examination, this research underscores the seamless collaboration, early issue detection, and maintenance advantages offered by BDD. Furthermore, it underscores the pivotal role of Gherkin in promoting universal comprehension of software requirements. Finally, the study discusses potential avenues for future research and enhancements in the domain of automated testing for medical applications, contributing to the advancement of software quality and reliability in the medical sector.

Keywords: Automated testing · Gherkin · Medical applications · Information systems · Quality assurance · Software testing

1 Introduction

In the realm of the medical industry [1, 2], software testing [3, 4] stands as an essential procedure. This necessity arises from the stringent regulatory demands and the potential risks posed to patients, users, and the environment.

To understand why these regulations are crucial, it's essential to recognize that the use of automated testing [5] in medical applications and information systems is becoming increasingly common. This is due to the following factors:

- **Increasing Complexity:** Medical applications and information systems [6] are becoming progressively intricate, demanding robust quality assurance measures.

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- **Criticality to Patient Care:** These applications play a critical role in patient care, necessitating utmost reliability and safety.
- **Risk Mitigation:** Automated testing serves as a proactive approach to detect and rectify software defects early in the development cycle, mitigating the potential for patient harm.
- **Tool Availability:** The growing availability of automated testing tools and frameworks has facilitated their adoption in this sector.

Automated testing is a process that leverages software to execute comprehensive tests on other software components, encompassing functionality, performance, and security evaluations. This approach proves invaluable in identifying and rectifying software flaws in their nascent stages, ultimately safeguarding patient well-being.

The benefits [7] of automated testing for medical applications and information systems are manifold:

- **Enhanced Reliability:** Early defect detection ensures a higher level of software reliability, contributing to patient safety.
- **Cost Reduction:** Automated testing reduces the overall expenses associated with software development and maintenance.
- **Increased Efficiency:** By automating testing procedures, developers and testers can allocate more time to innovation and issue resolution.
- **Confidence Boost:** Automated testing instills confidence in the software's quality, reassuring both developers and testers.
- However, this approach is not without its challenges, including:
- **Specialized Skillset:** Effective automated testing requires a specialized skill set in software development and testing, posing a training and resource hurdle.
- **Cost Considerations:** Acquiring and maintaining automated testing tools and frameworks can be costly, potentially straining budgets.
- **Maintenance Demands:** Automated tests must be continually updated to align with evolving software changes.

Despite these challenges, the advantages of employing automated testing in medical applications and information systems far outweigh the potential drawbacks. Automated testing emerges as an indispensable tool [8] for upholding the quality of these critical applications, with a profound impact on patient safety.

Moreover, Behavior-Driven Development (BDD) [9, 10] seamlessly integrates with the automated testing paradigm for medical applications and information systems. BDD's emphasis on software behavior simplifies the creation of tests that cater to the requirements of non-technical stakeholders. Additionally, Cucumber's [11, 12] support for Gherkin [13–18], a plain-language syntax, further ensures that these tests are comprehensible to a broader audience.

In the ensuing discussion, we will delve into the specifics of using automated testing with Gherkin in the context of medical applications. This exploration will encompass an overview of automated testing and Gherkin, elucidating the advantages of incorporating automated testing in the medical field.

In conclusion, integrating automated testing, mainly through Behavior-Driven Development (BDD) and Gherkin, plays a pivotal role in ensuring the reliability and safety

of medical applications, outweighing its challenges and underscoring its significance in the healthcare industry.

2 Literature Review

The integration of software has become a vital element in modern medical devices, enhancing their functionality. However, this increasing reliance on software in the health software industry presents a formidable challenge in terms of quality management and defect reduction [2]. Regulatory bodies such as the Food and Drug Administration (FDA) [19] in the USA and the European Commission for medical devices in Europe play a pivotal role in ensuring patient safety. They meticulously review health software products and issue recalls for those that fail to meet their stringent standards [20].

An analysis of failures in computer-based medical devices underscores the significance of software-related issues, with 2,303,441 recalls out of 12,024,836 related to software problems. Software glitches accounted for 33.3% of class I recalls, 65.6% of class II recalls, and a staggering 75.3% of class III recalls [1]. Poorly defined requirements emerge as a leading cause of software failures [21]. Unfortunately, insufficient time and effort are often allocated to requirements-related activities.

To mitigate software failures, various software engineering methodologies and practices have been introduced. A software engineering methodology is a structured framework for planning, controlling, and guiding the software development process. It encompasses various levels of software quality assurance (SQA) activities, ranging from requirements engineering to testing and inspections [22]. Behavior-Driven Development (BDD), an agile [23] software engineering practice, promotes collaboration between technical and non-technical stakeholders to ensure comprehensive and mutually agreed-upon requirements [24].

Despite initial doubts about the suitability of agile methods in safety-critical domains like health software, recent research has demonstrated their adaptability to the unique needs of health software development. Agile methods have proven highly valuable in producing high-quality health software. BDD, in particular, emphasizes requirements engineering to generate test cases by illustrating software behavior and subsequently creating automated acceptance tests. This paper examines the application of various BDD practices to enhance software quality and user acceptance, with a focus on their relevance in the health software domain, including medical device software development.

BDD, initially conceived by Dan North in the early to mid-2000s, represents an evolution of Test-Driven Development (TDD), intended to streamline the software development process efficiently. BDD draws inspiration from agile and lean practices, especially TDD and Domain-Driven Design (DDD) [25].

To sum up, the increasing integration of software in modern medical devices has raised quality and safety concerns, with software-related issues being a prominent cause of recalls and failures. Adopting agile practices, particularly Behavior-Driven Development (BDD), has shown promise in addressing these challenges and improving the quality of health software.

3 Rationale for Embracing Behavior-Driven Development

The rationale for adopting Behavior-Driven Development (BDD) in the context of automated testing of medical applications and information systems is multi-faceted. It holds intrinsic benefits for software development processes. This section outlines the key reasons that underpin the embrace of BDD in this domain:

Tracing BDD's Evolution and Integration: Behavior-Driven Development, an evolutionary stride stemming from the foundations of Test-Driven Development (TDD) and Acceptance Test-Driven Development (ATDD), exemplifies a natural progression in software engineering methodologies. With its origins rooted in TDD and ATDD, BDD harmonizes and expands upon the strengths of these methodologies. By inheriting the virtues of its predecessors, BDD seamlessly aligns with Agile software development methodologies, fostering adaptability and responsiveness to evolving project needs.

Illustrated in Fig. 1, the process followed by Behavior-Driven Development (BDD) unfolds, showcasing its evolution from TDD and ATDD [9]. This visual representation emphasizes the progression and integration of BDD within the broader software development landscape.

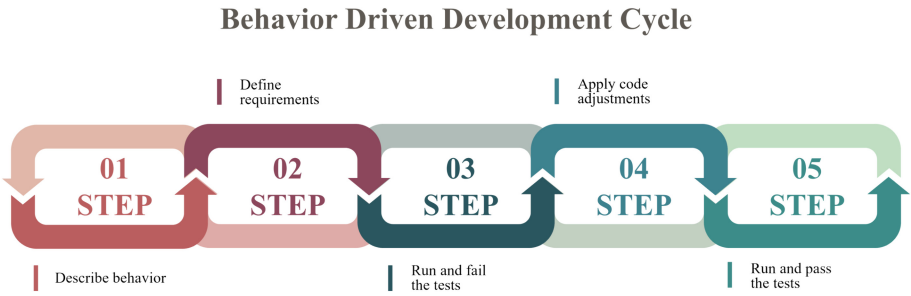

Fig. 1. Depicts the Behavior-Driven Development process

Fostering Collaborative Synergy: One of BDD's cardinal attributes is its potential to cultivate harmonious collaboration across diverse project stakeholders. Within the sphere of medical application development, this synergy encompasses developers, Quality Assurance (QA) professionals, and non-technical business participants.

By providing a common ground for stakeholders with varying technical proficiencies, BDD transcends traditional silos and bridges the gap between technical and non-technical domains. This collaborative harmony eliminates miscommunications, aligns expectations, and empowers stakeholders to contribute effectively, regardless of their technical background.

Early Identification of Desired Feature Behavior: A distinguishing feature of BDD lies in its proactive approach to feature behavior identification. By placing paramount importance on discerning and outlining the desired behavior of software features from the outset, BDD acts as a preventative measure against potential issues. This early emphasis on behavior definition enables developers, testers, and stakeholders to collectively

envision and conceptualize the software's operation. This proactive stance significantly diminishes the likelihood of issues escalating in later stages of development, ultimately enhancing software quality.

Alignment with Requirements Comprehension: The comprehensive comprehension of project requirements is a cornerstone of successful software development. BDD seamlessly aligns with this fundamental objective by providing a structured framework to express these requirements. Through the articulation of behavior-based scenarios, BDD's language transcends technical jargon, enabling developers, managers, business analysts, and other stakeholders to mutually comprehend the software's intended behavior. This alignment bridges the understanding gap and ensures the software development journey is guided by a shared and accurate understanding of the project's requirements.

Incorporating Behavior-Driven Development into the testing of medical applications and information systems transcends being merely a procedural choice; it represents a strategic alignment of methodology with the unique demands of this critical domain. BDD's evolutionary roots, collaborative prowess, emphasis on proactive prevention, and cohesive requirement comprehension all converge to elevate software quality and the efficiency of medical software development.

Figure 2 illustrates the opportunities and challenges of BDD, which shows that it is important to carefully select the development methodology for a specific project and specific conditions, as well as the need for continuous training of company employees and adaptation to new technologies.

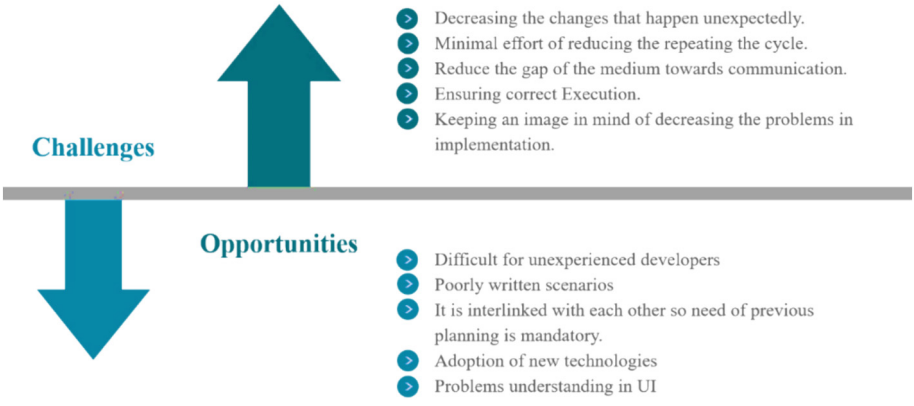

Fig. 2. Illustrates the opportunities and challenges of BDD

In summary, the adoption of Behavior-Driven Development (BDD) in the context of testing medical applications and information systems offers a well-rounded approach, drawing from its evolutionary heritage, fostering collaboration, early issue prevention, and enhancing requirements comprehension, ultimately contributing to improved software quality and efficiency in this critical domain.

4 The Role of Cucumber in BDD Automation

Cucumber, an open-source software testing tool meticulously designed for Behavior-Driven Development (BDD), plays a pivotal role in revolutionizing the automated testing landscape. This section delineates Cucumber's significance, functionality, and adaptability within the realm of BDD automation. Figure 3 illustrates the benefits of Cucumber testing.

Fig. 3. Benefits of Cucumber Testing

Introduction to Cucumber as a BDD Testing Tool: Cucumber emerges as a distinctive testing tool that aligns seamlessly with the principles of Behavior-Driven Development. Developed with the specific purpose of supporting BDD practices, Cucumber acts as a bridge between stakeholders of diverse backgrounds, facilitating effective communication and collaboration. With its foundation in BDD, Cucumber translates textual scenarios into executable tests, thus bridging the gap between requirements and code.

Cucumber's Role in Executing Gherkin-Authored Tests: Cucumber's primary role resides in the execution of tests authored in Gherkin syntax. As Gherkin serves as the language of BDD scenarios, Cucumber effectively translates these human-readable scenarios into automated test cases. This symbiotic relationship between Gherkin and Cucumber culminates in a seamless transition from requirement definition to test execution. Consequently, Cucumber acts as an interpreter, bridging the understanding of both technical and non-technical stakeholders.

Validating Application Functionality through Cucumber: Cucumber's core function lies in validating application functionality against the expectations outlined in Gherkin-authored tests. As it traverses through Gherkin scenarios, Cucumber interacts with the application as an end user would, executing a series of actions and validating the resultant outcomes. By performing this validation, Cucumber transforms abstract requirements into tangible verifications, ensuring that the application adheres to the desired behavior.

Adaptability to Multiple Languages and Expanding Test Scripts Repertoire: Cucumber's adaptability transcends language barriers, as it was originally written for Ruby but now extends support to numerous programming languages. This adaptability enhances its utility, allowing development teams to harness its capabilities

across a diverse technological landscape. Furthermore, Cucumber's expanding repertoire of test automation scripts empowers testing professionals with a broader toolkit to tackle various scenarios, enhancing the tool's versatility.

Incorporating Cucumber into the automated testing process for medical applications and information systems enhances the efficacy of BDD practices. As a dedicated BDD testing tool, Cucumber transforms Gherkin's human-readable scenarios into executable tests, ensuring the seamless translation of requirements into validated software functionality. Its adaptability to diverse languages and an ever-evolving suite of test automation scripts makes Cucumber a potent ally for ensuring the quality and reliability of medical software.

In 2023, over 3915 companies tracked by 6sense [17] and based on publicly available information started using Cucumber as a test automation tool, as shown in Table 1.

Table 1. Illustrates the example of 5 top companies using Cucumber

Company	Employee Range	Country
Toyota	350,000 +	Japan
SAP AG	110,000 +	Germany
ING Group NV	60,000 +	Netherlands
Domino's Pizza, Inc	13,000 +	United States
SoftServe	12,000 +	Ukraine

In conclusion, Cucumber stands as a transformative force in BDD automation, bridging the gap between requirements and code, validating application functionality, and evolving to meet the diverse needs of the software testing landscape, offering enhanced quality and reliability for medical software testing.

5 Gherkin: The Language of Behavior-Driven Testing

Gherkin, a fundamental component of Behavior-Driven Development (BDD), serves as a unifying language that bridges the gap between technical intricacies and comprehensive understanding. This section sheds light on Gherkin's essence, its role in software use cases, and its far-reaching impact on project stakeholders.

Defining Gherkin as a Language for Articulating Test Steps and Scenarios. Gherkin is the quintessential language meticulously designed for the purpose of articulating test steps and scenarios in the context of BDD. With its structured syntax, Gherkin facilitates the concise representation of software behavior. By adhering to a predetermined structure, Gherkin ensures that test scenarios are outlined in a standardized manner, eliminating ambiguity and facilitating precise communication.

Figure 4 illustrates the Gherkin terminology that is used to define test steps and scenarios.

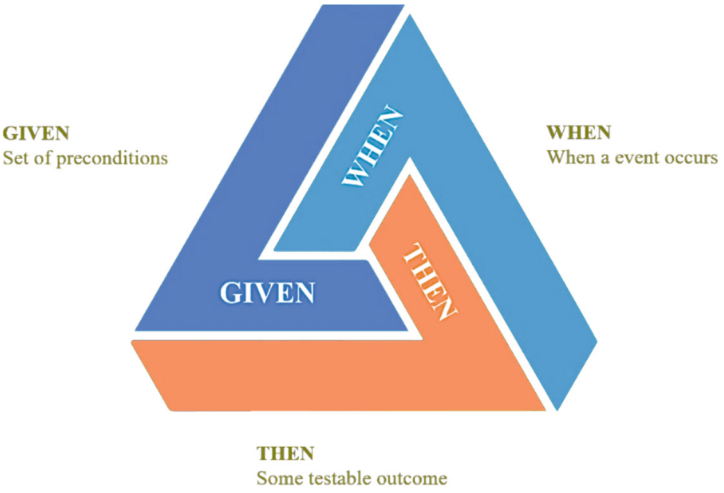

Fig. 4. Illustration of Gherkin terminology

An illustration of the Gherkin syntax structure [5] can be found in Fig. 5, providing a visual representation of the standardized format used to define test scenarios.

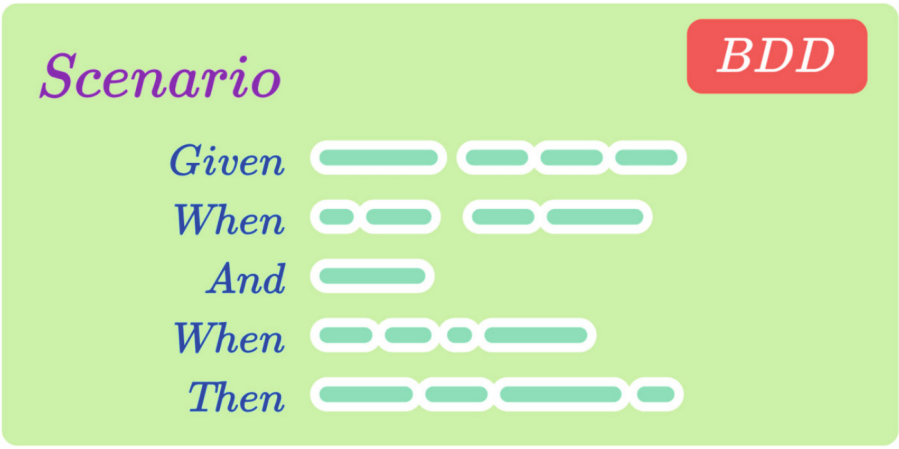

Fig. 5. Illustrates the Gherkin syntax structure

Leveraging Plain English for Universally Understandable Use Cases. Gherkin's remarkable strength lies in its utilization of plain English, enabling the expression of intricate software use cases in a universally understandable manner.

By using familiar language constructs, Gherkin ensures that technical complexities are distilled into terms that resonate with all stakeholders, irrespective of their technical expertise. This linguistic transformation empowers diverse team members to actively participate in defining software behavior.

Emphasizing Gherkin's Role in Fostering the Behavior-Driven Testing Approach. Gherkin's role extends beyond linguistic clarity; it serves as the linchpin of the behavior-driven testing approach. The language's syntax is structured around behavior, and its use cases mirror the expected actions and outcomes of software features. By embracing this structure, Gherkin nurtures a methodology that centers on anticipated behavior, aligning testing efforts with software objectives and end-user expectations.

Demonstration of Gherkin's Power in Enabling Comprehensive Comprehension. Gherkin's true power materializes in its ability to bridge comprehension gaps and ensure alignment across diverse project stakeholders. Developers, managers, and business analysts can collaboratively engage with Gherkin-authored scenarios, facilitating a unified understanding of project requirements and life cycle. This unification eliminates misinterpretations, fostering seamless communication and harmonious project execution.

The integration of Gherkin as the language of behavior-driven testing fundamentally transforms the way medical applications and information systems are tested. Its capacity to convey complex software behavior in understandable terms, coupled with its role in fostering a behavior-centric approach, enriches the testing process.

By enabling cross-functional comprehension, Gherkin becomes a conduit for unifying project vision and ensuring the integrity of medical software solutions.

Gherkin Syntax: Structuring Scenarios for Testing Medical Applications and Medical Systems. The application of Gherkin syntax in testing medical applications and systems is exemplified through the following representative test scenario. This scenario illustrates the utilization of Gherkin to encapsulate the behavior-driven testing approach in the context of creating and reading Patient records.

Overall, Gherkin serves as a pivotal language for articulating software behavior, promoting universal understanding, and fostering a behavior-driven testing approach, enhancing the precision and clarity of testing medical applications and information systems.

Figure 6 presents a sample test authored using Gherkin syntax [5], demonstrating its application in testing the creation and editing of a Patient record. This test exemplifies the structured manner in which Gherkin outlines scenarios, allowing for clear and comprehensive communication of software behavior.

Explanation:

1. **Feature Declaration:** The feature "@Patient" encapsulates the scope of testing pertaining to Patient records, delineating the various scenarios associated with its creation and reading.
2. **Scenario: Create Patient:** This scenario encapsulates the process of creating a Patient record.
   - The "Given" step outlines the testing context, associating the scenario with a specific test case ("480").

```
@Patient
Feature: Patient

  @POST
  Scenario: Create Patient
    Given I am Testing Case: "480"
    And I Set the POST Patient service API endpoint
    When I Set request HEADER and PAYLOAD
    And I Send a POST HTTP request
    Then I receive a valid Response for the POST Patient service

  @GET
  Scenario: Read Patient
    Given I am Testing Case: "481"
    And I Set the GET Patient API endpoint
    When I Set request HEADER
    And I Send a GET HTTP request
    Then I receive a valid Response for the GET Patient service
```

Fig. 6. Presents a sample test authored using Gherkin syntax, demonstrating its application in testing the creation and editing of a Patient record.

- The subsequent steps ("And") convey the actions taken, such as setting the POST Patient service API endpoint, configuring request headers and payload, and sending a POST HTTP request.
- The final step ("Then") denotes the expected outcome, which is to receive a valid response for the POST Patient service.

3. **Scenario: Read Patient:** This scenario pertains to the reading of Patient records.

- Similar to the previous scenario, the "Given" step establishes the testing context linked to a specific test case ("481").
- Subsequent "And" steps detail actions including setting the GET Patient API endpoint, configuring request headers, and sending a GET HTTP request.
- The final "Then" step conveys the anticipated outcome of receiving a valid response for the GET Patient service.

In this illustrative example, Gherkin syntax is employed to clearly define the steps and expected outcomes of behavior-driven tests for medical applications. The combination of scenario structuring, context establishment, action definition, and outcome validation encapsulates the essence of Gherkin in expressing testing scenarios in an intuitive and universally understandable manner. This syntax ensures that testing objectives are translated into executable steps, thereby facilitating comprehensive and effective testing of medical systems.

6 Conclusion and Insights

By establishing these testing objectives and metrics, the evaluation of medical applications and systems becomes systematic and robust. The combination of functional and non-functional testing ensures that software not only functions as intended but also performs optimally under varying conditions. The defined pass rates, code coverage targets, and performance/load testing metrics provide a quantifiable basis for assessing the software's quality and reliability in the context of medical solutions.

The study's exploration into automated testing with Behavior-Driven Development (BDD) and Gherkin syntax within the realm of medical software applications has unveiled a paradigm shift in testing methodologies, yielding remarkable benefits and insights. This concluding section encapsulates the study's findings, emphasizing the advantages of BDD and Gherkin while also considering potential future directions for advancement.

Benefits of Automated Testing with BDD and Gherkin in Medical Software: The adoption of BDD coupled with Gherkin as a language for defining test scenarios has proven to be transformative in the testing of medical applications. The study has revealed several noteworthy benefits:

- **Seamless Collaboration:** BDD's collaborative approach fosters harmonious collaboration between developers, Quality Assurance (QA) professionals, and non-technical stakeholders. This synergy eradicates misunderstandings, aligns expectations, and empowers stakeholders from diverse domains to contribute effectively.
- **Early Issue Detection:** The proactive stance of BDD in identifying desired behavior from the outset drastically reduces the likelihood of issues escalating during later stages of development. This early detection approach curtails the potential for costly and time-consuming rectifications.
- **Software Maintenance:** BDD's emphasis on behavior-driven testing promotes the creation of comprehensive and automated test suites. The maintenance of these tests remains synchronized with software evolution, ensuring that software changes do not compromise existing functionality.

Critical Role of Gherkin in Universal Understanding: Gherkin emerges as a linguistic conduit that translates complex technical requirements into universally understandable terms. Its plain English syntax bridges comprehension gaps, facilitating a shared understanding of software behavior and objectives among developers, managers, business analysts, and other stakeholders. This linguistic empowerment harmonizes the software development journey and safeguards against misinterpretations.

Future Avenues for Research and Enhancement: The study opens doors for future research and enhancement in the domain of automated medical software testing:

- **Enhancing Non-Functional Testing:** Further exploration of advanced techniques for performance, load, and security testing in medical contexts can refine the software's resilience and reliability.

- **Incorporating AI and ML:** Integration of Artificial Intelligence (AI) and Machine Learning (ML) algorithms can enhance test generation, execution, and analysis, further augmenting the accuracy and efficiency of testing processes.
- **Regulatory Compliance Testing:** Investigating how automated testing aligns with regulatory requirements in the medical domain ensures that software adheres to stringent industry standards.

In conclusion, the study illuminates the potency of automated testing with BDD and Gherkin in the realm of medical software applications. By fostering collaboration, early detection, and precise comprehension, this methodology elevates software quality and reliability.

Gherkin, as a language of universal understanding, catalyzes effective communication among stakeholders. As the medical software landscape advances, further research and exploration promise to refine these practices and contribute to the evolution of automated medical software testing.

References

1. Alemzadeh, H., Iyer, R.K., Kalbarczyk, Z., Raman, J.: Analysis of safety-critical computer failures in medical devices. IEEE Secur. Priv. **11**(4), 14–26 (2013). Article 6509886. https://doi.org/10.1109/MSP.2013.49
2. Ronquillo, J.G., Zuckerman, D.M.: Software-related recalls of health information technology and other medical devices: implications for FDA regulation of digital health. Milbank Q. **95**, 535–553 (2017). https://doi.org/10.1111/1468-0009.12278
3. Software Testing Help. Cucumber Gherkin Tutorial: Automation Testing Using Gherkin (2023). Retrieved from https://www.softwaretestinghelp.com/cucumber-gherkin-framework-tutorial/
4. TestingXperts. Cucumber Testing The Secret Weapon for Effective Software Testing (2023). Retrieved from https://www.testingxperts.com/blog/cucumber-testing/ca-en
5. Ona. Improving Automated Testing, Interoperability, and Privacy of OpenSRP (2023). Retrieved from https://ona.io/home/improving-automated-testing-interoperability-and-privacy-of-opensrp/
6. Anjum, M., Mahon, S., McCaffery, F.: Development of Health Software using Behaviour Driven Development – BDD (2020). https://doi.org/10.5220/0008984201490157, ISBN: 978–989–758–400–8; ISSN: 2184–4348
7. Optisol Business Solutions. 5 Key Benefits of Test Automation in Healthcare Applications (2023). Retrieved from https://www.optisolbusiness.com/insight/5-key-benefits-of-test-automation-in-healthcare-applications
8. Tuteja, M., Dubey, G.: A research study on importance of testing and quality assurance in software development life cycle (SDLC) models. Int. J. Soft Comput. Eng. (IJSCE) **2**(3) (2012)
9. Brainhub. Behavior-Driven Development (2023). Retrieved from https://brainhub.eu/library/behavior-driven-development
10. Farooq, M.S., Omer, U., Ramzan, A., Rasheed, M.A., Atal, Z.: Behavior Driven Development: A Systematic Literature Review (2023). https://doi.org/10.1109/ACCESS.2023.3302356
11. Cucumber. Gherkin Reference (2023). Retrieved from https://cucumber.io/docs/gherkin/
12. Wynne, M., Hellesoy, A.: The Cucumber Book: Behaviour-Driven Development for Testers and Developers. Pragmatic Bookshelf (2017)

13. Pucciani, G.: Gherkin and Behavior Driven Development. In: Boozang from the Trenches, pp. 217–224. Apress (2023)
14. Hasan, S.: Behavior Driven Development with Gherkin|The Complete Guide for BDD Testing. Testsigma Blog (2023). Retrieved from https://testsigma.com/blog/behavior-driven-development-bdd-with-gherkin/
15. QATechTools. Getting started with Cucumber BDD and Gherkin (2023). Retrieved from https://qatechtools.com/2021/03/02/getting-started-with-cucumber-bdd-and-gherkin/
16. Udemy. Gherkin and Cucumber: BDD Testing for IOS, Android, and Web (2023). Retrieved from https://www.udemy.com/course/gherkin-and-cucumber-bdd-testing-for-apps-and-websites
17. 6sense. Customers of Cucumber (2023). Retrieved from https://6sense.com/tech/test-automation/cucumber-market-share
18. Lambdatest. Behavior Driven Development Tutorial: Selenium Testing With Gherkin (2023). Retrieved from https://www.lambdatest.com/blog/behaviour-driven-development-by-selenium-testing-with-gherkin/
19. FDA – "Medical Device Recall". (2023). Retrieved from https://www.fda.gov/medical-devices/medical-device-safety/medical-device-recalls
20. Zuckerman, D.M., Brown, P., Nissen, S.E.: Medical device recalls and the FDA approval process. Arch. Internal Med. **171**(11), 1006–1011 (2011). https://doi.org/10.1001/archinternmed.2011.30
21. Ward, J.R., Clarkson, P.J.: An analysis of medical device-related errors: prevalence and possible solutions. J. Med. Eng. Technol. **28**(1), 2–21 (2014). https://doi.org/10.1080/03091900310001237 47
22. Tian, J.: Software Reliability Engineering. Software Quality Engineering, pp. 371–387 (2005). https://doi.org/10.1002/0471722324.ch22
23. (AAMI, 2023). Technical Information Report AAMI TIR45: Guidance on the use of AGILE practices in the development of medical device software
24. Smart, J.F., North, D.: BDD in action: Behavior-driven development for the whole software lifecycle. Shelter Island, NY: Manning (2015)
25. Solis, C., Wang, X.: A study of the characteristics of behaviour driven development. In: 2011 37th EUROMICRO Conference on Software Engineering and Advanced Applications (2011). https://doi.org/10.1109/seaa.2011.76

Ensuring Cybersecurity of the Cyber Physical System of Combined Fleets of Unmanned Aerial, Ground and Sea Vehicles

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Abstract. As unmanned cyber physical systems, comprising Unmanned Aerial Vehicles (UAVs), Unmanned Ground Vehicles (UGVs), Unmanned Underwater Vehicles (UUVs), and Unmanned Surface Vehicles (USVs), continue to redefine the landscape of modern transportation, the critical imperative of cybersecurity cannot be overstated. This article addresses the multifaceted challenges and intricacies associated with ensuring the cybersecurity of these autonomous vehicles. Examining the unique vulnerabilities inherent in UAVs, UGVs, UUVs, and USVs, the study explores comprehensive strategies to mitigate cyber threats. From encryption protocols and intrusion detection systems to behavioral analysis and regulatory compliance, the article provides insights into a holistic approach for fortifying these unmanned transportation systems against evolving cyber risks. The proposed cybersecurity measures aim to safeguard data integrity, operational continuity, and the overall reliability of unmanned transportation in an interconnected and digitally dependent era.

Keywords: Unmanned transportation systems · cybersecurity · UAVs · UGVs · UUVs · USVs · encryption · intrusion detection · behavioral analysis · regulatory compliance · data integrity · operational continuity · reliability · cyber risks

1 Introduction

In the ever-evolving landscape of transportation technology, the proliferation of unmanned vehicles has heralded a new era of efficiency, accessibility, and innovation. Unmanned Aerial Vehicles (UAVs), Unmanned Ground Vehicles (UGVs), Unmanned Underwater Vehicles (UUVs), and Unmanned Surface Vehicles (USVs) represent a paradigm shift, promising unparalleled advancements in various industries, from logistics and surveillance to exploration and defense.

In recent years, the successful applications of unmanned systems in the battlefield, space, the deep sea and other dangerous and distant environments have attracted much research interest. Autonomy has been defined in many studies, but the definition pro-posed by the autonomy levels for unmanned systems(ALFUS) working group of the National Institute of Standards and Technology (NIST) is the most comprehensive and standardized [1]. From this definition, one may conclude that "autonomy" is

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the unmanned system's capability of being independent of an operator and being self-managed. One, then, can define autonomous vehicles as machines which can operate themselves without human input or supervision.

Autonomous and unmanned vehicle technology has seen significant development. Modern cars possess semi-autonomous features like self-parking and adaptive cruise control. Unmanned aerial systems (UAVs), prevalent in military use for decades, signify the rapid advancement in this field [2]. The foreseeable future anticipates the integration of self-driving cars, UAVs, and robotic devices into everyday life.

Vehicles crucial to human safety, defense, logistics, and public service must emulate human decision-making, especially during cyber-attacks or hardware failures.

Unmanned vehicles have evolved from remote control to sophisticated ground (UGVs), aerial (UAVs), and maritime (UMVs) systems. These vehicles operate autonomously, relying on environment recognition or preset programming [3, 4].

Originally designed for military applications like explosive disposal and surveillance, UGVs now expand into civilian domains like supply and agriculture [5, 6]. UAVs excel in surveillance and data gathering, exploring dangerous or inaccessible areas with speed and advanced visual and communication capabilities [7–9]. Civilian use of UAVs spans shipping, aerial photography, agriculture, and weather monitoring [10–12].

UMVs, encompassing USVs and UUVs, play pivotal roles in naval operations, including mine control, maritime security, and blockade missions [10]. UUVs, divided into ROVs and AUVs, explore inaccessible underwater areas using cameras, sonar sensors, and robotic arms for sample collection. They serve diverse purposes in military and civilian realms such as marine research, mine clearance, and reconnaissance [12, 13].

A new heterogeneous swarm surveillance system that goes beyond a single platform and monitors the entire area in cooperation with UAVs, UGVs, USVs, and UUVs has been actively studied [14–16]. From a single platform, the fields of land, sea, air, space, electromagnetics, and networks are increasingly becoming interconnected in the battlespace, transforming into a multiplatform combat mode of multiple environments [17].

Recently, studies using cooperation between unmanned vehicles, such as UAV–UGV and UAV–USV combinations, have been actively conducted [18–20].

However, this technological leap forward also brings forth a pressing concern: cybersecurity. As these unmanned transportation systems become increasingly integrated into critical operations, the vulnerability to cyber threats becomes more pronounced. Ensuring the security and resilience of these systems against potential cyberattacks is imperative to safeguard not only data but also the integrity and safety of operations.

This article delves into the multifaceted realm of securing unmanned transportation systems, examining the intricacies of protecting UAVs, UGVs, UUVs, and USVs against cyber threats. From encryption protocols to behavioral analysis and regulatory compliance, a comprehensive approach is indispensable in fortifying these systems against evolving cybersecurity risks.

The objective of this work is to comprehensively analyze and propose effective cybersecurity measures tailored specifically for unmanned transportation systems encompassing UAVs, UGVs, UUVs, and USVs. By examining the unique vulnerabilities inherent in these autonomous vehicles and exploring robust strategies to mitigate cyber threats, this

study aims to establish a comprehensive framework that ensures the secure and resilient operation of unmanned transportation systems in various domains, safeguarding data integrity, operational continuity, and overall system reliability.

This paper is structured as follows: Sect. 2 presents a state-of-the-art interoperability framework for current UVs already deployed in various sectors, focusing on their implementation potential; Sect. 3 presents modern vulnerabilities for threats to the system; and Sect. 4 briefly discusses IMECA's analysis of threats, attacks, and system vulnerabilities, as well as countermeasures for them. Finally, conclusions and future directions are also presented, which are related to research directions in the multifunctional UV system.

2 UV System Model

The CPSCF UV conceptual diagram is a system-in-system (SIS) architecture that maximizes the benefits of operating the larger system and understands the functions, interactions, and uses of each small component. This design approach helps to view the system as a whole, focusing on how components interact, how they function over time, and how they function in the context of a larger, evolving system that can scale to missions and situations.

Following the analysis, Fig. 1 illustrates a diagram that conceptualizes the overall structure of the system and the interaction between its components (UAV, UGV, UUV and USV fleets, charging stations, databases, cloud storage, communication centers, operators, satellites, mobile charging and communication stations, other components). These components play a key role in the operation and management of the system. The focus is on the main aspects of interconnection and interaction with the multi-functional USV fleet.

The multi-functional unmanned vehicle infrastructure, which combines UAV (unmanned aerial vehicle), UGV (unmanned ground vehicle), UUV (unmanned underwater vehicle) and USV (unmanned surface vessel), is a complex system consisting of various components and subsystems. Here is a detailed description of the main elements of this infrastructure:

– UAVs (Unmanned Aerial Vehicles):

  - Drones: Flying apparatus equipped with sensors and navigation systems to execute a myriad of tasks, from observation and mapping to search and rescue operations.
  - Control Stations: Central points from which the operation and monitoring of unmanned aerial vehicles are conducted.

– UGVs (Unmanned Ground Vehicles):

  - Transporter Robots: Autonomous mobile platforms for transporting goods and performing various tasks on land.
  - Control Centers: Locations where remote control and monitoring of unmanned ground vehicles take place.

- UUVs (Unmanned Underwater Vehicles):
  - Underwater Drones: Devices designed for exploring the underwater world, ensuring maritime asset security, and gathering data.
  - Underwater Bases: Command and monitoring centers for unmanned underwater vehicles.
- USVs (Unmanned Surface Vehicles):
  - Unmanned Vessels: Waterborne vehicles performing diverse tasks, including patrolling, security provision, and safeguarding maritime routes.
  - Maritime Communication Centers: Infrastructure for managing and communicating with unmanned surface vehicles.
- Charging Stations: Stationary and Mobile Charging Points: Infrastructure for recharging batteries and sustaining the energy needs of unmanned transportation vehicles.
- Databases and Cloud Storage:
  - Databases: Data repositories for storing and processing information collected by unmanned transportation vehicles.
  - Cloud Storage: Data accessibility from anywhere, ensuring scalability and flexibility.
- Communication Centers:
  - Operator Centers: Locations where real-time management and monitoring of the entire unmanned transportation system occur.
  - Communication Stations: Infrastructure ensuring uninterrupted communication between unmanned transportation vehicles and operator centers.
- Satellites: Satellite Communications: Provision of global coverage and stable communication with unmanned transportation vehicles across various parts of the world.

This integrated infrastructure model facilitates comprehensive management, monitoring, and interaction among diverse components of multifunctional unmanned transportation, ensuring efficiency and safety in various application scenarios.

The combined use of various types of unmanned aerial, ground, underwater, and surface vehicles (UAV, UGV, UUV, USV) in a unified system can provide diverse functional capabilities and address various tasks. Below are examples of systems and tasks that can be achieved through such interaction:

- Emergency Situation Surveillance and Response System:
  - UAV (Unmanned Aerial Vehicles): Provide an aerial overview, detecting incidents such as fires, floods, or other emergencies.

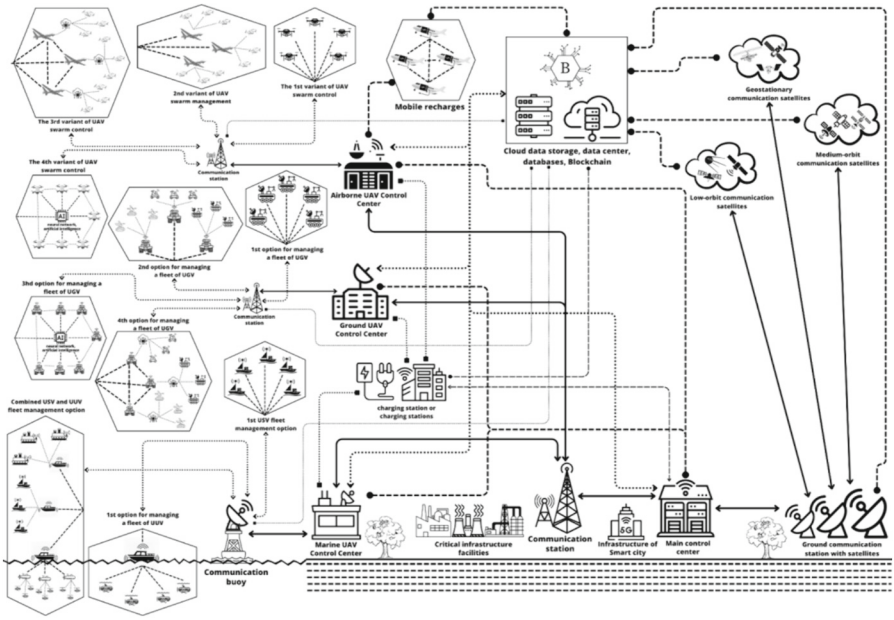

Fig. 1. The CPSCF UV conceptual diagram

- UGV (Unmanned Ground Vehicles): Conduct damage assessment by moving through the affected area and gathering on-site information.
- USV (Unmanned Surface Vehicles): Ensure coastal monitoring and protection in case of floods or other coastal emergencies.
- UUV (Unmanned Underwater Vehicles): Conduct additional underwater research for leak detection, assessing damage to underwater structures, etc.

– Logistics and Transportation:

- UGV and UAV: Collaboratively ensure efficient delivery of goods from point A to point B, where the UGV can pick up cargoes from a central warehouse and transfer them to a take-off point for UAV delivery.
- USV and UUV: Together, they can provide transportation and underwater search, for example, delivering research equipment to a marine station.

– Environmental Monitoring:

- UAV and UGV: Can work together for ecological monitoring, using various sensors and equipment to analyze soil, air, and vegetation in a specific area.
- USV and UUV: Can conduct ocean research and ecosystem monitoring, for example, detecting and analyzing water pollution or studying marine fauna.

Such integrated systems allow for the effective utilization of the advantages of each type of unmanned vehicle to solve various tasks in different environments (air, land, water).

3 CPSCF UV Cyber Physical Threats and Vulnerabilities

Threats to UV fleet systems are often associated with terrorism, which has several aspects. Such threats can be divided based on the actions of the perpetrators (physical or cyber), their origin (internal or external), and the context in which they occur (isolated or quantitative targets). Understanding the types of threats that networks face is the first step in developing appropriate defense strategies and properly understanding threat models and offenders.

In the UV fleet industry, safety and reliability are key elements that require constant attention and protection. The CPSCF UV has many different components and systems that are exposed to different threat sources. Many factors must be considered to ensure UV safety. After the analysis of existing systems and solutions, the following main elements of UV, which are most exposed to threats, are highlighted, Fig. 2: control channels, software, hardware and data transmission channels (multimedia).

Vulnerabilities are found in software and hardware, communication protocols, control systems, and other aspects of the infrastructure. Each vulnerability is assessed for severity and potential for abuse by different threat actors. Threats are diverse, including data manipulation, DoS attacks, access restrictions, and data ransom attacks. Traditional cyber-vulnerability issues applicable for autonomous unmanned systems can be summarized as in Table 1.

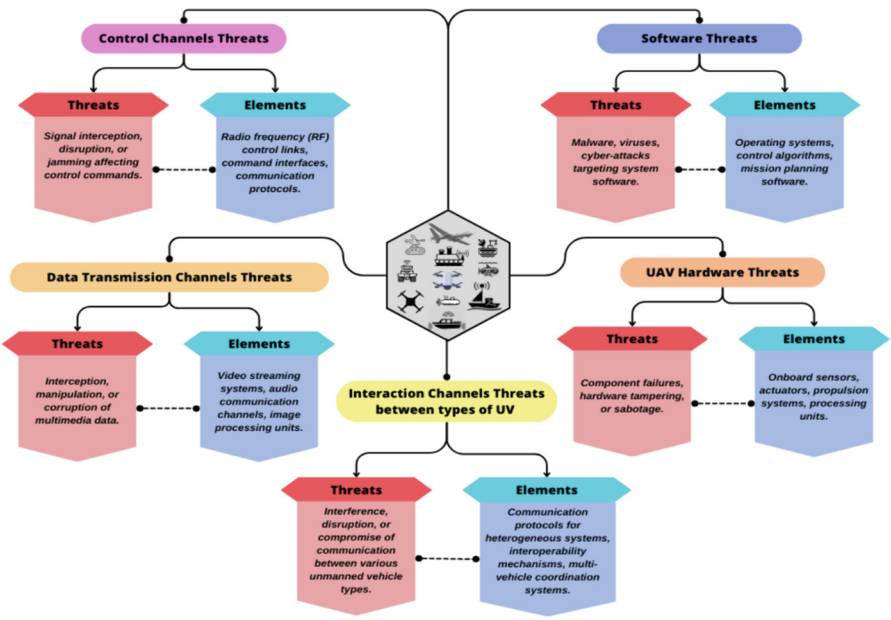

Fig. 2. Classification of threats in CPSCF UV

Table 1. Vulnerability for SMF UV

№	Vulnerability
1	Inadequate policies, procedures, and culture developing and maintaining autonomous vehicle software
2	Inadequately designed networks with insufficient defense-in-depth
3	Remote access without appropriate access control
4	Separate auditable administration mechanisms
5	Inadequately secured wireless communication
6	Use of a non-dedicated communications channel for command and control
7	Lack of easy tools to detect/report anomalous activity
8	Installation of inappropriate applications on critical host computers
9	Inadequately scrutinized control system software
10	Unauthenticated command and control data

Violators of the CPSCF UV according to European and world standards and legislation are organizations or people who commit actions that contradict the laws of one or another country in the field of use and operation of fleets of various drones: UAV, UGV, UUV and USV. These include individuals, legal entities or groups of individuals who do not take into account the specifics of using UV and thereby violate the legal norms established by the state.

Assumptions about the goals (motivations) of violators are made taking into account the goals and tasks of the information system, the type of information being processed, as well as taking into account the results of assessing the degree of possible consequences (damages) from the violation of confidentiality, integrity, observability or availability of information [21].

Therefore, IMESA carried out an analysis of cyber threats to the CPSCF UV, which are most often implemented by various violators.

4 Cyber-Attack Analysis for CPSCF UV and Countermeasures

Utilizing the classification of vulnerabilities and threats specific to the CPSCF UV, our approach involves a structured assessment of potential attacks based on their respective levels of danger, employing a formal methodology aligned with the fundamental principles of the IMECA (Intrusion Modes and Effects Criticality Analysis) method, as demonstrated in reference [22]. Our evaluation of the danger level will involve an in-depth analysis considering the following parameters:

- threat – what is used to attack the system;
- vulnerability – a weak part of the system, thanks to which an attack is possible;
- attack – type of invasion;
- type UV – type of unmanned transport: UAV, UGV, UUV and USV;

- consequences - losses that were caused after the attack;
- probability (P) – how probable the attack is (A – High, B – Medium, C – Low);
- severity (S) – how serious and dangerous the attack will be in terms of consequences (A – High, B – Medium, C – Low);
- risk (R) – what is the total impact of the attack on the system based on probability and severity (A – High, B – Medium, C – Low);
- countermeasures – measures and actions aimed at countering attacks (1 - Encryption Protocols, 2 -Intrusion Detection Systems (IDS), 3 - Multi-Factor Authentication, 4 - Secure Firmware and Software Updates, 5 - Cyber-Physical System Security, 6 - Behavioral Analytics and Anomaly Detection, 7 - Network Segmentation, 8 - Redundancy and Fail-Safe Mechanisms, 9 - Secure Remote Access Protocols, 10 - Cybersecurity Training and Awareness Programs).

The amalgamation of indicators assessing the likelihood of an event and its potential severity establishes the risk level, serving as a criticality indicator. Effective countermeasures play a pivotal role in diminishing this criticality. Notably, a high severity score coupled with inadequate countermeasures is particularly concerning for attacks that pose the greatest threat to the security of the CPSCF UV. The outcomes of the IMECA analysis are presented in Table 2.

Based on the results of the analysis of attacks by level of danger for the CPSCF UV, we will construct a matrix of criticality (cyber risks) of these systems (Table 3) and a matrix of criticality after the implementation of the considered countermeasures (Table 4). Green indicates low risk (attack), yellow - medium risk (attack), red - high (attack).

Countermeasures will generally work best against attacks for which direct protection measures are implemented in the proposed countermeasures. For example, the use of Encryption Protocols can effectively protect against an Eavesdropping attack because it encrypts data, making it unreadable to unauthorized persons. This reduces the likelihood of successful eavesdropping and data tampering [23].

In addition, the use of Multi-Factor Authentication effectively reduces the likelihood of successful penetration during Unauthorized Access attacks. This is because, in addition to the password, an additional authorization factor is required, which increases the level of access security.

However, some attacks may remain less susceptible to countermeasures due to their nature or complexity. For example, Hardware Hijack attacks can sometimes bypass defenses because they aim to physically tamper with devices, which may be difficult to prevent with software countermeasures. Also, Unusual Installation Attempt attacks can be difficult to detect because they do not always follow standard attack patterns, making them more difficult to detect despite the countermeasures put in place [24].

Thus, the effectiveness of countermeasures depends on their direct applicability to specific attacks and their ability to provide protection against typical attack scenarios.

To secure cyber-physical systems with the CPSCF UV, standardizing wireless communication protocols solely for UV networks is crucial. Combining cutting-edge security techniques will shield the infrastructure from potential cyber threats, addressing specific challenges. These advanced security measures surpass current mechanisms by offering

Table 2. IMECA analysis of cyber-attacks and countermeasures for CPSCF UV security

№	Threat	Vulnerability	Attack	Type UV	Impact	Criticality			Defenses
						P	S	R	
1	2	3	4	5	6	7	8	9	10
1	Compromised Software	Inadequate policies, procedures, and culture in software dev	Eavesdropping	UAV	Data theft, manipulation	A	A	A	Encryption Protocols, Secure Firmware and Software Updates
2	Network Vulnerability	Inadequately designed networks	Man-in-the-middle	UGV	Unauthorized access	B	A	A	Intrusion Detection Systems, Network Segmentation
3	Unauthorized Access	Remote access without proper control	Unauthorized access	UUV	System manipulation	A	A	A	Multi-factor Authentication, Cybersecurity Training
4	Admin Access Control	Separate auditable administration mechanisms	Obfuscation	USV	Identity spoofing	B	B	B	Cyber-Physical System Security, Behavioral Analytics
5	Wireless Comms Security	Inadequately secured wireless communication	Zombie devices	UAV	Network takeover	A	B	A	Anomaly Detection, Redundancy and Fail-Safe Mechanisms
6	Communication Channel	Use of a non-dedicated comm channel for command & control	Hardware hijack	UGV	System compromise	A	B	A	Secure Remote Access Protocols, Network Segmentation
7	Anomaly Detection Tools	Lack of easy tools to detect/report anomalous activity	Malware poison	UUV	System malfunction	B	B	B	Behavioral Analytics, Cybersecurity Training
8	Insecure Applications	Installation of inappropriate apps on critical hosts	Unusual installation attempt	USV	System instability	C	A	A	Secure Firmware Updates, Cyber-Physical Security
9	Control System Scrutiny	Inadequately scrutinized control system software	Unauthorized access	UAV	System failure	B	A	A	Anomaly Detection, Cybersecurity Training
10	Unauthenticated Data	Unauthenticated command and control data	Zombie devices	UGV	Command manipulation	B	A	A	Encryption Protocols, Secure Remote Access Protocols

specialized tools that efficiently safeguard the CPSCF UV from cyber threats. Leveraging artificial intelligence, these methods effectively fortify the CPSCF UV, enhancing overall system security.

Table 3. Criticality matrix of cyber risks of the CPSCF UV

	Severity		
Probability of occurrence	Low	Middle	High
Low			8
Middle		4, 7	2, 9, 10
High		5, 6	1, 3

Table 4. Matrix of criticality of cyber risks of the CPSCF UV after implementation of countermeasures

	Severity		
Probability of occurrence	Low	Middle	High
Low	4	7, 8	
Middle	1, 10	2, 6, 9	
High	3, 5		

5 Conclusions

This article conducts a comprehensive risk-based analysis of cybersecurity for multifunctional UV fleets, exploring threats, vulnerabilities, and potential attack models. The study reveals vulnerabilities in these systems, posing risks to confidentiality, integrity, availability, and observability. The main takeaway emphasizes the crucial necessity for effective cybersecurity strategies and measures tailored to multifunctional UV fleets. Trusted authentication systems, lightweight cryptographic protocols, AI-based waveforms, and blockchain technologies emerge as effective security methods.

Future research in this field aims to enhance proposed strategies, adapting them to evolving threats and refining attack models in the dynamic cyber environment. The analysis of cyber-attacks and countermeasures using the IMECA methodology highlights the need for further improvement and development. Upcoming research will focus on creating a model and methodology for evaluating countermeasures, enhancing their effectiveness against cyber threats.

This ongoing process involves identifying and analyzing attack types, developing responsive strategies, and creating criteria with expert assessments to evaluate the current protection level. The goal is not only to assess but also to adapt countermeasures for more effective defense against diverse attacks. Future research aims to establish a system capable of predicting and analyzing threat evolution for swift responses to new cyberattacks, minimizing their impact on fleet of UV security. Overall, the continued work seeks to elevate protection levels and ensure safe different of UV operation across various scenarios.

References

1. Wang, Y., Liu, J.: Evaluation methods for the autonomy of unmanned systems. Chin. Sci. Bull. **57**(26), 3409–3418 (2012). https://doi.org/10.1007/s11434-012-5183-2,lastaccessed2023/11/19
2. Marshall, J.A.: et al.: A guidance system for tactical autonomous unmanned aerial vehicles. J. Intell. Robot. Syst. **103**(4), 1–36 (2021). https://doi.org/10.1007/s10846-021-01526-8, last accessed 2023/11/19
3. Beni, G.: From swarm intelligence to swarm robotics. In: Şahin, E., Spears, W.M. (eds.) SR 2004. LNCS, vol. 3342, pp. 1–9. Springer, Heidelberg (2005). https://doi.org/10.1007/978-3-540-30552-1_1
4. Dias, P.G.F., Silva, M.C., Rocha Filho, G.P., Vargas, P.A., Cota, L.P., Pessin, G.: Swarm robotics: a perspective on the latest reviewed concepts and applications. Sensors **21**, 2062 (2021)
5. Bini, D., Pamela, D., Prince, S.: Machine vision and machine learning for intelligent agrobots: a review. In: Proceedings of the 2020 5th International Conference on Devices, Circuits and Systems (ICDCS), Coimbatore, India, 5–6 March 2020, pp. 12–16 (2020)
6. Li, N., Remeikas, C., Xu, Y., Jayasuriya, S., Ehsani, R.: Task assignment and trajectory planning algorithm for a class of cooperative agricultural robots. J. Dyn. Syst. Meas. Control **137**, 1–9 (2015)
7. Rezwan, S., Choi, W.: Artificial intelligence approaches for UAV navigation: recent advances and future challenges. IEEE Access **10**, 26320–26339 (2022)
8. Yu, Y., Shi, C., Shan, D., Lippiello, V., Yang, Y.: A hierarchical control scheme for multiple aerial vehicle transportation systems with uncertainties and state/input constraints. Appl. Math. Model. **109**, 651–678 (2022)
9. Brust, M.R., Danoy, G., Bouvry, P., Gashi, D., Pathak, H., Gonçalves, M.P.: Defending against intrusion of malicious UAVs with networked UAV defense swarms. In: Proceedings of the 2017 IEEE 42nd Conference on Local Computer Networks Workshops (LCN Workshops), Singapore, 9 October 2017, pp. 103–111 (2017)
10. McNeal, G.S.: Drones and the future of aerial surveillance. George Wash. Law Rev. **84**, 354 (2016)
11. Bai, Z., Feng, Q., Qiu, Y.: Design and research of UAV for campus express delivery. In: Proceedings of the 2021 2nd International Conference on Intelligent Design (ICID), Xi'an, China, 19 October 2021, pp. 208–213 (2021)
12. Yaqot, M., Meneze, B.C.: Unmanned aerial vehicle (UAV) in precision agriculture: business information technology towards farming as a service. In: Proceedings of the 2021 1st International Conference on Emerging Smart Technologies and Applications (eSmarTA), Sana'a, Yemen, 10–12 August 2021, pp. 1–7 (2021)
13. Agarwala, N.: Integrating UUVs for naval applications. Marit. Technol. Res. **4**, 254470 (2022)
14. Brantner, G., Khatib, O.: Controlling ocean one: human–robot collaboration for deep-sea manipulation. J. Field Robot. **38**, 28–51 (2021)
15. Bella, S., Belbachir, A., Belalem, G.: A centralized architecture for cooperative air-sea vehicles using UAV-USV. Int. J. Comput. Inf. Eng. **13**, 201–210 (2019)
16. Hu, C., Fu, L., Yang, Y.: Cooperative navigation and control for surface-underwater autonomous marine vehicles. In: Proceedings of the IEEE 2nd Information Technology, Networking, Electronic and Automation Control Conference (ITNEC), Chengdu, China, 15–17 December 2017, pp. 589–592 (2017)
17. Khaldi, B., Cherif, F.: An overview of swarm robotics: Swarm intelligence applied to multi-robotics. Int. J. Comput. Appl. **126**, 2 (2015)

18. Nedjah, N., Junior, L.S.: Review of methodologies and tasks in swarm robotics towards standardization. Swarm Evol. Comput. **50**, 100565 (2019)
19. Harik, E.H.C., Guérin, F., Guinand, F., Brethé, J.F., Pelvillain, H.: UAV–UGV cooperation for objects transportation in an industrial area. In: Proceedings of the 2015 IEEE International Conference on Industrial Technology (ICIT), Seville, Spain, 17–19 March 2015; pp. 547–552 (2015)
20. Krizmancic, M., Arbanas, B., Petrovic, T., Petric, F., Bogdan, S.: Cooperative aerial–ground multi-robot system for automated construction tasks. IEEE Robot. Autom. Lett. **5**, 798–805 (2020)
21. Pevnev, V., Tsuranov, M., Zemlianko, H., Amelina, O.: Conceptual Model of Information Security. In: Nechyporuk, M., Pavlikov, V., Kritskiy, D. (eds.) ICTM 2020. LNNS, vol. 188, pp. 158–168. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-66717-7_14
22. Torianyk, V., Kharchenko, V., Zemlianko, H.: IMECA based assessment of internet of Drones systems cyber security considering radio frequency vulnerabilities. In: IntelITSIS, pp. 460–470 (2021)
23. Pevnev, V., Frolov, A., Tsuranov, M., Zemlianko, H.: Ensuring the Data Integrity in Infocommunication Systems. Int. J. Comput. **21**(2), 228–233 (2022). https://doi.org/10.47839/ijc.21.2.2591, last accessed 2023/11/19
24. Pevnev, V.Y., Toryanyk, V.V., Kharchenko, V.S.: Cyber security of wireless smart systems: interference channels and radio frequency vulnerabilities. Radioelectronic Comput. Syst. (4), 79–92 (2020). https://doi.org/10.32620/reks.2020.4.07, last accessed 2023/11/19

Optimizing the CubeSat On-Board Computer Power Consumption Under Hard Real-Time Constraints

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Abstract. As the CubeSat concept became very popular among academia, business, and the military, its problems demanded solutions. The key challenge for the CubeSat avionics is its power budget and power consumption. The authors in the article provide a comprehensive overview of the existing solutions for power management via a satellite onboard computer (OBC) task scheduling and point out their limited use. At the same time, the authors concentrate on less widely described hybrid hardware and software methods of OBC power and frequency control. Using the developed by the authors OBC "Falco" which is based on Atmel's ATSAMV71Q21B processor, the authors propose a mathematical model that helps to define and prove the potential power saving via the supply voltage and operation frequency control of the processor, namely Dynamic Frequency Scaling (DFS) and Run-To-the-Dark (RTD) methods. Via conducting the experiments, by computing a defined classical computation task at different supply voltages and operating frequencies of the OBC's processor, the authors have defined a potential energy-saving range. Concluding the experiment with its results, the authors define the next steps that will combine an RTOS scheduling approach and the author's DFS and RTD approach to potentially design a more overarching and efficient model for power saving. The key aim of the paper is to propose a method of optimization problem solving to determine the energy-efficient mode of the CubeSat on-board computer.

Keywords: CubeSat · nanosatellite · efficiency · OBC · Falco · SSA · energy model · power · ATSAMV71 · DFS · RTD

1 Introduction

1.1 A CubeSat Concept

CubeSat standard [1] which was launched in 1991 by CalPoly has become a very popular way of near-space exploration and low-earth orbit (LEO) research. Being a parasitic load for the big space rockets and thus making the orbit delivery very cheap, CubeSats are used by the military, commercial firms, and academia today. Since the program started, there have been more than 2400 satellites at the LEO [2].

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A typical CubeSat is a sub-class of nanosatellites that are defined by their size of being 1U to 12U in size, where 1U is 10 × 10 × 10 cm. The concept of the CubeSat is to enclose all small spacecraft avionics as well as actuators and payload into an inner perimeter of the xU (where x is 1 to 12) construction. From the outer perimeter, a CubeSat is normally represented by solar panels, and antennas and tailored to a specific payload, optical and electro-mechanical sensors (Fig. 1).

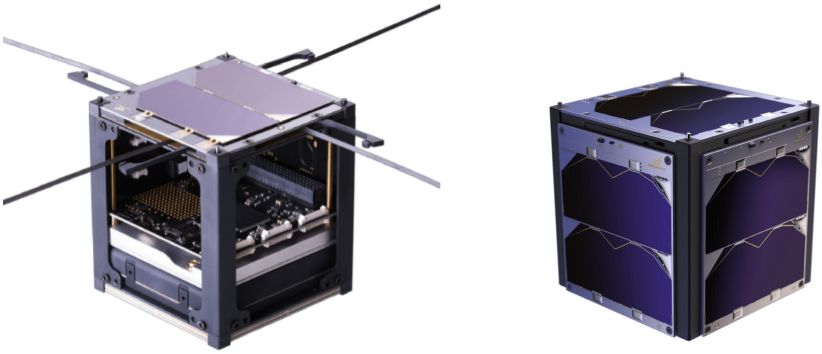

Fig. 1. A typical 1U CubeSat Look (EnduroSat)

CubeSats appear to be fast transitioning beyond their initial role as low-cost educational and technology demonstration tools. They are now serving as platforms for high-quality scientific experiments, commercial applications [3, 4], major communication satellite constellations [5], and military satellites [6]. This shift is driven by advancements in hardware miniaturization, higher hardware integration levels, rising computation power, and over 15 years of research and innovation. While presenting new opportunities, it also poses challenges for the research community, companies, academics, and national space agencies, particularly in enhancing the reliability and efficiency of the technology, as well as the complex development [20], testing and commissioning process.

1.2 Onboard Energy as the Key Satellite Constraint

One of the main problems of any, but in particular a CubeSat type, satellite – is its onboard energy budget that is the scarcest resource during the entire satellite lifecycle. As the complexity of the CubeSat grows, more payload is planned for it, and more energy is required to be able to acquire, process, and communicate the payload work results to the ground stations.

As the size of a CubeSat is given, namely 1 to 12U, and the efficiency of the solar panels is assumed to be pretty similar, the amount of the onboard energy for a defined satellite size is therefore given too. In this situation, the only way to make a CubeSat more advanced and more capable, in terms of the more complex payload, is to use onboard energy in a smart manner.

The fact that there are hundreds of 1U satellites at the LEO, means that the typical power from four 10 × 10 cm solar panels is enough for the satellite operation. There

are even 0.25U satellites that are capable of making their missions with a very limited amount of solar power. However, making the analysis of the popularity of the different sizes of the satellites – the most popular size is still 3U as it provides both freedom for the more complex payload and also for the bigger amount of the harvested energy, obviously due to its bigger solar panels surface.

The typical power budget for the 1U to 3U CubeSat is 2 to 8 W whereas the academia satellites are definitely at a lower end of this range. At the same time the computation-heavy CubeSats, i.e. the ones that do image processing and based on FPGA, might consume up to 12,5 W of energy [9].

Such an orthogonal problem of the required and available power balance, requires a serious design approach, constraint-based implementation, and verification and validation of the entire CubeSat small spacecraft avionics (SSA).

1.3 State-of-the-Art Approaches to the Analysis and Synthesis of Hard Real-Time Systems

As a typical CubeSat is a complex machine – it's SSA consists of several different boards that are all consuming onboard energy. Having the majority of the SSA boards being powered by their own micro-controller unit (MCU), they are still logically controlled by the on-board computer (OBC) board. The OBC is responsible for the overall electronics and software orchestration and thus is a key component to gain or lose the energy.

Another key component is the electrical power system (EPS) itself where the power conversion is done. Different EPS efficiency and control models are well described in the comprehensive researches [8, 11, 12] and in general very well optimized. As many CubeSats are using COTS EPSes, mainly due to its complexity of development, testing and verification and validation, we will not concentrate on that matter in this article.

Whether some of the OBC designs are multi-MCU or the combinations of MCU and FPGA [9] or even a mini-computer based on a CPU or even a smartphone [19] – all of the OBC designs require minimization of their power consumption.

There are few key approaches on how to use energy in a balanced manner – either by scheduling the planned OBC tasks (and corresponding SSA) in a smart manner, or generally optimize the power consumption by several different mixed hardware and software techniques.

The scheduling optimization is a widely addressed task and concentrates on an approach that helps to plan the tasks to be executed at a point of time where either the energy is available (i.e., during the energy generation by the solar panels), or the particular task has to be executed due to its priority definition and thus other tasks must be put on hold. Many of such scheduling algorithms are based on typical priority-based scheduling of tasks in operation systems (OSes), like unmet system capacity (USC) [18] assessment, some use even a deep reinforcement learning (DRL), or more advanced graphs-based methods, i.e., branch-cut-and-price ones. [10] Many of these algorithms are heavily loaded by the need of solving mixed-integer linear programming (MILP) [13] and thus are pretty resource demanding by themselves. The other drawback of the majority of the revised approaches is a desire of finding a global optimal solution that doesn't count on a specific platform or/and operation system.

The second method of the power optimization is a mix of hardware and software techniques that utilizes a variety of different MCU's power modes, clocking control strategies, and overall smart peripheral power control. Let's look into the most potential ones for the developed by the authors OBC platform called Falco.

The review [21] provides the following classification of energy saving methods and techniques of the mentioned above type:

1. DVFS methods (dynamic voltage and frequency scaling) and power-aware scheduling.
2. The use of low power consumption modes, called power mode management (PMM), or dynamic power management (DPM).
3. Microarchitectural techniques to conserve energy in individual components, such as memory.
4. The use of multi-processor SSA architectures to use barely required computation resources [14].
5. The use of non-traditional computers, such as DSP or GPU FPGAs.

In this article, we will limit ourselves to studying only dynamic power management. And the only platform we will concentrate on will be the developed by the authors OBC platform called Falco.

2 The On-Board Computer Based on the CDHM Platform "Falco SBC 1.0"

In order to make an On-Board Computer power effective, the proper power management both for the software and hardware peripherals shall be designed and developed. It is very seldom when the entire computation power, i.e., an entire available system time, is required to make all required mission calculations and thus – power optimization for the system idle time shall be considered.

In a microcontroller with the FreeRTOS operating system, the management of a limited energy budget is managed by hardware and software [22] When a task is waiting for an interruption or the end of a time interval, it is blocked. If all tasks enter the blocked state, FreeRTOS will execute the idle task with the lowest priority. Therefore, when the processor is idle, the idle task can put the processor into a power-saving mode. This mechanism can be useful in some scenarios, but if the clock speed is too high, the processor will waste energy and time to enter and exit the standby mode. Therefore, saving power by using this mechanism will not be useful. Therefore, to provide an appropriate energy saving mechanism, the technique of idling without a system tick was introduced - "Tickless idle [23]". The technique uses a time tracking mechanism to turn off the source of clock source for a certain period of time to put the processor into hibernation mode, until an external interrupt or a higher priority kernel interrupt occurs.

In [20], useful techniques for measuring the time spent on such service operations such as interrupt handling and thread switching delays for virtual machines. They will be further adapted for a computing platform based on ATSAMV71Q21 chip. Devices based on the ATSAMV71Q21 chip have three low power saving modes, which can be selected programmatically: Sleep, Wait and Backup modes. In Sleep mode, the processor stops,

and all other functions can work. In Wait mode, all clocks and functions are stopped, but some peripherals can be configured to wake up the system based on predefined conditions. This feature, called "SleepWalking", performs a partial asynchronous wakeup, thus allowing the processor to come out of sleep mode only when only when needed. The Backup mode includes 32-bit low-power Real-time Timer (RTT), Real Time Clock (RTC), and wake-up logic. In addition, the device can meet the most stringent requirements in this mode Key-Off while maintaining 1 KB of SRAM. To optimize power consumption, the clock system has been designed to support different clock speeds for selected peripherals. In addition, the processor and bus clock speeds can be changed without affecting processing, such as USB, U(S)ART, AFE, and the timer counter [14].

3 The Method of Optimizing CubeSat On-Board Computer Power Consumption Under Hard Real-Time Constraints

Suppose that for a hard real-time system, we know the time needed to perform scheduled tasks in a specific time interval at the maximum clock frequency of the processor. Then, to save energy, we need to choose between applying dynamic frequency regulation or using an energy-saving mode.

3.1 The Experiment Plan

Aim of the experiment: Construction of mathematical models for further solving the optimization problem of determining the energy-efficient mode of operation of the on-board computer. The optimization criterion is the minimum power consumption of the on-board computer using different energy-saving modes:

$$P(\eta) = \min(P_{DFS}(\eta), P_{RTD}(\eta), P_{DFS+RTD}(\eta)), \quad (1)$$

where η - relative CPU time costs sufficient to warrant real-time constraints;

$P_{DFS}(\eta), P_{RTD}(\eta), P_{DFS+RTD}(\eta)$ - energy costs for the operation of the on-board computer if the following approaches are used to save energy:

- dynamic frequency scaling (DFS);
- race-to-dark algorithm (RTD) (sometimes Race-to-sleep) executes tasks as fast as possible so that the processor can be put into a sleep mode that minimizes leakage current [14];
- combined algorithm (DFS + RTD), when the software sets the minimum possible clock frequency after working at the maximum frequency before going to sleep mode.

As a result of the experiment, it is necessary to build:

- dependences of the power consumption of the on-board computer on the clock frequency and power supply voltage in active mode and low-power sleep mode:

$$P_{Active}(U, f), \; P_{Sleep}(U, f), \quad (2)$$

– dependence of the time required to perform a certain computing job on the clock frequency of the processor concerning the time spent performing the same job at the maximum frequency:

$$k_T(f) = \frac{T(f)}{T(f_{max})}, \tag{3}$$

where $T(f)$, $T(f_{max})$ - time spent on the job at two frequencies;

The articles [15, 16] outline several essential points regarding the dependence of processor power consumption (P) on supply voltage and clock frequency, the main of which is as follows: processor power consumption is directly proportional to the square of the supply voltage and proportional to the clock frequency:

$$P = ACV^2f + VI_{leak} \tag{4}$$

In the linear model, the time (T) to solve a task on a microprocessor is proportional to the number of machine commands (n) and inversely proportional to the product of the number of required cycles per command (c) by the clock frequency:

$$T(f) = \frac{n}{c} \cdot f^{-1}. \tag{5}$$

Deviation from the theoretical model can be observed due to the action of many factors, such as a delay during interaction with memory or external devices due to their limited speed, the operation of cache memory, etc. As a result, the actual power exponent (a_f) obtained from experimental data will differ from the theoretical one, -1.

$$T(f) = T(f_{max}) \cdot \left(\frac{f}{f_{max}}\right)^{a_f} \Rightarrow k_T(f) = \left(\frac{f}{f_{max}}\right)^{a_f}. \tag{6}$$

3.2 Measurements Technique

Measurements were made for all possible combinations of processor clock frequency – f, MHz and supply voltage – V, V, which are allowed in the technical documentation for the processor [17]:

$$f \in \{30,\ 100,\ 200,\ 300\},\ V \in \{1.8,\ 2.4,\ 3.0,\ 3.3\}.$$

The experiment was carried out on a platform that performed only one periodic job. As a load job, we used the task of sorting an integer array using the bubble algorithm, after which the instruction Wait for Interrupt (WFI) switched the processor to Sleep mode; when the processor functions are stopped, the peripheral clocks were enabled, and the current consumption in this mode is hardware-dependent. An on-board timer interrupt triggers processor wakeup.

To measure the time intervals and the electrical power consumed by the onboard computer, a Keithley 2281S high precision DC bench power supply is used that guarantees the accuracy of the measurements: time intervals - not worse than 15 ms, and the consumed electric power - no worse than 0.0001 W.

As an example of the primary results we obtained, we propose Fig. 2. The primary results have sufficiently high accuracy; the error of measuring time intervals does not exceed 2%, and the power consumption root mean square deviation is no more than 0.1%

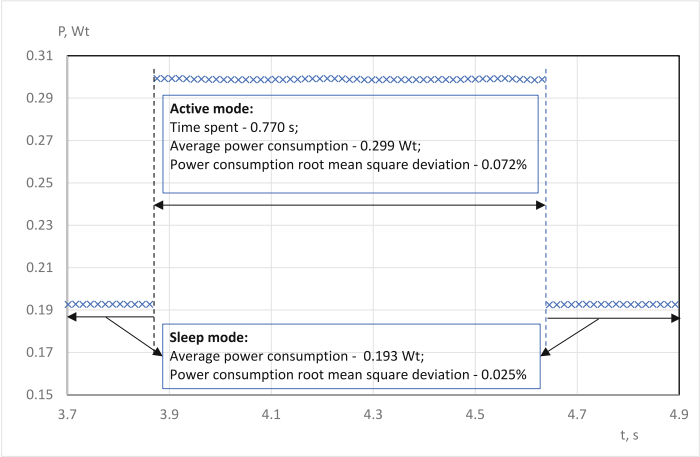

Fig. 2. Primary experimental results: power measurements for frequency 300 MHz, voltage 3.3 V

3.3 The Mathematical Model

Power Consumption. In contrast to the recommended model (4), it was possible to achieve a better match between measurement results and calculations using the following equation (Fig. 3, Table 1) both for the Active mode and for the Sleep mode of the microcontroller used, with the different coefficients:

$$P(V,\ f) = a_1 Vf + a_2 V^2 + a_3 V. \tag{7}$$

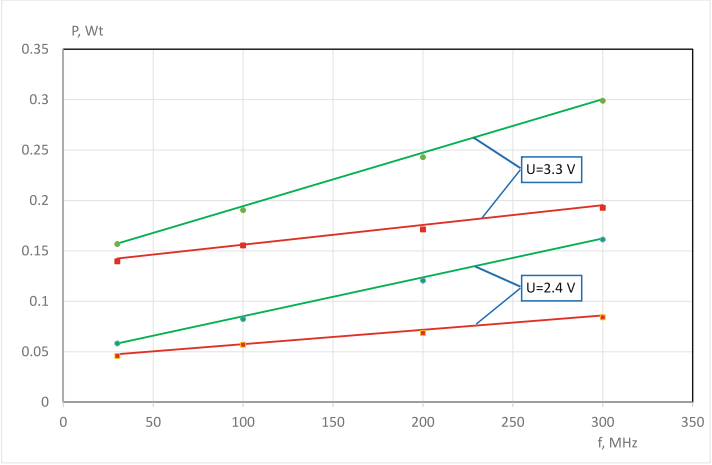

Fig. 3. Experimental data and the constructed model calculations (green color - Active mode, red – Sleep mode)

Table 1. Model coefficients a_1, a_2, a_3 and coefficient of determination - R^2

	a_1	a_2	a_3	R2
Active mode	0.0001607	0.026005	−0.042979	0.99965
Sleep mode	0.0000593564	0.025951038	−0.044252153	0.99927

The time required to perform specific computing work at a clock frequency other than the maximum requires the determination of only one coefficient - the exponent $a_f = -0.8178$ (Fig. 4). This coefficient does not depend on the supply voltage, so each point on the graph corresponds to all four possible voltage values $\{1.8,\ 2.4,\ 3.0,\ 3.3\}$.

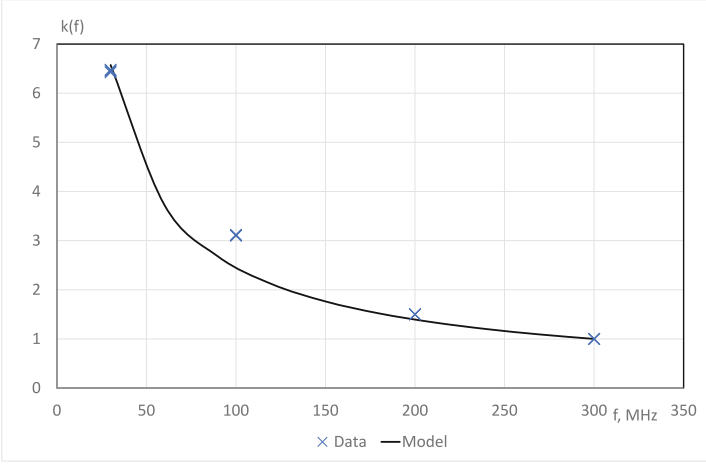

Fig. 4. The relative coefficient of increase in calculation time when the processor's clock frequency is reduced.

When dependencies (2) are built, it is possible to determine the components of the minimum power consumption criterion of the onboard computer when using different power saving modes as follows:

$$\begin{aligned} &P_{DFS}(\eta, V,\ f) = P_{Active}(V,\ f^*),\ \text{where } f^* = f_{max} \cdot \eta^{a_f}\ , \\ &P_{RTD}(\eta, V,\ f) = \eta \cdot P_{Active}(V,\ f) + (1-\eta) \cdot P_{Sleep}(V,\ f), \\ &P_{DFS+RTD}(\eta, V,\ f) = \eta \cdot P_{Active}(V,\ f) + (1-\eta) \cdot P_{Sleep}(V,\ f_{min}). \end{aligned} \tag{8}$$

3.4 Results and Discussion

We consider the main result to be the fact that we obtained an optimistic assessment of the possibility of energy saving due to the use of software control of the computer's operating modes, namely:

– dynamic frequency scaling (DFS);
– race-to-dark algorithm (RTD) (sometimes Race-to-sleep) executes tasks as fast as possible so that the processor can be put into a sleep mode that minimizes leakage current [14];
– combined algorithm (DFS + RTD), when the software sets the minimum possible clock frequency after working at the maximum frequency before going to sleep mode.

This estimate (Fig. 5) is optimistic, as it does not consider the expenses for the work of the scheduler and dispatcher of the operating system. At the same time, the obtained quantitative results are the basis for optimizing the computer hardware components design.

The obtained quantitative results indicate that the use of DFS is more beneficial than RTD, but it is necessary to consider that DFS use will reduce the system's reactivity. Therefore, it is necessary to find a certain compromise between energy saving and the system's reactivity.

An auxiliary result is the proposed methodology for performing similar assessments.

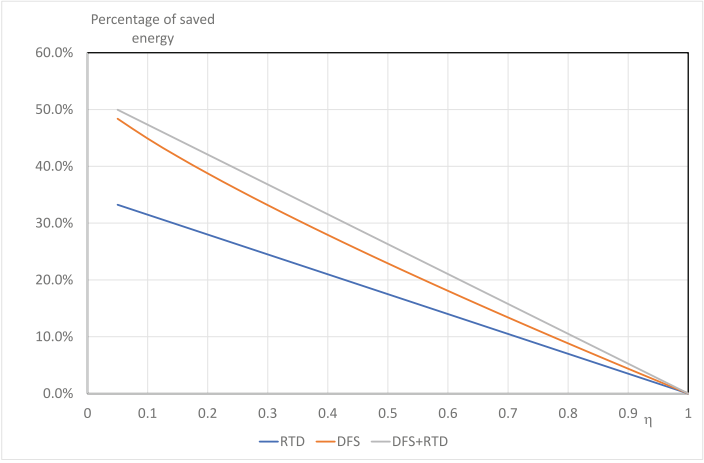

Fig. 5. Dependence of the onboard computer saved energy on η when using different energy saving modes.

4 Conclusions and Further Work

The power consumption of the onboard computer of the student nanosatellite must be reduced, both at the expense of the hardware and the software part.

In the article, we compared the energy-saving capabilities of a specific computing platform, "Falco SBC 1.0" when using different methods, namely dynamic frequency scaling (DFS), race-to-dark (RTD), and combined algorithm. The criterion for choosing the control algorithm was the minimum energy consumption under conditions of guaranteed fulfillment of the real-time systems constraints.

Mathematical models were created to capture the relationships between power consumption, clock frequency, supply voltage, and computation time. These models made it possible to formulate and solve the optimization problem quantitatively.

DFS is the most effective solution from an energy-saving point of view. The combined method does not significantly differ from the DFS, but simultaneously, the system's reactivity deteriorates, so it is necessary to look for a certain compromise considering specific application requirements.

The disadvantage of our work is that the results obtained are idealized since they do not consider the additional overhead costs of the scheduler and dispatcher of the multitasking operating system.

Nevertheless, the methodology developed here to analyze the simulation, measurement, and optimization of onboard computer power consumption can be a basis for reuse in evaluating other hardware/software platforms.

As a further development of the work, we are planning three directions:

- The first one is a study of a computer's energy consumption in processor operating modes, such as Wait and Backup.
- The second and main one is determining overhead costs for operating a multi-threaded real-time operating system, which is more complicated. Predicting behavior in real-time is very difficult; tasks may be completed more slowly than expected; they may crash during execution or experience unexpected delays.
- The third one will be concentrated on research of flexible power control of the other than processor facilities of the computer, i.e. memories, communication interfaces, and others.

Addressing these issues in multi-threaded real-time operating systems is an essential area of research.

References

1. CubeSat Design Specification. Rev 14.1, by the CubeSat Program, Cal Poly SLO. https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/62193b7fc9e72e0053f00910/1645820809779/CDS+REV14_1+2022-02-09.pdf. Accessed 28 Apr 2023
2. Kulu, E.: "Nanosats Database". https://www.nanosats.eu/#figures. Accessed 29 Nov 2023
3. Villela, T., Costa, C.A., Brandão, A.M., Bueno, F.T., Leonardi, R.: Towards the thousandth CubeSat: a statistical overview. Int. J. Aerosp. Eng. **2019**, 13 (2019). Article ID 5063145. https://doi.org/10.1155/2019/5063145
4. Saint Louis University: "CubeSat Database". https://sites.google.com/a/slu.edu/swartwout/cubesat-database. Accessed 11 Apr 2023
5. De, R., Abegaonkar, M.P., Basu, A.: Enabling science with CubeSats—trends and prospects. IEEE J. Miniaturization Air Space Syst. **3**(4), 221–231 (2022). https://doi.org/10.1109/JMASS.2022.3209897
6. Cappelletti, C., Robson, D.: 2 - CubeSat missions and applications. In: Cappelletti, C., Battistini, S., Malphrus, B.K. (eds.) Cubesat Handbook, pp. 53–65. Academic Press (2021). https://doi.org/10.1016/B978-0-12-817884-3.00002-3. ISBN 9780128178843
7. Edpuganti, A., Khadkikar, V., Moursi, M.S.E., Zeineldin, H., Al-Sayari, N., Al Hosani, K.: A comprehensive review on CubeSat electrical power system architectures. IEEE Trans. Power Electron. **37**(3), 3161–3177 (2022). https://doi.org/10.1109/TPEL.2021.3110002

8. Arnold, S.S., Nuzzaci, R., Gordon-Ross, A.: Energy budgeting for CubeSats with an integrated FPGA. In: 2012 IEEE Aerospace Conference, Big Sky, MT, USA, pp. 1–14 (2012). https://doi.org/10.1109/AERO.2012.6187240
9. Seman, L.O., Rigo, C.A., Camponogara, E., Munari, P., Bezerra, E.A.: Improving energy aware nanosatellite task scheduling by a branch-cut-and-price algorithm. Comput. Oper. Res. **158**, 106292 (2023). https://doi.org/10.1016/j.cor.2023.106292. ISSN 0305-0548
10. Slongo, L.K., Martínez, S.V., Eiterer, B.V.B., Pereira, T.G., Bezerra, E.A., Paiva, K.V.: Energy-driven scheduling algorithm for nanosatellite energy harvesting maximization. Acta Astronautica **147**, 141–151 (2018). https://doi.org/10.1016/j.actaastro.2018.03.052. ISSN 0094-5765
11. Bernardo, V.P., Seman, L.O., Bezerra, E.A., Ribeiro, B.F.: Hardware-in-the-loop simulation of an on-board energy-driven scheduling algorithm for CubeSats. IEEE Embed. Syst. Lett. (2023). https://doi.org/10.1109/LES.2023.3268575
12. Rigo, C.A., Seman, L.O., Camponogara, E., Filho, E.M., Bezerra, E.A.: Task scheduling for optimal power management and quality-of-service assurance in CubeSats. Acta Astronautica **179**, 550–560 (2021). https://doi.org/10.1016/j.actaastro.2020.11.016. ISSN 0094-5765
13. Dobiáš, P., Casseau, E., Sinnen, O.: Online fault tolerant energy-aware algorithm for CubeSats. Sustain. Comput. Inf. Syst. **38**, 100853 (2023). https://doi.org/10.1016/j.suscom.2023.100853. ISSN 2210-5379
14. Ali, H., et al.: A survey on system level energy optimisation for MPSoCs in IoT and consumer electronics. Comput. Sci. Rev. **41** (2021). https://doi.org/10.1016/j.cosrev.2021.100416
15. Craig, K., Shakhsheer, Y., Calhoun, B.H.: Optimal power switch design for dynamic voltage scaling from high performance to subthreshold operation. In: Proceedings of the ACM/IEEE International Symposium on Low Power Electronics and Design, pp. 221–224, July 2012
16. Wolf, M.: The Physics of Computing || Processors and Systems, pp. 149–203 (2017). https://doi.org/10.1016/B978-0-12-809381-8.00005-5
17. Atmel | SMART ARM-based Flash MCU – 2016, 20 October 2023. https://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-44003-32-bit-Cortex-M7-Microcontroller-SAM-V71Q-SAM-V71N-SAM-V71J_Datasheet.pdf
18. Gueguen, C., Merlhe, C.: Fair energy efficient scheduler providing high system capacity for wireless networks. SN Appl. Sci. **2**, 2116 (2020). https://doi.org/10.1007/s42452-020-03965-8
19. Bridges, C., Kenyon, S., Underwood, C., Lappas, V.: STRaND-1: the world's first smartphone nanosatellite. In: 2011 2nd International Conference on Space Technology, Athens, Greece, pp. 1–3 (2011). https://doi.org/10.1109/ICSpT.2011.6064651
20. Liubimov, O., Turkin, I., Pavlikov, V., Volobuyeva, L.: Agile software development lifecycle and containerization technology for CubeSat command and data handling module implementation. Computation **11**, 182 (2023). https://doi.org/10.3390/computation11090182
21. Mittal, S.: A survey of techniques for improving energy efficiency in embedded computing systems. Int. J. Comput. Aided Eng. Technol. **6**(4), 440–459 (2014). https://doi.org/10.1504/IJCAET.2014.065419ff. ffhal-01101854
22. Oliveira, G., Lima, G.: Scheduling and energy savings for small scale embedded FreeRTOS-based real-time systems. Des. Autom. Embed. Syst. **27**, 3–29 (2023). https://doi.org/10.1007/s10617-023-09267-7
23. Low Power Support: Tickless Idle Mode. http://www.freertos.org/low-power-tickless-rtos.html. Accessed 20 Oct 2023

The Creation of an Optimisation Component-Oriented Model for the Formation of the Architecture of Science-Based Products

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Abstract. In the conditions of martial law and economic instability, there is a need to shorten the life cycle of a complex technical items. The task of optimising the design processes of the high-tech products which produced is set and solved. The goal of the research is the development of an optimisation modal for the formation of the architecture of science-intensive products based on the component approach. The work shows the necessity of using formalised experience of past developments at the early stages of creating a new technical system. By decomposition, the complex object is divided into smaller parts in order to obtain the architecture of a new product. The experience of past developments can be represented by already successfully implemented projects, information about which is available to the project organisation. Implemented projects are also subject to decomposition in order to obtain ready-made components for reuse. Taking into account that the process of creating high-tech products architecture of which has a hierarchical structure, is considered, options for reusable components must be selected at individual levels of product detail. The following mathematical models and methods are used: system analysis, optimisation, integer (boolean) programming, multi-criteria optimisation, expert assessment, classification. The proposed optimisation model for the architecture formation, based on the component approach, will allow to optimise the decisions made at the design stage of complex product and generally reduce the duration of the life cycle.

Keywords: high-tech products · shortening the life cycle of new technique · component approach · design · architecture of a technical product

1 Introduction

In modern approaches to creating complex technical systems, there are tendencies to reduce product development time [1], and consequently, to shorten the product life circle. The current situation is especially relevant for high-tech military product assignment [2]. The life cycle design stage is the most important stage in product creation [3, 4]. The design task involves the resolution of many controversial requirements and is aimed at creating the architecture of a new complex product [5, 6].

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Consequently, there is the need of new methodology for designing the architecture of complex technical systems, which will improve the quality and timing of early decisions on project development.

Problem Statement. To begin with, existing approaches and tendencies in design should be considered [7, 8]. Modern approaches and methodology to design are focused on taking into account all stages of the life cycle up to disposal of designed object [9, 10]. Knowledge management, obtained as a result of production activities is aimed at integrating data into design process [11]. A multi-stage manufacturing environment is directly dependent on decisions made at the early stages of product creation, which prevent pricy defects from occurring [12]. The product life cycle modelling process may involve data mining techniques and the development of new design at an early design stage [13]. Such intelligent design methods are aimed at assessing the safety of the decision being made [14]. Requirements for a design at different stages of life cycle stages are controversial. When supporting the planning process for the integration of complex aircraft systems, the requirements can be presented in the form of functional-logical-physical model [15]. At the same time, the task of designing an object according to technical specifications contains requirements, which usually given in the form of inequalities. If no suitable solution exists, it is recommended to look for a new object structure diagram or change the requirements. Existing design methodologies [16] aim to analyse existing products in terms of their functional and physical architecture. Functional components are identified and functional analysis is performed. An important aspect in the implementation of the life cycle of complex product is tracking communication links both within the enterprise and among all the teams involved in the manufacture of products [17]. Quite often the problem of assessing manufacturability of complex products is solved with the help of expert systems [18, 19].

The proposed methods and approaches are effective for solving particular tasks, but do not provide a formalised description of the solution to the optimisation task of reducing the time required for the design stage of a complex technical product. And also, not enough attention is paid to systematisation and formalisation of the component approach [20] with the detection of its qualitative characteristics. The purpose of this article is to consider the early stage of a technical product design with the view to constructing an optimisation component-oriented model for the formation of the architecture of science-intensive products, which will, in the future, lead to a reduction in the life cycle of high-tech products.

2 Materials and Methods

When creating new models of science-intensive technology, many developers intuitively use the experience of past developments in form of approved design solutions [21]. Using positive experience reduces financial expenditures and shortens design time. But a new product introduces new functional tasks which cannot always be solved using ready-made decisions. The timing of the entire project largely depends on the timing of the implementation of new components.

In order to solve the tasks of reducing the design stage, this work offers an optimisation component-oriented model for the formation of the architecture of high-tech products (Fig. 1).

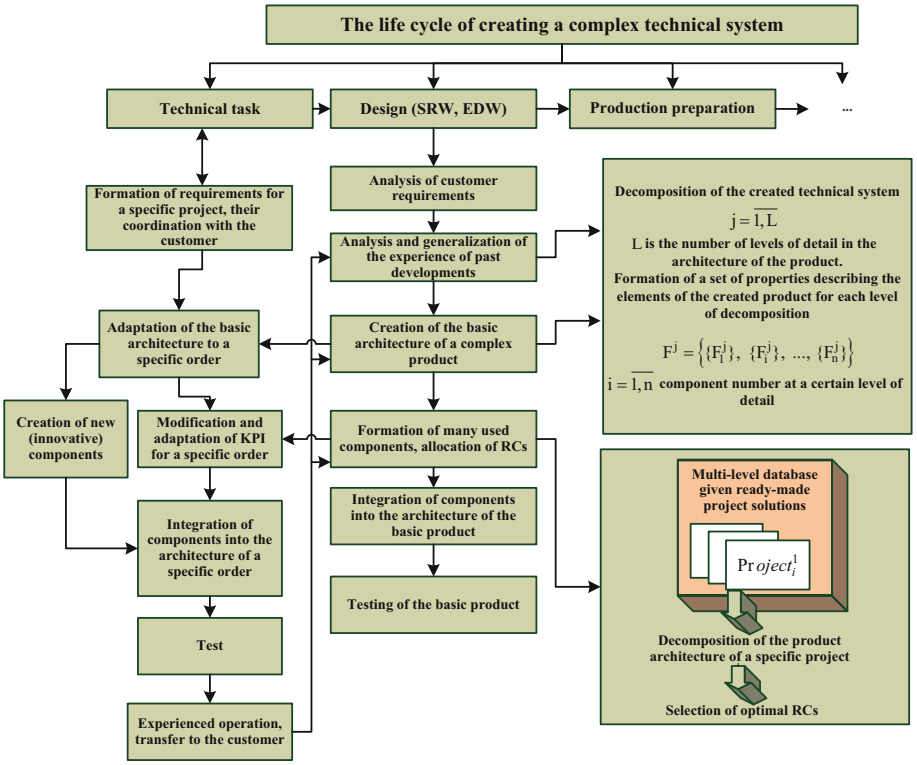

Fig. 1. Optimisation component-oriented model for the formation of the architecture of high-tech products

Here the main component elements of the proposed optimisation model are considered.

Technical Task. The first stage of the project implementation is the development of its concept [22]. The formation of a project concept requires the construction of many forecasts, including a prediction of the state or behaviour of external systems, interacting with the design object, a prediction of the development of competing or opposing systems, prediction of the degree of influence of various risk-generating factors [23] etc. Therefore, an important part of the design process is the analysis of the entire life cycle of the object being created, allowing not only to estimate its possible service life, but also to take into account environmental factors that may influence design decisions [24]. In the beginning of the development cycle of complex technical systems, it is necessary to find a solution to the problem of choosing a product design taking into account customer requirements. At this stage, based on market needs, a technical specification (TS) is formed, which is subsequently analysed. The TS is formed upon agreement between the requirements of the customer and the contract. The TS outline the basic requirements and characteristics of the product. This includes the data necessary to form the component architecture of a complex technical product.

Formation of Requirements for a Specific Project, Their Coordination with the Customer. The requirements for the creation of new product can be classified into various groups: economic requirements are associated with optimising the cost of developing a new product, taking into account the active use of the component attitude (searching for the cost-optimal multi-level component composition of the product); organizational; technological requirements are related to the creation of a new design model based on component approach, with the help of which the life cycle of a new product is optimisation, etc.

In system design, when harmonising requirements, the general Task can be described by set of formalised Task = <M, A, E, S, X, Y>, where M—a set of models of the design object; A—a set of initial data; E—set of restrictions; S—set of design solutions; X—set of evaluations of design solutions; Y—set of decision procedures.

Formation of Multiple Components Used, Allocation of Reusable Components (RCs). The formation of numerous ready-made solutions can be represented as a complex multi-stage process based on the use of a number of methods. It is assumed that there is a precedent base (database) [25], which contains open information on existing projects for creating complex technical systems. Initially, it is necessary to identify many successful projects (technical items), at the first level of decomposition (at the level of the product itself), as analogues for their further more detailed examination.

$$\text{Pr}oject^1 = \left\{\text{Pr}oject_1^1, \text{Pr}oject_i^1, ..., \text{Pr}oject_s^1\right\}, \quad (1)$$

where s – number of selected projects at the first level of decomposition.

The choice of analogues must be carried out according to certain indication. Among which we can highlight the following: identity of the functional purpose of the product; close list of tasks to be solved; similarity of architecture (structure and composition of elements) of the analogue and the product being created; similarity of characteristics (parameters) of the analogue and the created product.

The list of specified characteristics can be expanded for more thorough selection of many analogues. To solve the problem of selecting analogue projects on given characteristics is carried out with the help of experts. Each feature is assigned the weighting coefficient for the significance of the feature. Then each project from the precedent database is graded according to the selected criteria (features). The assessment can be presented on both quantitative and qualitative scales. After evaluating the project, it is possible to use lexicographic streamlining of analogous projects to create complex technical systems. As a result of lexicographic streamlining, a certain set of projects can be identified, from which reuse components will be selected in the future. Among the options for solving tasks of selecting analogue projects, the use of classification methods are possible [26, 27]. In this case, a cluster of projects is determined based on the weighting coefficients of the features and their ratings given by experts. Ratings are converted into a numerical scale and rationed. After this, the degree of similarity between analogous projects and the created technical sample is calculated. The option of calculating one additive (generalised) criterion to determine the degree of similarity is also not excluded.

Identification of a preliminary set of *Project 1* close analogues of complex technical products make it possible to narrow the scope of the search for precedents at the component level when synthesising the architecture of a new technical product. After receiving a preliminary set of precedents, a process of functional and criterion decomposition of the created technical products is carried out into their constituent components and private criteria that characterise the properties, necessary to solve functional tasks, are generated. This gives an opportunity to look for relevant precedents at lower levels and find suitable precedents for the components, identified as a result of the decomposition process.

Using functional decomposition, you can split any product into individual components. Depending on the decomposition level, the architecture of complex technical product can be represented as a set of main components inherent in this level.

For conducting the architecture decomposition of a technical system, a set-theoretic description can be used [28, 29]:

$$\left\{K_i^j\right\} = \left\{\left\{K_1^{j+1}\right\}, \ldots, \left\{K_i^{j+1}\right\}, \ldots, \left\{K_{n_j}^{j+1}\right\}\right\}, \tag{2}$$

where $\left\{K_i^j\right\}$ is a subset of components of a complex component of j-th level of product architecture decomposition;

$\{K_1^{j+1}\}$ is a subset of nested lower-level component;

$j = \overline{1, L}$ is number of product decomposition level;

L is a number of levels of detail in the product architecture.

As a result of decomposition of finished samples from a preliminary sat of precedent bases, the classification of components in relation to the product being created may contain the types of components [30] presented in Fig. 2:

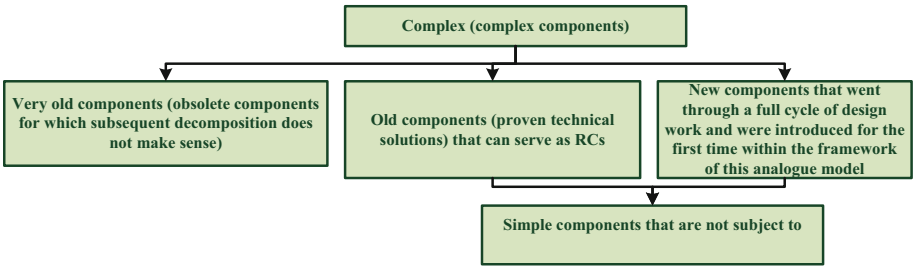

Fig. 2. Classification of components of analogue samples from an allocated set of analogue projects

Thus, complex «old» and «new» components, as well as their components, located at a lower level of decomposition, can be used as RCs. The selection of RCs which can be used when creating a new complex product is carried out at various levels of the product architecture from the top to the bottom levels. Consequently, many alternative RCs are formed for each level of the architecture of the product being created. For each component that can be used as RC, a list of characteristics (functional decomposition) is identified,

which, according to certain criteria, can be comparable with the requirements for the component of the technical system being created. Some of the most important criteria that can be identified are: the identity of the functional purpose of the analogue component when creating the architecture of a new product and the similarity of the characteristics (parameters) of the analogue component and the component of the product being created. The proposed criteria may be assessed by experts using both quantitative and qualitative ratings scales.

The characteristics of the created product and analogue component can be described in the form of a tuple of their technical specifications:

$$K_i^j = \left\langle v_1, v_2, ..., v_{s_i^j} \right\rangle, \tag{3}$$

where $v_1, v_2, ..., v_{s_i^j}$ is values of technical characteristics (requirements);

s_i^j is number of characteristics (requirements) of the j-th component of the product architecture decomposition level.

In addition, in the process of selecting RC, it is necessary to take into account other indicators: the duration of adaptation of the PC to the requirements for the component of the technical product being created, the cost of adaptation, the quality of the obtained component after adaptation, its competitiveness, innovativeness, the risk of performing design work to adapt the RC.

Let's introduce a boolean variable $x_{d_{ij}}$, showing the choice d-th analogue component as RC of the j-th decomposition level of the component architecture of the product of i-th component name. Meanwhile:

$$x_{d_{ij}} \begin{cases} 1 - \text{ means to select the d - th th analogue component as the PC} \\ \quad \text{of the j - th level of detail of the component architecture;} \\ 0 - \text{otherwise (no choice).} \end{cases} \tag{4}$$

In its turn:

$i_j = \overline{1, n_j}$, i_j is the number of the component type at the j-th detail level of the created product, n_j is the number of components at the j-th decomposition level of the created product;

$d_{ij} = \overline{1, m_{ij}}$, m_{ij} is the number of alternatives for choosing the i-th type of RC at the j-th decomposition level of the architecture of the product being created;

$j = \overline{1, L}$, L is the number of product architecture detail level.

Furthermore, it is necessary to take into account

$$\sum_{d=1}^{m_{i_j}} x_{d_{i_j}} = 1, \tag{5}$$

which means compulsory choice one of the possible alternatives to the RC.

Let's enter the following characteristics to analyse the process of adaptation of the RC:

$t_{d_{ij}}$ is the duration of the adaptation, connected with the selection of the d-th component as a RC for the i-th type of component at the j-th detail level of the component architecture of the product being created;

$z_{d_{ij}}$ is the cost of implementing adaptation of the RC in the case of choosing the d-th component as the RC for the i-th type of component of the j-th detail level;

$p_{d_{ij}}$ is the quality of product (component) in case of choosing the d-th RC for i-th type of component of the j-th detail level for adaptation;

$q_{d_{ij}}$ is competitiveness of products (component) connected with the choice for adaptation of the d-th RC of the i-th type of component of the j-th detail level;

$h_{d_{ij}}$ is product (component) innovativeness, connected with the choice of the d-th RC for adapting the i-th type of component at the j-th detail level;

$r_{d_{ij}}$ is the risk of carrying out design work to adapt the d-th RC of the i-th type of component at the j-th detail level of the component architecture;

$g_{d_{ij}}$ is the identity of the functional purpose of the d-th analogue component and the required i-th type of component of the j-th detail level;

$k_{d_{ij}}$ is the similarity of characteristics (settings) of the d-th RC of the required i-th type of component at the j-th detail level when creating the architecture of a new product.

Then the choice of RC for adapting the i-th type of component of the j-th detail level of the component architecture of the created product can be assessed as follows:

$$\begin{aligned} &T_{ij} = \sum_d x_{d_{ij}} t_{d_{ij}}, Z_{ij} = \sum_d x_{d_{ij}} z_{d_{ij}}, P_{ij} = \sum_d x_{d_{ij}} p_{d_{ij}}, Q_{ij} = \sum_d x_{d_{ij}} q_{d_{ij}}, \\ &H_{ij} = \sum_d x_{d_{ij}} h_{d_{ij}}, R_{ij} = \sum_d x_{d_{ij}} r_{d_{ij}}, G_{ij} = \sum_d x_{d_{ij}} g_{d_{ij}}, K_{ij} = \sum_d x_{d_{ij}} k_{d_{ij}}. \end{aligned} \tag{6}$$

For the reasonable choice of RC, and taking into account all the features of the RC adaptation process, it is necessary to optimise the selected indicators. Let's minimise the duration of RC adaptation to a new project through rational RC choose:

$$\min T_{ij} = \sum_d x_{d_{ij}} t_{d_{ij}}, \tag{7}$$

with implementing requirements $Z_{ij} \le Z'_{ij}$, $P_{ij} \ge P'_{ij}$, $Q_{ij} \ge Q'_{ij}$, $H_{ij} \ge H'_{ij}$, $R_{ij} \le R'_{ij}$, $G_{ij} \ge G'_{ij}$, $K_{ij} \ge K'_{ij}$.

where Z'_{ij} is the acceptable cost for RC adaptation of the i-th component type of the j-th detail level of the architecture of the product being created. The acceptable values of the remaining selected indicators can be presented in the similar way. Let's minimise the expenditure of adapting the RC to a new project:

$$\min Z_{ij} = \sum_d x_{d_{ij}} z_{d_{ij}}, \tag{8}$$

with implementing requirements $T_{ij} \le T'_{ij}$, $P_{ij} \ge P'_{ij}$, $Q_{ij} \ge Q'_{ij}$, $H_{ij} \ge H'_{ij}$, $R_{ij} \le R'_{ij}$, $G_{ij} \ge G'_{ij}$, $K_{ij} \ge K'_{ij}$.

where T'_{ij} is permissible duration of the i-th component type of the j-th detail level with creating the architecture of a new product.

In similar way, it is necessary to obtain the maximum indicator of quality, competitiveness and innovation, identity of functional purpose, similarity of RC characteristics

(parameters) of the i-th component type of the j-th detail level. Let's minimise the risks of conducting the design work to adapt the RC:

$$\min R_{ij} = \sum_{d} x_{d_{ij}} r_{d_{ij}}, \tag{9}$$

with implementing requirements:

$T_{ij} \le T'_{ij}, Z_{ij} \le Z'_{ij}, P_{ij} \ge P'_{ij}, Q_{ij} \ge Q'_{ij}, H_{ij} \ge H'_{ij}, G_{ij} \ge G'_{ij}, K_{ij} \ge K'_{ij}$.

At the next stage, multi-criteria optimisation is produced to ensure the optimal choice of RCs in conditions of reducing the design stage of a new complex product. To do it, let's enter a complex criterion in the form of a sum of individual indicators:

$$F_{ij} = \alpha_{T_{ij}} \hat{T}_{ij} + \alpha_{Z_{ij}} \hat{Z}_{ij} + \alpha_{P_{ij}} \hat{P}_{ij} + \alpha_{Q_{ij}} \hat{Q}_{ij} + \alpha_{H_{ij}} \hat{H}_{ij} + \alpha_{R_{ij}} \hat{R}_{ij} + \alpha_{G_{ij}} \hat{G}_{ij} + \alpha_{K_{ij}} \hat{K}_{ij},$$

where $\alpha_{T_{ij}}$, $\alpha_{Z_{ij}}$, $\alpha_{P_{ij}}$, $\alpha_{Q_{ij}}$, $\alpha_{H_{ij}}$, $\alpha_{R_{ij}}$, $\alpha_{G_{ij}}$, $\alpha_{K_{ij}}$ are weighting coefficient T_{ij}, $Z_{ij}, P_{ij}, Q_{ij}, H_{ij}, R_{ij}, G_{ij}, K_{ij}$, obtained through expert assessment of their importance. While:

$$\begin{aligned} &0 \le \alpha_{T_{ij}} \le 1, 0 \le \alpha_{Z_{ij}} \le 1, 0 \le \alpha_{P_{ij}} \le 1, 0 \le \alpha_{Q_{ij}} \le 1, \\ &0 \le \alpha_{H_{ij}} \le 1, 0 \le \alpha_{R_{ij}} \le 1, 0 \le \alpha_{G_{ij}} \le 1, 0 \le \alpha_{K_{ij}} \le 1. \\ &\alpha_{T_{ij}} + \alpha_{Z_{ij}} + \alpha_{P_{ij}} + \alpha_{Q_{ij}} + \alpha_{H_{ij}} + \alpha_{R_{ij}} + \alpha_{G_{ij}} + \alpha_{K_{ij}} = 1. \end{aligned} \tag{10}$$

Adaptation indicators $\widehat{T}_{ij}, \widehat{Z}_{ij}, \widehat{P}_{ij}, \widehat{Q}_{ij}, \widehat{H}_{ij}, \widehat{R}_{ij}, \widehat{G}_{ij}, \widehat{K}_{ij}$ are normalised (converted into a dimensionless scale $0 \div 1$):

$$\begin{aligned} &\hat{T}_{ij} = \frac{\mathrm{T_{ij}} - \mathrm{T^*_{ij}}}{\mathrm{T'_{ij}} - \mathrm{T^*_{ij}}}, \hat{Z}_{ij} = \frac{Z_{ij} - Z^*_{ij}}{Z'_{ij} - Z^*_{ij}}, \hat{P}_{ij} = \frac{P^*_{ij} - P_{ij}}{P^*_{ij} - P'_{ij}}, \hat{Q}_{ij} = \frac{Q^*_{ij} - Q_{ij}}{Q^*_{ij} - Q'_{ij}} \\ &\hat{H}_{ij} = \frac{H^*_{ij} - H_{ij}}{H^*_{ij} - H'_{ij}}, \hat{R}_{ij} = \frac{R_{ij} - R^*_{ij}}{R'_{ij} - R^*_{ij}}, \hat{G}_{ij} = \frac{G^*_{ij} - G_{ij}}{G^*_{ij} - G'_{ij}}, \hat{K}_{ij} = \frac{K^*_{ij} - K_{ij}}{K^*_{ij} - K'_{ij}} \end{aligned} \tag{11}$$

where, in its return, T^*_{ij}, $Z^*_{ij}, P^*_{ij}, Q^*_{ij}, H^*_{ij}, R^*_{ij}, G^*_{ij}, K^*_{ij}$ is the extreme value of indicators, obtained by local optimisation at the previous stage. It is necessary to minimise the complex criterion F_{ij} taking into account the requirements for reducing the design stage of a new complicated product, through optimal adaptation of the RC:

$$\min F_{ij}, \tag{12}$$

$$\begin{aligned} &F_{ij} = \alpha_{T_{ij}} \hat{T}_{ij} + \alpha_{Z_{ij}} \hat{Z}_{ij} + \alpha_{P_{ij}} \hat{P}_{ij} + \alpha_{Q_{ij}} \hat{Q}_{ij} + \alpha_{H_{ij}} \hat{H}_{ij} + \alpha_{R_{ij}} \hat{R}_{ij} + \alpha_{G_{ij}} \hat{G}_{ij} \\ &+\alpha_{K_{ij}} \hat{K}_{ij} = \alpha_{T_{ij}} \frac{T_{ij} - T^*_{ij}}{T'_{ij} - T^*_{ij}} + \alpha_{Z_{ij}} \frac{Z_{ij} - Z^*_{ij}}{Z'_{ij} - Z^*_{ij}} + \alpha_{P_{ij}} \frac{P^*_{ij} - P_{ij}}{P^*_{ij} - P'_{ij}} + \alpha_{Q_{ij}} \frac{Q^*_{ij} - Q_{ij}}{Q^*_{ij} - Q'_{ij}} \\ &+\alpha_{H_{ij}} \frac{H^*_{ij} - H_{ij}}{H^*_{ij} - H'_{ij}} + \alpha_{R_{ij}} \frac{R_{ij} - R^*_{ij}}{R'_{ij} - R^*_{ij}} + \alpha_{G_{ij}} \frac{G^*_{ij} - G_{ij}}{G^*_{ij} - G'_{ij}} + \alpha_{K_{ij}} \frac{K^*_{ij} - K_{ij}}{K^*_{ij} - K'_{ij}} \end{aligned}$$

with fulfilling restrictions $T_{ij} \le T'_{ij}, Z_{ij} \le Z'_{ij}, P_{ij} \ge P'_{ij}, Q_{ij} \ge Q'_{ij}, H_{ij} \ge H'_{ij}, R_{ij} \le R'_{ij}$, $G_{ij} \ge G'_{ij}, K_{ij} \ge K'_{ij}$.

Thus, the RCs selection for the constituent elements of the designed product is carried out at the considered decomposition levels.

Creation of New (Innovative) Components. In case if the RCs cannot be found, it becomes necessary to create a new component, which can lead to increased risk, as well as project duration and additional financial cost. When creating a new component, it is necessary to conduct a full cycle of design work. The development of a component involves carrying out scientific research work (SRW), during which the concept of the component is developed, and experimental development work (EDW). The planning stage of work on the realisation of a component allows to determine the timing of its implementation, testing and transfer of the product element. Thus, the number and degree of complexity, as well as the availability of qualified performers of new, currently non-existent components to be developed, affect the duration of the project and, in general, its feasibility. We will determine and optimise the duration of obtaining innovative solutions. To find optimal solutions, it is necessary to evaluate the rational choice of measures (actions) from the set of existing ones for a given component. The contradictions lie in the fact that new components make it possible to increase competitiveness of the product, but, at the same time, increase the risk of implementing a project to create new equipment. Thus, we present the main indicators of i-th implementation type of innovative component of j-th detail level of the component architecture of the created product as follows:

$$\begin{aligned} T_{i_j} &= \sum_{\lambda} x_{\lambda_{i_j}} t_{\lambda_{i_j}}, Z_{i_j} = \sum_{\lambda} x_{\lambda_{i_j}} z_{\lambda_{i_j}}, P_{i_j} = \sum_{\lambda} x_{\lambda_{i_j}} p_{\lambda_{i_j}}, \\ Q_{i_j} &= \sum_{\lambda} x_{\lambda_{i_j}} q_{\lambda_{i_j}}, H_{i_j} = \sum_{\lambda} x_{\lambda_{i_j}} h_{\lambda_{i_j}}, R_{i_j} = \sum_{\lambda} x_{\lambda_{i_j}} r_{\lambda_{i_j}}, \end{aligned} \tag{13}$$

where $x_{\lambda_{i_j}}$ is boolean variable, corresponding to the choice of specific event to crest the i-th new component type of the j-th detail level of the architecture of the product being created:

$$x_{\lambda_{i_j}} \begin{cases} 1 - \text{means to select the } \lambda\text{ - th event to create the i - th new component} \\ \quad \text{at the j - th level of detail of the component architecture;} \\ 0 - \text{otherwise (no choice).} \end{cases} \tag{14}$$

$\lambda_{i_j} = \overline{1, e_{i_j}}$, e_{i_j} is the the number of alternatives for choosing project work to create the i-th of new component at the jth decomposition level of the architecture of product being created. A rational choice of measures will allow, depending on the indicator (T, Z, Q, H, R), to optimise the design under the conditions of acceptable value of the main indicators ′, Z′, Q′, H′, R′. To reduce the implementation time of new component, it is necessary to find min T:

$$\min T_{i_j} = \sum_{\lambda} x_{\lambda_{i_j}} t_{\lambda_{i_j}}, \tag{15}$$

in conditions of limited capabilities, connected with meeting the requirements presented by the customer, in terms of other indicators:

$$Z_{i_j} \le Z'_{i_j}, P_{i_j} \ge P'_{i_j}, Q_{i_j} \ge Q'_{i_j}, H_{i_j} \ge H'_{i_j}, R_{i_j} \le R'_{i_j}.$$

An important point in optimising the design process is the selection of possible measures (design actions) for each i-th type of new component of the j-th detail level of architecture of the product being created. To solve this problem, it is advisable to use the opinions of experts on the creation on complex techniques. The ultimate goal of the decision-making task when forming the architecture of a new product is to select the best option from possible set (optimisation task). The criterion for the effectiveness of decisions should take into account both the positive effect (the achievement degree of the goal) and the cost of achieving it.

3 Conclusions

An analysis of existing approaches to implementing the life cycle of complex technical systems was carried out. The main tendencies in the market for the creation of high-tech products are highlighted. The design stage of the life cycle of high-tech product is considered for the formation of its multi-level architecture, which includes many reusable components. In this work, the following tasks were considered and solved:

1. An optimisation component-oriented model for the formation of the architecture of high-tech products has been constructed, which is based on a component approach and takes into account the positive experience of past developments. Guided by the presented optimisation model, an approach to the formation of a set of RCs at various levels of the hierarchy is proposed.
2. A model for the optimal RCs choice at the various levels of decomposition is presented. The selected RCs may be subject to further adaptation if the feasibility of implementing such design decisions is determined. The model takes into account the following indicators: the duration of RCs adaptation to the requirements for the component of the technical product being created, the cost of adaptation, the quality of the resulting component after adaptation; its competitiveness, innovativeness, the risk of performing design work to adapt the RCs, etc. The model is based on the use of multi-criteria optimisation.
3. As part of architecture of the product being created, there are always new (innovative) components that carry the greatest risk. The work presents a model for the optimal selection of project actions to create new solutions (components), based on expert opinions. New components can be used in subsequent projects or order portfolios.

The occurrence of new optimisation component-oriented model for the formation of the architecture of high-tech products allows the design time of a high – tech product to be reduced, which, in turn, will lead to a reduction in the life cycle of the created high-tech products.

References

1. Grijota, C.G., Acero, R., Yagüe-Fabra, J.A.: Product development methodology “scalability.” Procedia CIRP **100**, 571–576 (2021). https://doi.org/10.1016/j.procir.2021.05.125
2. Den Boer, J., Lambrechts, W., Krikke, H.: Additive manufacturing in military and humanitarian missions: advantages and challenges in the spare parts supply chain. J. Cleaner Prod. **257** (2020). https://doi.org/10.1016/j.jclepro.2020.120301

3. Mio, A., Fermeglia, M.: Multiscale modelling techniques in life cycle assessment: application to product design. Procedia CIRP **105**, 688–693 (2022). https://doi.org/10.1016/j.procir.2022.02.115
4. Zhang, D., Zhang, Y.I., Zhang, G., Qian, C.H.: An exploratory architecture using data and knowledge to close the loop between design and maintenance from a product quality perspective. Adv. Eng. Inf. **56** (2023). https://doi.org/10.1016/j.aei.2023.101920
5. Stief, P., Dantan, J.-Y.V., Etienne, A., Siadat, A.: Contribution to the design of reconfigurable multi-product assembly systems by architecture solutions generation through a new locating-driven approach. CIRP J. Manuf. Sci. Technol. **41**, 108–123 (2023). https://doi.org/10.1016/j.cirpj.2022.12.003
6. Breimann, R., et al.: A method for optimizing product architectures for the management of disturbance factors. Procedia CIRP **119**, 1041–1046 (2023). https://doi.org/10.1016/j.procir.2023.02.179
7. Kolossváry, T., Feszty, D., Dőry, T.: Systems engineering in automotive product development: a guide to initiate organisational transformation. J. Open Innov. Technol. Market Complex. **9**(4) (2023). https://doi.org/10.1016/j.joitmc.2023.100160
8. de Romeral, P.A.A.F., Zancul, E., Nakano, D.: Product development process for complex hardware-based solutions: current trends. Procedia CIRP **119**, 885–890 (2023). https://doi.org/10.1016/j.procir.2023.03.133
9. Kobayashi, H., Matsumoto, T., Fukushige, S.: A simulation methodology for a system of product life cycle systems. Adv. Eng. Inform. **36**, 101–111 (2018). https://doi.org/10.1016/j.aei.2018.03.001
10. Liu, H., Chu, X., Xue, D.: An optimal concurrent product design and service planning approach through simulation-based evaluation considering the whole product life-cycle span. Comput. Ind. **111**, 187–197 (2019). https://doi.org/10.1016/j.compind.2019.07.008
11. Elsouri, M., Gao, J., Simmonds, C.: Integrating manufacturing knowledge with design process to improve quality in the aerospace industry. Procedia CIRP **84**(4), 374–379 (2019). https://doi.org/10.1016/j.procir.2019.04.179
12. Zörrer, H., Steringer, R., Zambal, S., Eitzinger, C.H.: Using business analytics for decision support in zero defect manufacturing of composite parts in the aerospace industry. IFAC-PapersOnLine **52**(13), 1461–1466 (2019). https://doi.org/10.1016/j.ifacol.2019.11.405
13. Bertonia, M., Pezzottab, G., Scandellab, B., Walla, J., Jonsson, P.: Life cycle simulation to support cross-disciplinary decision making in early PSS design. Procedia CIRP **83**, 260–265 (2019). https://doi.org/10.1016/j.procir.2019.03.138
14. Jiao, Z., et al.: An intelligent design method for actuation system architecture optimization for more electrical aircraft. Aerosp. Sci. Technol. **93** (2019). https://doi.org/10.1016/j.ast.2019.03.048
15. Li, T., Lockett, H., Lawson, C.: Using requirement-functional-logical-physical models to support early assembly process planning for complex aircraft systems integration. J. Manuf. Syst. **54**, 242–257 (2020). https://doi.org/10.1016/j.jmsy.2020.01.001
16. Stief, P., Dantan, J.-Y., Etienne, A., Siadat, A.: A new methodology to analyze the functional and physical architecture of existing products for an assembly oriented product family identification. Procedia CIRP **70**, 47–52 (2018). https://doi.org/10.1016/j.procir.2018.02.026
17. Mourtzis, D., Gargallis, A., Zogopoulos, V.: Modelling of customer oriented applications in product lifecycle using RAMI 4.0. Procedia Manuf. **28**, 31–36 (2019). https://doi.org/10.1016/j.promfg.2018.12.006
18. Matuszek, J., Seneta, T., Dulina, L., Bigosova, E.: Manufacturability assessment of the product assembly processes design in the automotive industry. Commun. Sci. Lett. Univ. Zilina **22**(4), 112–120 (2020). https://doi.org/10.26552/com.C.2020.4.112-120

19. Matuszek, J., Seneta, T., Moczała, A.: Evaluation of design manufacturability in assembly processes by modified Lucas design for assembly method. Mechanik **91**(7), 532–534 (2018). https://doi.org/10.17814/mechanik.2018.7.75
20. Wu, S.H., Lu, W.-Z.H., Qin, C.H., Wen, B., Wu, D., Xiang, Y.U.: A goal-oriented planning approach for two-dimensional cutting components in architectural design: coupling BIM and Parametric design (PD). J. Build. Eng. **76** (2023). https://doi.org/10.1016/j.jobe.2023.107156
21. Fedorovich, O., Uruskyi, O., Kosenko, V., Lutai, L., Zamirets, I.: Methodology of architecture-oriented synthesis in component design of aerospace complexes. In: Innovative Integrated Computer Systems in Strategic Project Management: Collective Monograph, pp. 35–86. European University Press. ISMA, Riga (2022). https://doi.org/10.30837/MMP.2022.035
22. Sow, D., Imoussaten, A., Couturier, P., Montmain, J.: A possibilistic approach to set achievable and feasible goals while designing complex systems. IFAC-PapersOnLine **50**(1), 14218–14223 (2017). https://doi.org/10.1016/j.ifacol.2017.08.2094
23. Luther, B., Gunawan, I., Nguyen, N.: Identifying effective risk management frameworks for complex socio-technical systems. Saf. Sci. **158** (2023). https://doi.org/10.1016/j.ssci.2022.105989
24. Hapuwatte, B.M., Jawahir, I.S.: A total life cycle approach for developing predictive design methodologies to optimize product performance. Procedia Manuf. **33**, 11–18 (2019). https://doi.org/10.1016/j.promfg.2019.04.003
25. Matokhina, A.V., Kizim, A.V., Skvaznikov, D.E., Aleshkevich, A.A., Malikov, V.P., Kravchenko, D.A.: Development of the intelligent platform of technical systems modernization at different stages of the life cycle. Procedia Comput. Sci. **121**, 913–919 (2017). https://doi.org/10.1016/j.procs.2017.11.118
26. Emmendorfer, L.R., de Paula Canuto, A.M.: A generalized average linkage criterion for hierarchical agglomerative clustering. Appl. Soft Comput. **100** (2021). https://doi.org/10.1016/j.asoc.2020.106990
27. Cabrera, N.G., Ortiz-Bejar, J., Zamora-Mendez, A., Arrieta Paternina, M.R.: On the Improvement of representative demand curves via a hierarchical agglomerative clustering for power transmission network investment. Energy **222** (2021). https://doi.org/10.1016/j.energy.2021.119989
28. Urrea-Quintero, J.-H., Hernandez, H., Ochoa, S.: Towards a controllability analysis of multiscale systems: application of the set-theoretic approach to a semi-batch emulsion polymerization process. Comput. Chem. Eng. **138** (2020). https://doi.org/10.1016/j.compchemeng.2020.106833
29. Honcharenko, T., Mihaylenko, V.: Set-theoretic description of spatial data in the information model of the construction territory. Herald Nat. Tech. Univ. "KhPI" **24**(1300), 149–159 (2018). https://doi.org/10.20998/2411-0558.2018.24.13
30. Fedorovich, O., Kosenko, V., Lutai, L., Zamirets, I.: Methods and models of research of investment attractiveness and competitiveness of project-oriented enterprise in the process of creating innovative high-tech. Innov. Technol. Sci. Solutions Ind. **3**(21), 51–59 (2022). https://doi.org/10.30837/ITSSI.2022.21.051

Engineering Methodology for the Synthesis of Control Algorithms for Digital Electric Drives of Mechatronic Devices of Flying Search Robots

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Abstract. The article is dedicated to the presentation of an engineering methodology for the synthesis of control algorithms for digital electric drives of mechatronic devices of flying search robots. Usage of the algorithms proposed in the article for correcting characteristics of the electric drive and the observer of the angular velocity and rotation angle of the rotor of direct current motor, included in the mechatronic system of the electric drive of the orientation and stabilization systems in a given position of the main rotor of the flying search robot or the sensitivity axes of directional sensors (search sensors) of the same robot, makes it possible to reduce the weight and dimensions of the digital automatic control system for the electric drive and increase its reliability.

Keywords: Correction of dynamic characteristics of electric drives · Mechatronic devices · State observer · Digital automatic control of electric drives · Computer modeling in state-space · Flying search robots

1 Introduction

1.1 Introduction to the Problem

Electromechanics of flying search robots (FSR) is actively modernized thanks to the use of digital mechatronic devices [1–5]. The number of digital electric drives of mechatronic devices on board of the multicopter exceeds several hundred [6–8].

Hardware modernization has practically reached its limit [9, 10]. It is possible to significantly increase the speed and reliability of digital electric drives of mechatronic devices, to reduce mass and size indicators with a negligible increase in energy consumption only thanks to algorithmic modernization. For the segment of flying search robots that use only electric energy or hybrid energy sources, it is extremely important not to be energy-consuming.

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Success of search and rescue operations in areas of natural disasters in the absence of telecommunication infrastructure is 80% determined by the effectiveness of the FSR [11]. For flying search robots, increasing reliability of their functioning and accuracy of identifying search object in the difficult conditions of a natural or man-made disaster is primary importance. For this reason, the task of algorithmic modernization of digital electric drives of mechatronic FSR devices, which are part of systems of orientation and stabilization in a given position of FSR main rotors or sensitivity axes of directional sensor (search sensors, which have a higher sensitivity in relation to the search object compared to omnidirectional sensors). Algorithmic modernization makes it possible to increase the reliability of mechatronic devices by replacing mechanical sensors with algorithmic ones (state observers), reduce (in the limit reduce to zero) the delay in control signal processing mechanisms.

The article makes a significant contribution to the development of promising engineering methods for designing new and modernizing of the existing digital control systems for the electric drives of mechatronic devices of flying search robots.

The article includes six sections. The first is an introduction. The second is devoted to the analysis of the current situation in unmanned aviation (FSR), which relates to the digital control of electric drives of mechatronic devices. In the same section, the research problem is stated. And the third section outlines the methodology and example of algorithmic modernization of digital electric drives of mechatronic FSR devices. The fourth section discusses the results of the computer experiment. The fifth is devoted to conclusions, and the sixth to prospects for further research.

2 Literature Review and Problem Statement

Currently, digital control of electric drives of mechatronic devices for unmanned aircraft (including FSR) is carried out, at best, by digital proportional-integral-derivative controllers (PID controllers) [11–17]. These digital PID controllers are parametrically adjusted on mathematical models during periodic maintenance or at the request (complaints) of the operator who controls the actions of FSR or based on the results of analysis of objective control records [18–20]. Algorithmic correction of the dynamic characteristics of the electric drive is not performed. To measure the angular velocity of rotation of the rotor or the angle of rotation of the rotor of an electric drive, special mechanical sensors (primary information sensors) are used, which do not have a sufficiently high reliability and, at the same time, increase the mass of the electric drive. Thus, the urgent task is to develop a methodology for algorithmic modernization of the digital electric drive of mechatronic FSR devices.

Problem Statement: As an example, let us consider the control of the angular orientation of the axis of rotation of one of the main rotors of a helicopter-type FSR [21–25].

The task is to: reduce the time of the transient response in the main rotor orientation control channel; improve quasi-invariance indicators with respect to external disturbances (reduce the amplitude of the burst in the rotor orientation angle caused by external disturbances and the duration of this burst); minimize additional energy costs which are caused by algorithmic correction of the dynamic characteristics of the electric

drive for rotor orientation; improve the performance characteristics of the electric rotor drive (by replacing mechanical meters of the turn rate and the angle of rotation of the rotor orientation axis with an algorithmic one).

3 Engineering Methodology for Algorithmic Modernization of a Digital Electric Drive

3.1 Stages of the Method

1. Use as a prototype a digital parametrically optimized controller of the type – digital proportional-integral-derivative controller (DPID controller). Build a computer mathematical model of a digital automatic control system for an electric drive (DACS - prototype) based on the DPID controller.
2. Perform parametric optimization of the DPID controller from the DACS prototype.
3. Synthesize the Lewinberger observer and connect it to the DPID - controller from the DACS - prototype. DACS - the prototype with a connected Lewinberger observer will be designated DACS0.
4. Using an internal correction circuit, adjust the dynamic characteristics of the electric drive based on the usage of the most common engineering methods: state regulation with the desired (given) characteristic equation (first method); modal regulation of state (second method); linear quadratic control (third method). To make a computer mathematical models of a digital automatic control system of the electric drive with a DPID controller and a controller of the internal correction circuit in accordance with the applied correction method. DACS numbering: DACS1; DACS2; DACS3 – corresponds to the method number.
5. Perform parametric optimization of DPID controller 1, 2, 3 from DACS1, 2, 3 respectively, and connect the Lewinberger observer to controllers from DACS1, 2, 3.
6. Based on a computational experiment, compare the qualitative and quantitative characteristics of the functioning of DACS0 and DACS1, 2, 3 with a connected Lewinberger observer.
7. General conclusion.

3.2 Performing Stages of the Method

Stage 1. As a DACS prototype, we choose a system that consists of a direct current motor (DC motor) and a DPID controller. The DC motor is an element of the electric drive of a mechatronic device, which can be used to control the position of the axis of rotation of the main rotor of the FSR. This type of DACS prototype is most often used in FSR [17–20] and, in addition, the DACS with a DPID controller has the property of first-order astatism (i.e., it is quasi-adaptive to step-like disturbances [26–29]).

As a mathematical model of a continuous control object, which is a DC motor, a continuous MIMO LTI (multidimensional stationary) mathematical model is considered. Quantitative values of the parameters of the continuous mathematical model of DC motor are shown in Fig. 1 (see block 5). The input signals of block 5 are: the voltage supplied to the DC motor armature (control via the armature circuit), which is supplied from the output of the DPID controller (block 3.1), and the braking torque, which is supplied from

block 2. The output signals of block 5 are: armature current $i(t)$ and the angular velocity of rotation of the armature (rotor) of the DC motor $w(t)$ or its angle of rotation $s(t)$. To measure $w(t)$ and $s(t)$ in the DACS prototype, mechanical primary information sensors are used, respectively, a digital tachogenerator (block 4.1, $w(n)$ is the digital value of the angular velocity of the DC motor rotor) and a digital rotation angle sensor (block 4.2, $s(n)$ - digital value of the DC motor rotor rotation angle). The prototype DACS is a dual-circuit system, in which the DPID controller is included in the internal circuit.

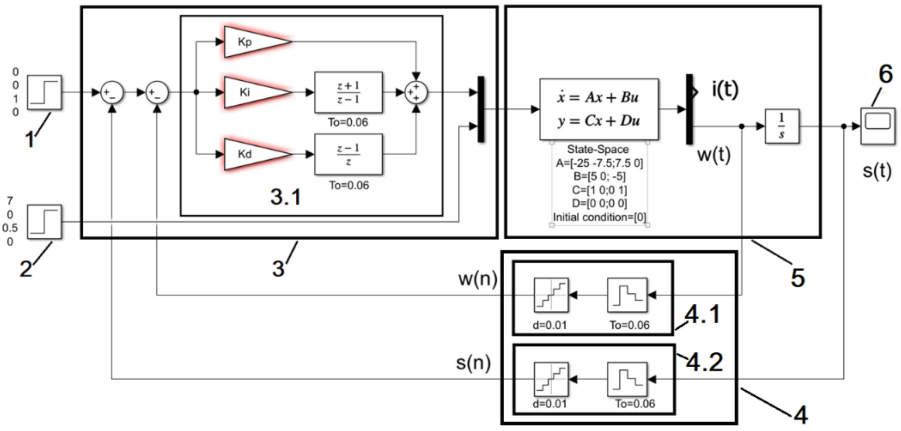

Fig. 1. Computer mathematical model of the DACS prototype, which shows the corresponding simulation blocks: 1- control signal; 2 - braking effect; 3 - digital control algorithm (3.1 - DPID controller algorithm); 4 - digital primary information sensors (4.1 – digital tachogenerator; 4.2 – digital rotation angle meter); 5 – DC motor; 6 – oscilloscope.

For calculations at subsequent stages of the method, a discrete MIMO LTI mathematical model of the DC motor will be needed. We use the continuous MIMO LTI mathematical model of the DC motor as the initial data. We apply the method of transition from a continuous MIMO LTI mathematical model of a DC motor to a discrete one [27, 28] and find the values of the parameters of a discrete MIMO LTI mathematical model of a DC motor (we assume that the sampling period is $T_o = 0.06$ s [27, 28]):

$$x(n+1) = A \cdot x(n) + B \cdot u(n); \tag{1}$$

$$y(n) = C \cdot x(n) + D \cdot u(n), \tag{2}$$

where A = [0.1841 −0.2256; 0.2256 0.9359], B = [0.1504 0.04274; 0.04274 −0.2928], C = [1 0; 0 1], D = [0 0; 0 0], t = nTo, n – discrete time.

Stage 2. As an optimality criterion, we select the duration of the transient response and perform parametric optimization of the DPID controller from the DACS prototype (Fig. 1, we observe the transient response and determine its duration using oscilloscope 6). Thus, we obtain quantitative values of the criterion using a computer mathematical model (Fig. 1), which we use as an algorithm for calculating the values of the criterion

(an algorithmically specified criterion). The first approximation of the values of the optimized parameters Kp, Ki, Kd is found by the Ziegler-Nichols method [27, 28] and then, using the Hooke-Jeeves method [26], we calculate the quasi-optimal values of these parameters: Kp = 1, Ki = 0.08, Kd = 1.47. The resulting (quasi-optimal) transient response and the reaction of the DACS prototype to a stepwise disturbance (see Fig. 2), applied at the 7th second, confirms the fact known from theory that the DACS prototype has first-order astatism and has the property of quasi-invariance [27, 28].

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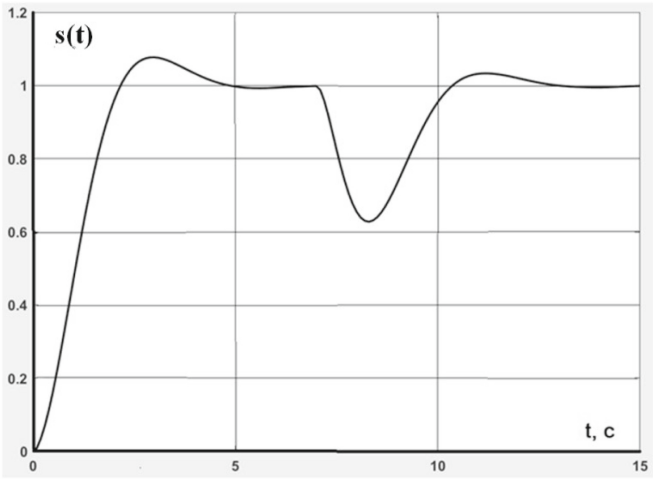

Fig. 2. Transient response of the DACS prototype according to the angle of rotation of the rotor and its response to a step disturbance: angle of rotation of the rotor is measured in relative units.

Figure 2 shows that at time t = 0c a step control action is applied to the first control input using block 1 (Fig. 1), and at time t = 7c a step disturbance is applied to the second control input using block 2 (Fig. 1). Under the influence of a disturbance, angle of rotation of the rotor decreases significantly, but then returns to the value that was set by block 1. This means that the prototype DACS has a positive property, which is called "quasinvariance". However, the disadvantage of the DACS prototype is that the transient process has overshoot, and the response to an external stepwise disturbance has a significant burst amplitude. Let us set a goal to reduce overshoot and burst amplitude using algorithmic correction of the dynamic characteristics of the DC motor.

Let us pay attention to the fact that the sequence in time and the magnitude of the control and disturbing influences remain unchanged when modeling using all computer mathematical models presented in the article (see Fig. 3, 4, 5). All signals in these figures are presented in dimensionless form.

Stage 3. The term Lewinberger observer refers to a special algorithm for processing the vector of the output signal of the control object (in this case DC motor) (see stage 1, expression (2)), which allows us to obtain estimation of the state vector of the control object in the form [27, 28]:

$$\hat{x}(n+1) = A \cdot \hat{x}(n) + B \cdot u(n) + H \cdot (\hat{y}(n) - y(n)).$$

According to Lewinberger's observer theory, search for the elements values of matrix can be performed using the characteristic equation

$$\det\left(z \cdot I - \left(A^T + C^T \cdot H^T\right)\right) = 0.$$

We set the desired values of the roots of the characteristic equation z_1, z_2 and solve the equation

$$\det\left(z \cdot I - \left(A^T + C^T \cdot H^T\right)\right) = z^2 - (z_1 + z_2) \cdot z + z_1 \cdot z_2.$$

with respect to the unknown elements of the matrix H.

Let's build a Lewinberger observer for a DC motor, provided that the armature current of the DC motor is measured using a special digital ammeter, i.e.

C = [1 0]. Assuming that $z_1 = z_2 = 0.5$ and using the discrete mathematical model of DC motor (see stage 1) we find that H = [0.1200; −0.6166].

DACS0 denotes DACS - a prototype with a connected Lewinberger observer (see Fig. 3).

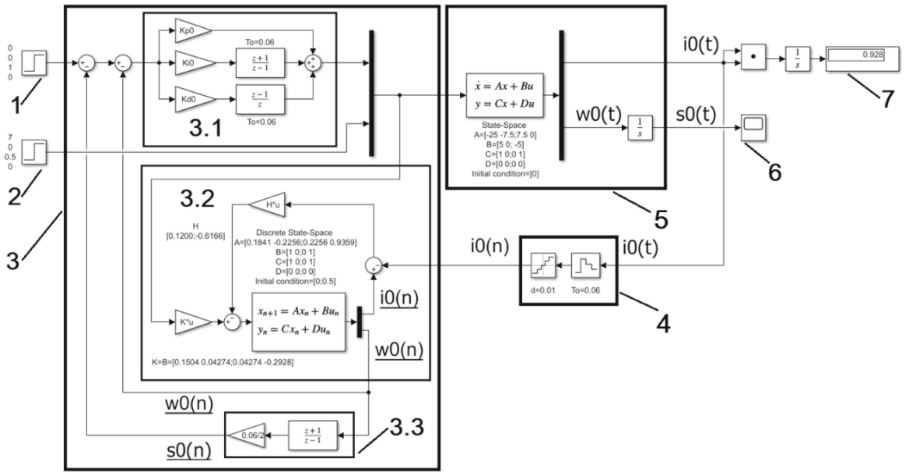

Fig. 3. Computer mathematical model of DACS0.

In Fig. 3 are indicated by the numbers 1, 2, 3, 3.1, 5, 6 - the same blocks as in Fig. 1. Blocks 3.2 and 3.3 are computer mathematical models, respectively, of Lewinberger's

observer and an integrator, which integrates the output signal of Lewinberger's observer according to the angular velocity of the DC motor rotor using the trapezoidal method, block 4 is a mathematical model of a digital ammeter that measures current in the armature circuit of the DC motor (this ammeter together with Lewinberger's observer and block 3.3 make it possible to abandon the use of two unreliable, relatively heavy mechanical sensors in the DACS DC motor (4.1 and 4.2 see Fig. 1)).

Please note that in this and subsequent figures, the numbers 0, 1, 2, 3 are used for designation of variables, indicating that this variable refers to the computer mathematical model of the DACSJ (J = 0, 1, 2, 3). In Fig. 3, 4, 5 the following designations are used: $iJ(t)$, $wJ(t)$ and $sJ(t)$ - current, angular velocity and angle of rotation of the DC motor armature at the output of the continuous computer mathematical model of the DC motor (block 5); $iJ(n)$, $wJ(n)$ and $sJ(n)$ - the values of the current and angular velocity of the DC motor armature calculated by the Lewinberger observer (block 3.2) and the rotation angle of the DC motor armature (rotor) calculated by the integrator (block 3.3); $iJ(n)$ – the value of the DC motor armature current at the output of the digital ammeter. Display 7 is designed to indicate the value $Q = \int_0^{15} iJ(t)^2 dt$, , which is proportional to the amount of energy released in 15 s (simulation time) at the active resistance of the DC motor armature (energy loss).

Stage 4. Let us correct the dynamic characteristics of the DC motor by creating another internal circuit inside the internal circuit of the DACS prototype. This will be an internal parallel correction circuit in the form of negative feedback with a matrix feedback coefficient, which can be calculated using one of the currently most used engineering methods.

DACS, corrected by the method of state regulation with the desired (given) characteristic equation, will be designated as DACS1. As a result of solving the correction problem, the characteristic equation of the mathematical model of the internal circuit of the DACS1 (see Fig. 4) should have the specified form.

The solution to the problem is as follows. We present the discrete mathematical model of the DC motor (1), (2) in the form

$$\begin{bmatrix} x_1(n+1) \\ x_2(n+1) \end{bmatrix} = \begin{bmatrix} a_{11}\ a_{12} \\ a_{21}\ a_{22} \end{bmatrix} \begin{bmatrix} x_1(n) \\ x_2(n) \end{bmatrix} + \begin{bmatrix} b_{11} \\ b_{21} \end{bmatrix} U(n) + \begin{bmatrix} b_{12} \\ b_{22} \end{bmatrix} m(n);$$

$$\begin{bmatrix} y_1(n) \\ y_2(n) \end{bmatrix} = \begin{bmatrix} 1\ 0 \\ 0\ 1 \end{bmatrix} \begin{bmatrix} x_1(n) \\ x_2(n) \end{bmatrix} + \begin{bmatrix} 0\ 0 \\ 0\ 0 \end{bmatrix} \begin{bmatrix} U(n) \\ m(n) \end{bmatrix},$$

where $U(n) = U_R(n) + U_G(n)$ is the control signal, which consists of a regulation signal $U_R(n)$ and a correction signal $U_G(n)$. Let's assume that

$$U_G(n) = K1 \cdot \begin{bmatrix} x_1(n) \\ x_2(n) \end{bmatrix} = [K_{11}\ K_{12}] \cdot \begin{bmatrix} x_1(n) \\ x_2(n) \end{bmatrix};$$

$U_R(n) = 1(n)$ –step action.

Based on a special calculation of the corrective feedback parameters K11 and K12, it is possible to achieve a reduction in the transition response time, the amount of overshoot and improve the response of the DACS to step disturbances. Using the method described in [19, 27], we obtain K1 = [0.1915 2.1337].

DACS, corrected by the method of modal state regulation, will be denoted as DACS2 (see block 4.4, Fig. 5, when J = 2 modal regulation is modeled). As a result of solving the correction problem, roots of the characteristic equation of the mathematical model of the internal circuit of the DACS2 should have the specified values.

Using the technique described in [19, 27], we obtain.

K2 = [−1.8068 −1.0343; −1.0344 −1.6399].

DACS corrected by the method of linear quadratic state regulation will be designated as DACS3 (see block 4.4, Fig. 5, when J = 3 linear quadratic regulation is modeled). As a result of solving the correction problem, the quadratic control quality criterion

$$J = x^T(N) \cdot Q \cdot x(N) + \sum_{n=0}^{N-1} \left(x^T(n) \cdot Q \cdot x(n) + u^T(n) \cdot R \cdot u(n) \right)$$

reaches its minimum value when moving system (1), (2) from the initial state $x(0)$ to the final state $x(N)$, where the matrices are symmetrical and, respectively, positive semidefinite and positive definite.

Using the mathematical model (1), (2) and assuming that Q = [1 0; 0 1], R = [0.7 0; 0 0.3], we calculate a quasi-optimal regulator with a constant matrix gain K3 [19, 27, 28]:

$$u(n) = -K3 \cdot x(n), \; K3 = \left(R + B^T \cdot P_0 \cdot B \right)^{-1} \cdot B^T \cdot P_0 \cdot A;$$

$$P_0 = Q + A^T \cdot P_0 \cdot \left(I - B \cdot \left(B^T \cdot P_0 \cdot B + R \right)^{-1} \cdot B^T \cdot P_0 \right) \cdot A.$$

As a result of the calculation, we get.

K3 = [0.0731 0.0623; −0.2964 −1.1854].

Stage 5. To configure parameters of the DPID controllers, we used tuning techniques that were outlined during step 2.

As a result, the following values of the DPID controllers parameters (DPID 1, 2, 3) were obtained for each of the options for correcting the dynamic characteristics of the DC motor, i.e., respectively for DACS1, 2, 3 (see stage 4).

Parameters of DPID1 from DACS1: Kp1 = 5; Ki1 = 0.8; Kd1 = 2.47.

Parameters of DPID2 from DACS2: Kp2 = 18; Ki2 = 5.5; Kd2 = 2.25.

Parameters of DPID3 from DACS3: Kp43 = 18; Ki43 = 5; Kd43 = 5.62.

Let's connect Lewinberger's observer to the computer mathematical models DACS1, 2, 3 (Fig. 4, 5). On the indicated computer mathematical models, the same blocks as in Fig. 3 are indicated by numbers 1, 2, 3, 3.1, 3.2, 3.3, 4, 5, 6 and 7. Block 3.4 models the operation of internal circuit regulators that correct the dynamic characteristics of the DC motor. Note that the computer mathematical model presented in Fig. 5 allows for J = 2 to simulate the operation of DACS2, and for J = 3 - DACS3.

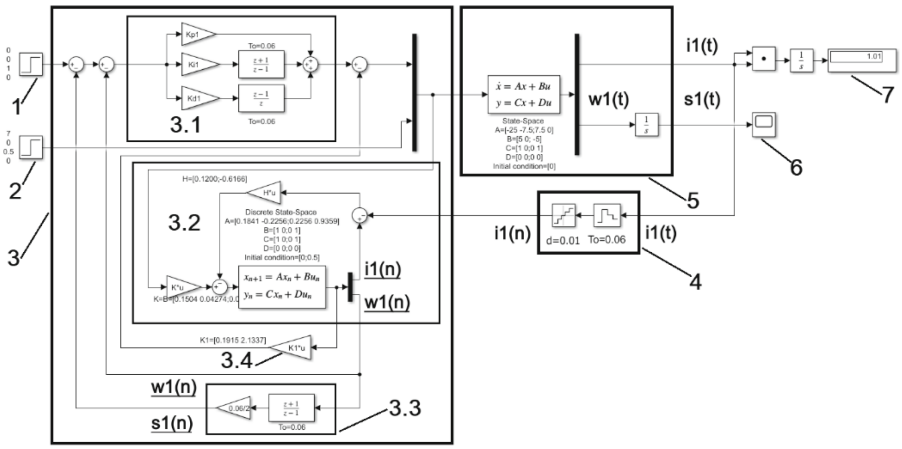

Fig. 4. Computer mathematical model of DACS1.

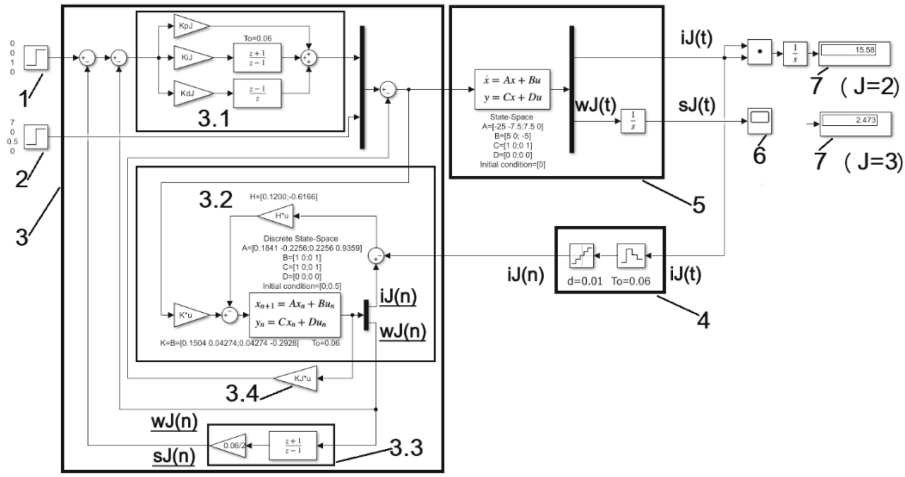

Fig. 5. Computer mathematical model of DACSJ (J = 1,2).

4 Results and Discussions (Corresponds to Stage 6 of the Methodology)

Comparison of the qualitative nature and quantitative indicators of the quality of the transient response in all DACSJ (J = 0, 1, 2, 3) will be carried out using the graphs presented in Fig. 6.

In all DACSJ (J = 1, 2, 3) the transient response ends approximately at 4 s; in DACS0 it lasts approximately 6 s.

All DACSJ (J = 1, 2, 3) are aperiodic, and in the transient response of DACS0 there is a significant overshoot.

DACSJ (J = 0, 1, 2, 3) are quasi-invariant to external step disturbance. However, the amplitude of the surge in the rotation angle of the DC motor rotor, caused by the stepwise disturbance that was applied at the 7th second, is 8 times less in DACS1, and approximately 10 times less in DACS2, 3 compared to DACS0.

Values $QJ = \int_0^{15} iJ(t)^2 dt$ (J = 0, 1, 2, 3) are proportional to the energy costs of the control system DACSJ (J = 0, 1, 2, 3) for the implementation of the corresponding transient responses sJ(t) (J = 0, 1, 2, 3), presented on oscilloscope 7 (Fig. 3, 4, 5): $Q0 = 0.928$ (see Fig. 3, block 7); $Q1 = 1.01$ (see Fig. 4, block 7); $Q2 = 15.58$ (see Fig. 5, block 7, J = 2); $Q3 = 2.473$ (see Fig. 5, block 7, J = 3).

Based on the physical meaning of the processes that are presented in Fig. 6, it is clear that increasing the intensity of the control object's transition from one state to another and reducing the amplitude of the DC motor response to an external stepwise disturbance can only be achieved through additional energy expenditure. A comparative analysis of the values $QJ(J = 0, 1, 2, 3)$ for the studied options for algorithmic correction of the dynamic characteristics of the DC motor confirms this fact. For this reason, it is proposed that, of all the options for the DACSJ (J = 0, 1, 2, 3), the best one is considered to be the one for which the additional energy costs will be the least. This is DACS1.

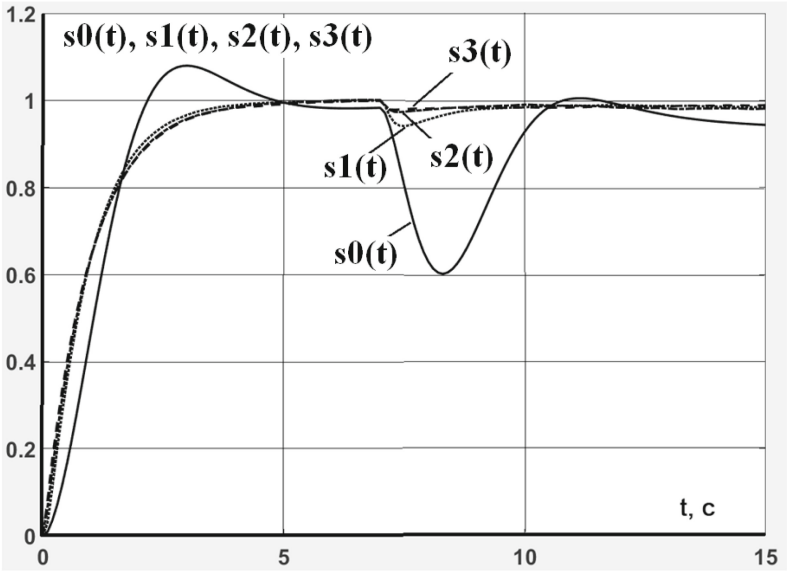

Fig. 6. Graphs of transient responses and reactions to stepwise disturbance according to the angle of rotation of the DC motor rotor (armature) sJ(t) (J = 0, 1, 2, 3) respectively in the DACSJ (J = 0, 1, 2, 3).

5 Conclusion (Corresponds to Stage 7 of the Methodology)

Algorithmic measurement (using a Lewinberger observer and an integrator) of the angular velocity and rotation angle of the DC motor rotor included in the mechatronic electric drive system of the orientation and stabilization systems in a given position of the main rotors of a flying search robot or the sensitivity axes of directional sensors (search sensors) of the same robot, allows you to reduce the weight and dimensions of the digital automatic control system of the electric drive and increase its reliability. The improvement is explained by the refusal to use a mechanical tachogenerator and angle meter in the feedback circuit of the DACS of the electric drive. To measure current in the DC motor armature circuit, it is proposed to use a small-sized digital sensor (ammeter), which has much lighter weight and dimensions compared to a tachogenerator and higher reliability. A digital ammeter supplies information to the input of Lewinberger's observer, for the operation of which a fairly "rough" MIMO LTI mathematical model of the DC motor must be known.

Connecting the Lewinberger observer to the algorithms of the PID controller and correction of the dynamic characteristics of the DC motor in all considered DACS does not affect the quality of the transient response and the response to step disturbance. The duration of the transient response according to the angle of rotation of the DC motor rotor in the DACS with the corrected dynamic characteristics of the DC motor remains equal to approximately 4 s. (improvement compared to the prototype is approximately 30%). The amplitude of the surge in the angular velocity of the DC motor rotor under the influence of a step disturbance of 0.5 relative units is approximately 0.05 relative unit (the amplitude of the surge in comparison with the prototype decreases by approximately 10 times).

Compared to the prototype DACS, any version of the DACS with adjusted dynamic characteristics of the DC motor allows overshoot to be completely eliminated. But at the same time, energy consumption increases. The most energetically efficient option is the correction of the dynamic characteristics of the DC motor by the method of regulating the state with the desired (specified) characteristic equation (energy consumption compared to the DACS prototype increases by less than 10%).

Using recommendations proposed in the article will allow us to achieve our goals: improve the dynamic characteristics of the electric drive of a mechatronic device with a slight increase in energy costs; increase reliability and reduce weight and size indicators of the electric drive.

6 Future Scope

Considering the fact that flying search robots, in most cases, operate in a complex interference environment, it is planned in subsequent studies to develop an engineering technique for synthesizing control algorithms for digital electric drives of mechatronic devices of flying search robots in such a way, that it would be possible to apply this technique in problems with stochastic models. In this case, it is intended to consider the use of optimal observers.

It is expected to consider an engineering methodology for the synthesis of self-organizing and (or) self-tuning digital automatic control systems with prompt identification of the parameters of the mathematical model of the electric drive.

It is intended to consider the influence on the electric drive of irremovable nonlinearities such as hysteresis, dead zone, and saturation.

To select the best option, it is proposed to use methods of multicriteria comparison of options.

References

1. Lundstrom, D.: Aircraft design automation and subscale testing - with special reference to micro air vehicles. Linköping Studies in Science and Technology, Dissertations No. 1480 (2012)
2. Shvorov, S.A.: Mathematical vehicle of organization of mobile robots' movement with recognition of obstacles. Sci. Technol. Air Force Ukraine **3**, 185–188 (2012)
3. Lin, L., Wu, P., He, B., Chen, Y., Zheng, J., Peng, X.: The sliding mode control approach design for nonholonomic mobile robots based on non-negative piecewise predefined-time control law. IET Control Theory Appl. **15**(9), 1286–1296 (2021)
4. Gudmundsson, S.: General Aviation Aircraft Design: Applied Methods and Procedures. Butterworth-Heinemann (2021)
5. Lundstrom, D., Amadori, K., Krus, P.: Distributed framework for micro aerial vehicle design automation. In: 46th AIAA/IEEE Aerospace Sciences Meeting and Exhibit, pp. 1–10. Reno, Nevada (2008)
6. Dantsker, O., Imtiaz, S., Caccamo, M.: Electric propulsion system optimization for long-endurance and solar-powered unmanned aircraft. In: AIAA Electric Aircraft Technologies Symposium, Indianapolis, IN, USA, pp. 1–11 (2019)
7. Mykhaylov, E.P., Skrynnyk, A.I.: Study of the means of local navigation of mobile robots. Lifting Transp. Equip. **3**, 55–61 (2017)
8. Streltsov, O.V., Saftiuk, M.P.: Investigation of methods for interactions of a group of mobile robots under limited communication range conditions. Sci. Comput. Technol. **266**(254), 76–80 (2015)
9. Dantsker, O., Theile, M., Caccamo, M.: A high-fidelity, low-order propulsion power model for fixed-wing electric unmanned aircraft. In: AIAA/IEEE Electric Aircraft Technologies Symposium, Cincinnati, OH, USA, pp. 1–16 (2018)
10. Sforza, P.: Commercial Airplane Design Principles. Elsevier Science & Technology Books. Elsevier, Oxford (2014)
11. Lysenko, O., Chumachenko, S., Valuiskyi, S., Yavisya, V., Novikov, V., Sushyn, I.: Expert-modeling system decision support for the deployment and management of a wireless sensor network with mobile sensors and telecommunication air platforms in the emergency zone. In: Methodological Aspects of Ensuring State Security in the Mind Hybrid Threats: Monograph, pp. 255–270. Košice Vysoka škola bezpečnosneho manažerstva v Košiciach, Slovakia (2023)
12. Sforza, P.: Manned Spacecraft Design Principles. Elsevier Science & Technology Books. Elsevier, Oxford (2015)
13. Alsadik, B., Karam, S.: The simultaneous localization and mapping (SLAM)-an overview. J. Appl. Sci. Technol. Trends **2**(4), 120–131 (2021)
14. Sebo, S., Stoll, B., Scassellati, B., Jung, M.: Robots in groups and teams. Proc. ACM Hum.-Comput. Interact. **4**, 1–36 (2020)
15. Streltsov, O.V., Danilenko, A.O.: Methods for distance determination to an obstacle during the motion of a mobile robot. Works Odessa Polytech. Univ. **2**(41), 238–241 (2013)

16. Aliofkhazraei, M., Makhlouf, A.S.H.: Handbook of Materials Failure Analysis with Case Studies from the Aerospace and Automotive Industries. Elsevier Science & Technology Books. Elsevier, Oxford (2015)
17. Lundström, D., Amadori, K., Krus, P.: Automation of design and prototyping of micro aerial vehicle. In: 47th AIAA Aerospace Sciences Meeting, pp. 1–16. American Institute of Aeronautics and Astronautics, Florida, USA (2009)
18. Lysenko, O., Tachynina, O., Guida, O., Furtat, O., Furtat, S., Sushyn, I.: Engineering methodology of express synthesis of digital automatic control system for precision mechatronic devices of mobile sensor networks. In: Proceedings of Vernadsky National University of Crimea. Technical Sciences Series, 33(72), vol. 5, pp. 11–19. Helvetika Publishing, Odessa, Ukraine (2022)
19. Lysenko, O., Tachinina, O., Alekseeva, I., Guida, O., Novikov, V., Sushyn, I.: Methodology of energy-efficient algorithmic modernization of dynamic characteristics of digital electric drives of mechatronic devices for small civil aviation. In: Ostroumov, I., Zaliskyi, M. (eds) ACASD 2023. LNNS, vol. 736, pp. 15–30. Springer, Singapore (2023). https://doi.org/10.1007/978-3-031-38082-2_12
20. Lysenko, O., Tachinina, O., Alekseeva, I., Novikov, V.: Mathematical modeling of motion of iron bird target node of security data management system sensors. In: CEUR Workshop Proceedings, vol. 2711, pp. 482–491, (2020). https://ceur-ws.org/Vol-2711/paper37.pdf. Accessed 23 Nov 2023
21. Moir, I., Seabridge, A.: Design and Development of Aircraft Systems. John Wiley & Sons, Ltd., Chichester, UK (2012)
22. Hassanalian, M., Abdelkefi, A.: Classifications, applications, and design challenges of drones: a review. Prog. Aerosp. Sci. **91**, pp. 99–131 (2017)
23. Sforza, P.: Theory of Aerospace Propulsion. Elsevier Science & Technology Books, Oxford (2011)
24. Papageorgiou, A., Tarkian, M., Amadori, K., Olvander, J.: Multidisciplinary design optimization of aerial vehicles: a review of recent advancements. Int. J. Aerosp. Eng. **2018**, 1–21 (2018)
25. Rajendran, S., Pagel, E.: Recommendations for emerging air taxi network operations based on online review analysis of helicopter services. Heliyon **6**(12), e05581 (2020)
26. Lysenko, O.: Mathematical programming and operations research in telecommunications, 14 Lectures. Handong Unitwin Fellowship, Korea (2017)
27. Digital automatic control systems for information communications engineers, 14 Lectures. Handong Unitwin Fellowship, Korea (2020)
28. Okoro, O., Zaliskyi, M., Dmytriiev, S., Solomentsev, O., Sribna, O.: Optimization of maintenance task interval of aircraft systems. Int. J. Comput. Netw. Inf. Secur. **14**(2), 77–89 (2022)
29. Solomentsev, O., Zaliskyi, M., Asanov, M., Melkumyan, V.: UAV operation system designing. In: 3rd International Conference on Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD), pp. 95–98. IEEE, Kyiv, Ukraine (2015)

Automated Penetration Testing in 5G Networks

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Abstract. The evolution of wireless communication has seen successive generations of technology, each introducing significant advancements in connectivity, speed, and capability. Despite numerous advantages, modern cellular networks are susceptible to a myriad of potential security vulnerabilities. The landscape of cyber threats continually evolves, with new examples of cyberattacks emerging regularly. In light of these challenges, it is imperative to consistently update the cybersecurity systems of cellular networks. This paper proposes innovative architectural and software solutions for automating the testing of security systems in 5G cellular networks. To achieve this objective, several scientific problems were addressed, including the analysis of the existing architecture of security systems in 5G cellular networks, identification of the primary vulnerabilities in these systems, development of an architecture for an automated penetration testing system in 5G networks, selection of necessary software and hardware solutions for penetration testing, and the creation of pseudo-code to ensure system performance. However, it remains crucial to accurately define parameters presented in the paper, such as the number of base stations connected to the server and the scan period. It is noteworthy that efficiency issues persist in the proposed approach, and we acknowledge the need to address them in the future. Additionally, there is a consideration of leveraging artificial intelligence to automate the penetration testing process.

Keywords: mobile networks · penetration testing · cybersecurity · 5G · fake base station

1 Introduction

The progression of wireless communication has been characterized by successive generations of technology, each contributing to notable advancements in connectivity, speed, and capability [1]. As we stand on the precipice of a new era in telecommunications, the fifth-generation (5G) wireless technology emerges as a transformative force poised to redefine the way we connect and communicate in the digital age.

Building upon the foundation laid by its predecessors, 5G represents a monumental leap forward in wireless networking, promising to unlock unprecedented possibilities

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for industries, individuals, and societies worldwide. At its core, 5G is characterized by its ability to deliver enhanced data rates, ultra-low latency, support for massive device connectivity, and network slicing—a novel approach to network virtualization. These foundational features lay the groundwork for a myriad of applications and services that were once the stuff of science fiction but are now rapidly becoming reality [2].

The deployment of fifth-generation (5G) wireless networks brings with it a host of transformative benefits, from unparalleled data speeds to ultra-low latency. However, these advancements also usher in a new era of security challenges and considerations. As 5G networks underpin critical infrastructure, support mission-critical applications, and interconnect vast numbers of devices, robust security mechanisms are paramount to protect against a range of threats.

The security of 5G networks is a complex and multifaceted challenge that requires proactive measures and continuous adaptation. As 5G becomes the backbone of modern communication and critical infrastructure, addressing these security concerns is not only imperative for the protection of users and data but also for maintaining the trust and reliability of the network itself. This paper analyzes the security problems of 5G and offers the new protection methodology. The authors of the paper offer the automate penetration testing system for 5G system, which will analyze and conduct the penetration testing of the system in real time.

2 Literature Review

Because of its significant role and the incorporation of new architectures and designs, 5G encounters numerous security threats, necessitating appropriate security technologies to address them. There are a lot of research papers are dedicated to the development of novel solutions in the sphere of cybersecurity for 5G. For, example, the novel threat models for 5G are deeply analyzed in [3]. Security systems for 5G and beyond were analyzed in several research papers and technical reports [4, 5, 6, 7]. A conceptual architecture of AI-driven zero-touch operations, security and trust in multi-operator 5G networks was proposed and analyzed in [8]. [9] proposes an automated attack and defense framework toward 5G security with the aim of providing exploratory guidance for 5G security research. [10] analyses the 5G Core from the security point of view, checking for any kind of vulnerabilities and weaknesses that can be exploited by baleful users. But it does not present the full description of penetration testing mechanisms that can be applied for 5G. The user requirements of a cyber range for 5G security testing and training are considered in [11]. SDS (Software Defined Security) as a means to provide an automated, flexible and scalable network defense system is described in [12]. Also promising is the application of artificial intelligence to meet the cybersecurity needs of 5G cellular networks. Testing of Deep Learning Based IDS System for 5G Network was presented in [13]. In [14] authors proposed the idea and functionality of 5G cybersecurity function. But these mentioned above papers do not present any methods and technologies for the automate penetration testing system for 5G system. Currently, this become a real necessity.

3 Problem Statement

As it follows from the analysis of literary sources and other research projects, there are not many works related to the development of new methods of automated penetration testing in 5G networks. Therefore, it is obviously necessary to develop effective mechanisms for constant monitoring of the state of security systems of new generation cellular networks, detection of inconsistencies, security violations. Therefore, the purpose of this work is to develop architectural and software solutions for automated testing of security systems of 5G cellular networks. To achieve the set goal, it was necessary to solve the following scientific problems:

1. To analyze the existing architecture of security systems of 5G cellular networks.
2. Identification of the greatest vulnerabilities of security systems of cellular networks.
3. Development of the architecture of the automated penetration testing system in 5G networks.
4. Selection of necessary software and hardware solutions for penetration testing.
5. Development of pseudo-code to ensure system performance.

4 Security Problems of 5G Networks

The emergence of fifth-generation (5G) wireless technology, with its promise of revolutionary speed, lower latency, and seamless connectivity, is undeniably transformative. However, as we embrace this technological leap, it is crucial to recognize and address the vulnerabilities inherent in 5G networks. These vulnerabilities, if left unmitigated, have the potential to undermine the security, reliability, and privacy of the network, challenging the very foundations of this groundbreaking technology.

1. **Network Slicing Security:** One of the innovative features of 5G is network slicing, which allows the creation of multiple virtual networks on a shared physical infrastructure. While this offers flexibility and customization, it introduces security concerns. Ensuring the isolation and security of each network slice is crucial to prevent cross-slice attacks and unauthorized access. Effective access controls, segmentation, and encryption are vital components in mitigating these risks.
2. **IoT Device Vulnerabilities:** 5G's support for massive IoT connectivity increases the number of connected devices exponentially. Many of these IoT devices, ranging from sensors in smart cities to medical devices in healthcare, may have limited security measures in place. As a result, they can become vulnerable to compromise and potentially serve as entry points for attackers. Implementing strong device authentication, secure bootstrapping, and over-the-air updates is essential to address these vulnerabilities.
3. **Edge Computing Security:** Edge computing, a key component of 5G networks, involves processing data closer to the source, reducing latency and improving performance for certain applications. However, securing the distributed edge nodes and the data processed at the edge is paramount. Edge devices must be protected against physical and virtual attacks, and data integrity and confidentiality must be maintained.

4. **Supply Chain Security:** The global supply chain for 5G equipment and components is complex and spans multiple vendors and regions. This complexity introduces potential risks, including the insertion of malicious hardware or software at various stages of the supply chain. Governments and organizations are increasingly scrutinizing supply chain security to ensure the integrity of 5G infrastructure components.
5. **Privacy Concerns:** 5G networks generate vast amounts of data, including location information and user behavior. Protecting the privacy of users is a significant concern. Unauthorized access to this data, whether by malicious actors or unscrupulous service providers, can lead to privacy violations. Robust data anonymization, encryption, and access controls are essential to mitigate these risks.
6. **Network Function Virtualization (NFV) and Software-Defined Networking (SDN):** 5G networks rely heavily on NFV and SDN, which introduce new attack vectors. Attackers may exploit vulnerabilities in virtualized network functions or manipulate network configurations. Hardening the NFV and SDN infrastructure and continuously monitoring for anomalies are essential for safeguarding 5G networks.
7. **Distributed Denial of Service (DDoS) Mitigation:** As 5G networks support higher data rates and lower latency, they can be more susceptible to large-scale DDoS attacks. Effective DDoS mitigation measures, such as traffic filtering, rate limiting, and anomaly detection, are critical to ensuring network availability and performance.

As 5G network must manage a lot of users from different sectors worldwide it is obligatory to identify the security attacks vectors on 5G [15–17]. According our research we have identified the following:

5 Protocol Vulnerabilities

There are several protocol vulnerabilities. They are analysed below.

Authentication and Key Agreement (AKA): Attackers may try to exploit weaknesses in the AKA protocol to gain unauthorized access to the network.

Signaling Protocols: 5G relies on complex signaling protocols like SIP and Diameter, which can be susceptible to various attacks such as spoofing, replay, and denial of service.

Man-in-the-Middle (MitM) Attacks: Attackers may attempt to intercept communication between a user and the network by positioning themselves as intermediaries. This can lead to eavesdropping or data manipulation.

Rogue Base Stations: Attackers can set up rogue base stations to trick mobile devices into connecting to them instead of legitimate networks. This allows attackers to intercept traffic and potentially launch various attacks.

Jamming: Jamming attacks involve sending interference signals to disrupt the 5G network's operation, causing denial of service for legitimate users.

Privacy Concerns: With the increased use of IoT devices in 5G networks, there are concerns about user and device privacy. Attackers may exploit vulnerabilities to gain access to sensitive user data.

Network Slicing Vulnerabilities: Network slicing, a key feature of 5G, allows networks to be divided into multiple virtual networks. If not properly isolated, attackers could potentially move from one slice to another, compromising security.

IoT Device Vulnerabilities: Many IoT devices have limited security measures. Attackers can target these devices to gain access to the 5G network or launch attacks on other devices within the network.

Distributed Denial of Service (DDoS): 5G networks are not immune to DDoS attacks. Attackers may target critical network components, overwhelming them with traffic and causing service disruptions.

Virtualization and Cloud-Based Attacks: 5G networks often use virtualization and cloud technologies, which introduce their own security challenges. Attackers may attempt to compromise virtual network functions or cloud resources.

Device Theft and Tampering: Stealing or tampering with 5G-enabled devices can provide attackers with physical access to the device, potentially allowing them to extract sensitive information or install malicious software.

Supply Chain Attacks: Compromising the supply chain of 5G equipment or devices can lead to the inclusion of malicious components, which can be exploited by attackers.

Emerging Threats: As 5G technology continues to evolve, new and unexpected threats may emerge. Keeping up with these evolving threats is a constant challenge for security professionals.

In order to protect 5G network it is obligatory to analyze the systems in real time [18, 19]. Thus we offer the methodology of automate penetration test of 5G infrastructure.

6 Automate Penetration Testing

5G base stations, also known as gNodeBs (gNBs), typically run on specialized and customized operating systems or software platforms designed for the specific requirements of telecommunications and networking equipment. These operating systems are often real-time operating systems (RTOS) or Linux-based distributions tailored for embedded systems [20].

Let us focus on Linux based ones. We offer to catch both local vulnerabilities of the system and main in the middle attack. For the local vulnerability we offer to use some automate tool, which can scan the system every n seconds. We can schedule it using cron. Cron is a time-based job scheduler in Unix-like operating systems, including Linux. It allows you to automate the execution of tasks or scripts at specified intervals, known as cron jobs. Cron jobs are often used for repetitive and scheduled tasks, such as backups, system maintenance, and running scripts. We offer to use it to automate the vulnerability scan of 5G system.

As a vulnerability scanner we offer to use Nessus, which is one of the most widely used vulnerability scanners [21]. It offers a vast database of vulnerability checks and can scan various types of assets, including network devices, servers, and web applications. It provides detailed reports and supports compliance audits. It must be emphasized that Nessus is a widely recognized and versatile vulnerability scanning tool with the features that can make it valuable for scanning and assessing the security of 5G networks. Nessus is be beneficial for scanning 5G networks because of following:

Extensive Plugin Library: Nessus has a vast collection of plugins that cover a wide range of vulnerabilities, including those related to network devices, servers, and web applications. While 5G networks have unique characteristics, they often rely on conventional network infrastructure and services that can be assessed using Nessus's plugins.

Asset Discovery: Nessus can perform asset discovery to identify devices and systems connected to a network. This feature can help organizations gain visibility into the components of their 5G networks, including routers, switches, servers, and IoT devices.

Compliance Scanning: Organizations deploying 5G networks may have specific compliance requirements and standards to meet. Nessus supports compliance scanning, allowing users to assess whether their 5G infrastructure complies with industry-specific security standards and regulations.

Policy Customization: The Policy Editor in Nessus enables users to create and customize scanning policies to meet their specific needs. This flexibility is beneficial when tailoring scans for 5G networks with unique configurations and requirements.

Integration: Nessus can integrate with other security tools and platforms, such as SIEM systems, ticketing systems, and reporting tools. This integration streamlines the vulnerability management process and allows for better coordination of security efforts.

Reporting: Nessus generates detailed vulnerability assessment reports, which are essential for understanding the security posture of 5G networks. These reports include information about identified vulnerabilities, their severity ratings, and recommended remediation steps.

API and CLI: Nessus provides an API and a command-line interface (CLI), making it suitable for automation and scripting purposes. This can be particularly useful when conducting regular and automated scans of 5G networks.

While Nessus has several features that can be advantageous for scanning 5G networks, it's essential to consider that 5G networks have unique characteristics, including their use of software-defined networking (SDN), network slicing, and virtualization. Therefore, scanning each station with Nessus and sending reports to the server can be very useful.

In addition, it is important to identify fake station in 5G Networks. For this we offer the Python script, which checks for the fake base stations and uses Airodump-ng is a popular command-line tool used in wireless network security assessments and penetration testing. It is part of the Aircrack-ng suite of tools, which is designed for assessing and auditing the security of wireless networks. Airodump-ng specifically focuses on capturing and displaying information about wireless access points (APs) and associated client devices within the proximity of the scanning system.

7 The Offered Model

On every 5G base stations we add a command to cron scheduler to run Nessus every once a day at time n. As a second task we add to run our Python script, which identifies the fake base station.

The number n must be identified based on the region. We must identify the period when the traffic is minimal. Like this, we can get the minimal efficiency loss. We add the server for every x base stations. The base stations send the identified fake station to the server and the server shares information about the fake station among other base stations. The number x we think to be in the range from [0; 10].

The base station will communicate with server using SCP protocol. The SCP (Secure Copy Protocol) is a network protocol used for securely transferring files and directories between a local host and a remote host or between two remote hosts. SCP is a secure alternative to the older, less secure FTP (File Transfer Protocol) and TFTP (Trivial File Transfer Protocol) for file transfers over a network.

Here are some key features and aspects of the SCP protocol. Security: SCP uses SSH (Secure Shell) for data transfer, which provides strong encryption and authentication. This makes it a secure method for copying files over a network, as the data is protected from eavesdropping and tampering.

We choose SCP protocol because of the following:

Cross-Platform: SCP is supported on a wide range of operating systems, including Unix-based systems (Linux, macOS, and various flavors of Unix), as well as Windows with the help of third-party SSH clients.

Efficiency: SCP is known for its efficient use of network resources, making it suitable for transferring large files or directories. It also supports resuming interrupted transfers.

Authentication: Users typically need SSH credentials (username and password or SSH keys) to authenticate themselves when using SCP. This ensures that only authorized users can perform file transfers.

Permissions and Ownership: SCP preserves file permissions and ownership information, making it a useful tool for backup and system administration tasks.

Error Handling: SCP provides detailed error messages to help diagnose and troubleshoot transfer issues.

As it was mentioned in the previous section, the Python script uses Airodump-ng. The pseudo code of the script is offered below.

Pseudo code:

```
                    :
Initialize essidc to 0
Initialize bssidc to 0
Print "Choose your wireless interface:"
Get a list of network interfaces and their indices using socket.if_nameindex()
For each interface i in the list:
    Print the interface name (i[1])
Prompt the user to input the interface name and store it in 'int'
Prompt the user to input the SSID and store it in 'essid'

Execute the command: "timelimit -t10 airodump-ng " + int + " -w scan --output-
format csv"
Open the file "scan-01.csv" in read mode and assign it to the variable 'scan'
For each line in 'scan':
    If 'essid' is found in the line:
        Extract the BSSID from the first 17 characters of the line and assign it to 'bssid'
Close the 'scan' file
Open the file "scan-01.csv" in read mode and assign it to the variable 'scan' again
For each line in 'scan':
    If 'bssid' is found in the line:
        Increment 'bssidc' by 1
    If 'essid' is found in the line:
        Increment 'essidc' by 1
    Print the line
Print the value of 'bssid'
Print "BSSID COUNT: " followed by the value of 'bssidc'
Print "ESSID COUNT: " followed by the value of 'essidc'
If 'bssidc' or 'essidc' is greater than 1:
    Print "ALARM!"
Close the 'scan' file
Execute the command: "rm scan-01.csv" to remove the file
```

Also we offer to add the software which will analyze the report of Nessus scans on the main server. Such as Splunk or Nessus professional. It must be mentioned that the scan reports must be also analyzed by the technician periodically.

The offered model is shown on Fig. 1.

8 Efficiency Analysis

The Nessus scan still has the efficiency problems, because we offer to make it in the period the most less traffic. It is obligatory to understand the details of efficiency loss and other limitations, when using Nessus scan.

Here are some common efficiency problems associated with Nessus scans:

1. Resource Intensive: Nessus scans can be resource-intensive, both on the scanning system and the target systems being scanned. If not properly configured or if you

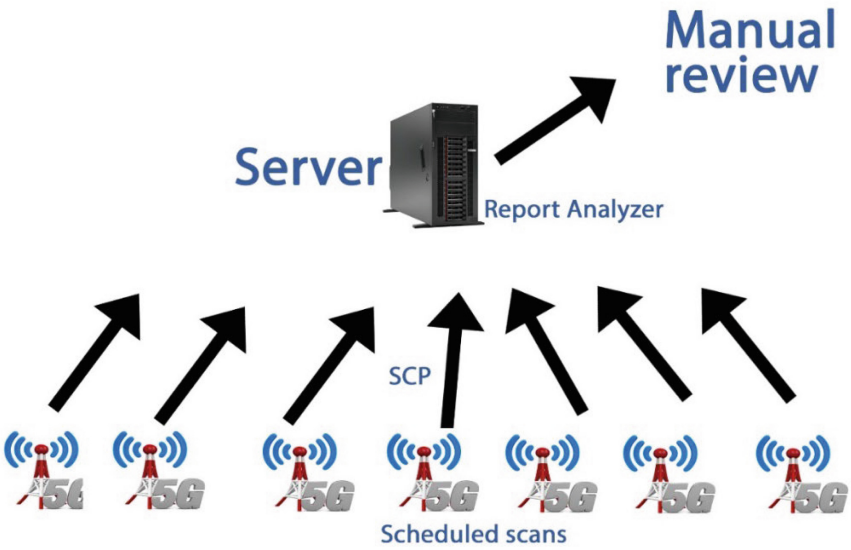

Fig. 1. Automatic Penetration test

attempt to scan too many systems simultaneously, it can lead to performance issues on the scanning host or disrupt the target systems.

2. Scan Duration: Nessus scans can take a significant amount of time, especially when scanning large networks or systems with many services. Long scan durations can disrupt regular network operations and may not be feasible in environments that require high availability.
3. Network Bandwidth: Scanning can consume a substantial amount of network bandwidth, potentially causing congestion or negatively impacting other network activities. Careful scheduling and rate limiting can help mitigate this issue.
4. Credentials and Authentication: Some scans require authentication or administrative credentials to perform in-depth scans. If credentials are not provided or configured correctly, Nessus may not be able to access certain aspects of the target system, leading to incomplete or inaccurate results.
5. Scan Policies: Inefficient scan policies can lead to issues. Overly aggressive or overly permissive policies may generate too many false positives or false negatives, which can waste time and resources.
6. Ineffective Configuration: Incorrect configuration of Nessus can result in scans that are less efficient. This includes not properly excluding certain hosts, services, or IPs, which can lead to scanning systems that shouldn't be scanned, or missing critical systems.
7. Scanning Impact: Running Nessus scans without proper authorization or not understanding the impact on the target systems can lead to disruptions, network instability, or even legal and compliance issues.

8. Lack of Prioritization: Failing to prioritize vulnerabilities based on severity can lead to inefficient resource allocation. Organizations should address critical vulnerabilities first to minimize risk.
9. False Positives: Nessus may generate false positives, which can waste time and resources investigating non-existent vulnerabilities. Careful validation and verification are necessary to reduce false positives.
10. Storage Requirements: Nessus generates and stores scan data, which can consume significant disk space. Organizations need to plan for appropriate storage capacity to retain historical scan data and reports.

To address these efficiency problems, it's essential to configure and run Nessus scans carefully, considering the specific requirements of your network and systems. Regularly update and optimize scan policies, schedule scans during off-peak hours, and monitor the performance of both the scanning system and the target systems to avoid disruptions and resource bottlenecks. Proper planning and coordination are crucial for efficient and effective vulnerability scanning using Nessus.

9 Results and Future Plans

As the result we offer the combined model of automate penetration scan. The offered model can analyze the vulnerabilities on 5G work stations it also can identify the fake base stations.

It is still very important to identify correctly the parameters offered in the paper such as number of base stations connected to the server and the period of the scan. It must be mentioned that the efficiency problems still exist in the offered approach and in the future, we think to bypass them. We also think to use AI for the automate the penetration testing process.

10 Conclusions

In recent times, cellular communication networks have become ubiquitous, integral to daily life, and indispensable for various applications such as smartphones, modern factories, smart cities, and homes. Despite the numerous advantages they offer, modern cellular networks are not without significant security vulnerabilities. The ever-evolving landscape of cyber threats continuously introduces new examples of cyberattacks. In light of these challenges, the ongoing necessity to update and enhance the cybersecurity systems of cellular networks is paramount. This paper proposes innovative architectural and software solutions for the automated testing of security systems in 5G cellular networks. To achieve this objective, the study addresses key scientific problems, including the analysis of the existing architecture of security systems in 5G cellular networks, identification of the most critical vulnerabilities in these systems, development of the architecture for an automated penetration testing system in 5G networks, selection of necessary software and hardware solutions for penetration testing, and the formulation of pseudo-code to ensure optimal system performance.

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References

1. Sharma, P.: Evolution of mobile wireless communication networks-1G to 5G as well as future prospective of next generation communication network. Int. J. Comput. Sci. Mob. Comput. **2**(8), 47–53 (2013)
2. Demestichas, P., et al.: 5G on the horizon: key challenges for the radio-access network. IEEE Veh. Technol. Mag. **8**(3), 47–53 (2013)
3. Daniele, G., Wissam, M.: Automated generation of 5G fine-grained threat models: a systematic approach. IEEE Access (2023)
4. Ahmad, I., Shahabuddin, S., Kumar, T., Okwuibe, J., Gurtov, A., Ylianttila, M.: Security for 5G and beyond. IEEE Commun. Surv. Tutorials **21**(4), 3682–3722 (2019)
5. Geller, M., Nair, P.: 5G security innovation with Cisco. In: Whitepaper Cisco Public, pp. 1–29 (2018)
6. Salahdine, F., Han, T., Zhang, N.: Security in 5G and beyond recent advances and future challenges. Secur. Priv. **6**(1), e271 (2023)
7. Cody, T., Beling, P., Freeman, L.: Towards continuous cyber testing with reinforcement learning for whole campaign emulation. In: 2022 IEEE AUTOTESTCON, pp. 1–5. IEEE, August 2022
8. Carrozzo, G., et al.: AI-driven zero-touch operations, security and trust in multi-operator 5G networks: a conceptual architecture. In: 2020 European Conference on Networks and Communications (EuCNC), pp. 254–258. IEEE, June 2020
9. Sun, Y., Tian, Z., Li, M., Zhu, C., Guizani, N.: Automated attack and defense framework toward 5G security. IEEE Netw. **34**(5), 247–253 (2020). https://doi.org/10.1109/MNET.011.1900635
10. Giambartolomei, F.: Penetration testing applied to 5G Core Network (2022)
11. Angelogianni, A., Politis, I., Polvanesi, P.L., Pastor, A., Xenakis, C.: Unveiling the user requirements of a cyber range for 5G security testing and training. In: 2021 IEEE 26th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), pp. 1–6. IEEE, October 2021
12. Lam, J., Abbas, R.: Machine learning based anomaly detection for 5G networks. arXiv preprint arXiv:2003.03474 (2020)
13. Odarchenko, R., Imanbayev, A., Pinchuk, A.: Development of the testbed for testing deep learning based IDS system for 5G network (2023)
14. Iavich, M., Gnatyuk, S., Iashvili, G., Odarchenko, R., Simonov, S.: 5G security function and its testing environment. In: Faure, E., Danchenko, O., Bondarenko, M., Tryus, Y., Bazilo, C., Zaspa, G. (eds.) ITEST 2022. LNDECT, vol. 178. pp. 656–678. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-35467-0_39
15. You, X.H., Pan, Z.W., Gao, X.Q., et al.: The 5G mobile communication: the development trends and its emerging key techniques (in Chinese). Sin Chin Inform. **44**, 551–563 (2014)
16. Huang, K.Z., Jin, L., Zhao, H.: Study on the security threat and protection technologies of 5G. Des. Tech. Post Telecommun. **6**, 8–12 (2015)
17. Dutta, A., Hammad, E.: 5G security challenges and opportunities: a system approach. In: 2020 IEEE 3rd 5G World Forum (5GWF), Bangalore, India, pp. 109–114 (2020). https://doi.org/10.1109/5GWF49715.2020.9221122
18. Park, S., Kim, D., Park, Y., Cho, H., Kim, D., Kwon, S.: 5G security threat assessment in real networks. Sensors **21**, 5524 (2021). https://doi.org/10.3390/s21165524

19. Bocu, R., Iavich, M.: Real-time intrusion detection and prevention system for 5G and beyond software-defined networks. Symmetry **15**, 110 (2023). https://doi.org/10.3390/sym15010110
20. Sanchez-Aguero, V., et al.: Deploying an NFV-based experimentation scenario for 5G solutions in underserved areas. Sensors **2021**, 21 (1897). https://doi.org/10.3390/s21051897
21. Kholidy, H.A.: Multi-layer attack graph analysis in the 5G edge network using a dynamic hexagonal fuzzy method. Sensors **22**, 9 (2022). https://doi.org/10.3390/s22010009

Smart System for Meat Quality Control

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Abstract. Consumers are increasingly questioning the quality of food products, especially meat, demanding reliable information about its freshness and safety. Traditional methods of assessing meat freshness, such as organoleptic and laboratory methods may be limited and time-consuming. This has led to the need for the development of effective and rapid methods for determining the freshness of meat. In this context, the relevance of using modern technologies, including neural networks, for meat freshness identification arises. Neural networks, which have become powerful tools in data processing and analysis, can provide precise and automated methods for determining the quality of food products. This research proposes combining a sensory network and a neural network to create a smart meat quality control system. This system integrates gas sensors and a color sensor, with the software using a neural network for analysis and decision-making. The authors have proposed the structure of the smart system, its principles of operation, features of the architecture, and the training of the neural network. The authors present the hardware and software components of the meat control and identification system. The project involves the integration of sensors, an Arduino microcontroller, and a Raspberry Pi single-board computer to implement a system capable of accurately and reliably identifying the freshness of meat.

Keywords: Control System · Neural Network · Food Safety

1 Introduction

The freshness of meat is a key parameter that determines its quality and safety for consumers, so the collection of data [1] on the quality of food products and their interpretation is crucial. Traditional methods of assessing the freshness of meat products, such as organoleptic and laboratory analyses, have their limitations, and a modern approach to this issue involves the use of smart sensors and neural networks. The proposed control system can be an effective means of addressing several issues simultaneously. On one hand, it has the potential to reduce food waste by accurately determining the freshness of meat. On the other hand, such scrutiny will help prevent artificial inflation of prices

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by sellers. Thirdly, more reliable control is likely to enhance the efficiency of combating food poisoning. The methodology of the electronic nose involves a comprehensive assessment of the sample, enabling quick and efficient monitoring of multi-parameter objects. Food products are complex objects of analysis, linked to potential variations in raw material composition and continuous physicochemical, microbiological, and biochemical transformations occurring within the sample matrix during production and storage. These dynamics create challenges for reliable identification, quality assessment, and safety evaluation. These dynamics create challenges for reliable identification, quality assessment, and safety evaluation. Despite the increasing number of studies in the field of multisensory systems, the need for integrated approaches and methodologies for the analysis of food products remains unresolved. Existing multisensory systems require optimization for reliable analysis of various groups of food products and accurate interpretation of the obtained results using the capabilities of artificial intelligence. For example current systems using electronic noses can address specific tasks related to the control of meat products, including the identification of meat types [2], discrimination of meat semi-finished products with unpleasant odors [3], determination of the shelf life of meat [4], classification of meat spoilage markers [5], assessment of microbiological spoilage of specific types of meat [6], determination of microbial contamination [7–9], classification of beef based on microbiological indicators [10], evaluation of the freshness of specific types of meat [11], and detection of certain signs of meat adulteration [12]. However, these methodologies do not allow for the simultaneous analysis of a set of standardized indicators and effective assessment of quality and safety during the monitoring of food objects. Therefore, to solve the problem of comprehensive control of meat freshness, it is necessary to develop a methodology for the analysis of data from multisensory systems, namely a hardware-software complex for computer synthesis and recognition of patterns, providing recommendations for selecting algorithms for processing multidimensional data and optimizing them for qualitative [13, 14] and quantitative analysis of food objects using neural networks.

2 Multisensory Network

2.1 Sensors of Electronic Noses and Their Characteristics

Among portable gas analyzers widely used for food product analysis, commercial devices from the PEN series (AIRSENSE Analytics GmbH, Germany) and FOODsniffer (ARS.LAB Inc., USA) based on MOS sensors, Cyranose 320 (Sensigent, USA) using CP sensors, VOC Meter with a PID photoionization detector (Research Instruments Ltd., UK), and others listed in Table 1 have gained the most popularity. Despite significant activity in this direction, sensory systems have a limited scope of application and several significant drawbacks, including device specificity (designed to detect specific groups of compounds and less effective for solving a variety of food product quality control tasks), reproducibility issues with basic characteristics of sensor arrays, system instability, the inability to conduct a substantial number of experiments in a short time, the absence of an intelligent image recognition system for automated comprehensive assessment of objects, and high cost for hybrid devices (based on chromatography and mass spectrometry) (Table 2).

Table 1. The main types of electronic noses.

The device model	System characterization	Manufacturer/country
Electronic noses based on one or several types of sensors		
PEN, i-PEN, PEN- EDU, PEN2, PEN3	6, 10 MOS sensors in an array; portable devices	AIRSENSE Analytics GmbH, Germany
FOX 2000, 3000	6, 12 та 18 MOS sensors in an array; stationary devices	Alfa MOS, France
NST 3320	10 MOSFET, 12 MOS, 1 IR (Infrared), 1 humidity sensor; stationary device	Applied Sensor, Netherlands, Sweden, USA
VOC series	4 MOS, 8 QCM sensors	
VOCcheck	QCM sensors; portable device	
SamDetect FF2, SamDetect FF2D, SamDetect GFDI	Intelligent systems with 6 MOS sensors for early detection of smoke during fires and gas leaks; portable devices	RST Rostock System-Technik GmbH, Germany
-	Arrays of 5, 6, 8, 14 MOS sensors from the TGS 815 series, 816, 821, 822, 823, 824, 825, 826, 832, 831, 842, 880, 2600, 2610, 2611, 2620	Figaro Engineering Inc., Japan
ScenTrak	MOS sensor matrix with coatings based on patented DNA materials; portable device for determining hazardous volatile compounds, mold, etc.	CogniSent Inc., USA
EOS Ambiente, EOS (835)	6 MOS sensors; automatic portable devices for continuous monitoring in open air	Sacmi, Italy
Cyranose 320	32 CP sensors with polymer coatings combined with technical carbon components; portable device	Sensigent, USA

Table 2. The main parameters of sensors in electronic nose systems.

Characteristics	Types of sensors				
	MOS	MOSFET	CP	QMB	SAW
Measurement principle	Stencil printing, radio frequency sputtering, thermal spraying, microelectronic technologies, chemical or electrochemical deposition	Microelectronic technologies, thermal spraying	Electrochemical, chemical polymerization, microprinting technology	Technology of applying microfilms by immersion, spraying, inkjet printing, static drop evaporation onto a rotating substrate (spin coating)	Photolithography, technology of applying microfilms by immersion, spraying, spin coating
Selectivity	Moderate	Moderate	Moderate	High	High
Detection limit	> 0,1 ppm	> 0,1 ppm	> 0,05 ppm	> 0,1 ppm	ppb
Operating temperature, °C	250–400	100–200	environment	20–40	environment
Response time, seconds	0,5	0,5–5,0	20,0–50,0	0,5–5,0	20,0–50,0
Recovery time	Fast	Fast	Slow	Slow	Slow
Service life, years	3–5	1–4	1–2	> 1	< 2
Advantages	High sensitivity, fast response and recovery time, low cost	Compact size, low cost, integrated and reproducible KMOH transistor	High sensitivity, wide range of coatings, low cost	High sensitivity and selectivity, diverse selection of coatings, compact size	High sensitivity and selectivity, diverse selection of coatings, integrated microchip
Disadvantages	High operating temperature, limited choice of coatings	High energy consumption, the need to control analysis conditions, drift of baseline	High sensitivity to temperature and humidity, baseline drift	Low noise characteristics, complex microchip, high sensitivity to humidity, and moderate sensitivity to temperature	Low reproducibility of readings for a batch of sensors, complex microchip, high sensitivity to temperature, and moderate sensitivity to humidity

2.2 Selection of Sensors for a Smart Quality and Freshness Control System for Meat

In solving the task of meat freshness identification, it is crucial to choose the right sensors that will provide the necessary information for the effective operation of the system [15–17]. For this project, a variety of sensors designed to measure different parameters that might affect the condition of the meat were selected (Table 3).

Table 3. Sensors for a Smart Meat Quality Control System.

Sensor Type	Sensor Purpose
MQ-135	Measures the concentration levels of various types of gases in the air. Particularly sensitive to ammonia, smoke, and other gases that may occur during meat spoilage
TGS2602AC	Ammonia concentration measurement sensor. Used to detect abnormalities in meat, as ammonia can be a product of protein breakdown
MQ-138	A sensor designed to detect various gases, including gasoline and acetone. Aids in identifying specific chemical processes that may occur in spoiled meat
MQ-137	A sensor for measuring the concentration of ammonia and gasoline. Used for additional monitoring of decomposition processes
TCS3200	Measures the intensity of light in different colors (red, green, blue). Used to analyze changes in the color of meat, which can indicate its freshness level

These sensors, in combination, provide comprehensive information about atmospheric and chemical parameters surrounding the meat, allowing the system to accurately identify its condition and freshness.

3 Meat Quality Control Using Neural Networks

3.1 Neural Networks and Their Characteristics

Neural networks prove to be an integral part of modern technologies for meat freshness identification, thanks to their unique properties and capabilities [18–20].

Learning from examples - The model learns to recognize patterns in sensory data and color parameters using training data, making it flexible and adaptive to changes in the environment.

Processing unstructured data - Neural networks analyze and consider various parameters, allowing for a comprehensive approach to identification.

Adaptability - Neural networks can adapt to changes in the environment and meat storage conditions, maintaining high accuracy in identification even under variable circumstances.

Advantages of Using Neural Networks Compared to Other Methods
A comparative analysis of using neural networks in the task of meat freshness identification indicates several advantages [21, 22]:

1. High accuracy - Neural networks demonstrate impressive accuracy in identifying the freshness level, thanks to their ability to adapt and learn from examples.
2. Generalization capability - Neural network models exhibit a high ability to generalize and adapt to different types of meat and storage conditions.
3. Processing large amounts of data - Neural networks efficiently handle large volumes of sensory data, making them effective in real-world production conditions.

The application of neural networks in the field of meat freshness identification opens up new possibilities and provides a reliable and accurate approach to determining the quality of the product.

3.2 Structure and Architecture of the Utilized Neural Network

Neural networks used for meat freshness identification are characterized by a unique architecture and structure specifically designed for efficiently solving the given task.

Network Structure

- Input layer: Receives normalized data from sensors such as MQ135, TGS2602AC, MQ138, MQ137, and data from the color sensor. The number of nodes in this layer corresponds to the number of input parameters.
- Hidden layers: Contain multiple layers, where each layer has several neurons. The architecture can be configured depending on the complexity of the task. Activation functions such as ReLU (Rectified Linear Unit) are used to account for non-linearity in the data.
- Output layer: Contains several nodes corresponding to different levels of meat freshness. Utilizes the softmax activation function to obtain probabilities of belonging to each category.

Architectural Features
The neural network architecture was selected with consideration for the specific requirements of the meat freshness identification task. It is crucial to account for the non-linearity of input data and the ability to detect subtle changes in the meat's condition indicating its freshness or spoilage. The result of such architecture is a neural network capable of efficiently utilizing information from sensors and accurately identifying the degree of meat freshness. With this structure and architectural features, the neural network can achieve high accuracy in meat condition identification, making it an effective tool for addressing food quality control challenges.

3.3 Training and Optimization of the Neural Network

Preparation of Training Data

The first step in training a neural network is the preparation of training data. We use data that contains information from sensors along with known labels indicating the state loading and preparing the data are implemented in the "train.py" file, as shown in Fig. 1.

```
from preprocessing import preprocess_input
from model import create_model
import json
import numpy as np
import tensorflow as tf

# Dummy training data
with open('training_data.json', 'r') as file:
    training_data = json.load(file)

# Preprocess the training data
def preprocess_training_data(training_data):
    processed_data = []
    labels = []

    for example in training_data:
        sensor_data = example["sensor_data"]
        processed_input = preprocess_input(sensor_data)
        processed_data.append(processed_input)

        label = example["label"]
        labels.append(label)

    return np.array(processed_data), np.array(labels)

# Preprocess the training data
X_train, y_train = preprocess_training_data(training_data)
```

Fig. 1. Loading and preparing data for training.

Configuration and Training of the Neural Network

After preparing the data, we can create and compile the neural network model. We use the model with the architecture described in the previous section and write the code (Fig. 2).

Optimizing model parameters is a crucial step to achieve the best identification accuracy. It may involve tuning hyper parameters such as layer sizes, number of neurons, learning rate, and others.

```
# Convert labels to one-hot encoded vectors
label_mapping = {"Fresh": 0, "Partly Spoiled": 1, "Spoiled": 2}  # Adjust as per your labels
num_classes = len(label_mapping)
y_train_encoded = tf.keras.utils.to_categorical([label_mapping[label] for label in y_train], num_classes)

# Create the model
model = create_model()

# Compile the model
model.compile(loss='categorical_crossentropy', optimizer='adam', metrics=['accuracy'])

# Train the model
model.fit(X_train, y_train_encoded, epochs=10, batch_size=32)

# Save the trained weights
model.save_weights('meat_spoilage_model_weights.h5')
```

Fig. 2. Creation and compilation of the model.

3.4 Technologies and Hardware Used

To implement the project (Fig. 3), the following hardware components were used:

- Neural Network: The utilized neural network (Sect. 3.2) was trained on preprocessed data obtained from sensors.
- Sensor Network: The project utilizes gas and color sensors such as MQ-135, MQ-138, TGS2602, and TCS3200. These sensors provide essential data on air quality in the meat monitoring area and the color of the product.
- Arduino Microcontroller: Arduino is used to read data from gas sensors and transmit it to the computational module.
- Raspberry Pi Single-Board Computer: Raspberry Pi is responsible for data processing, neural network operation, and receiving information from Arduino.

Integration with Sensors and Description of Interaction Between Components
The system interacts according to the following scheme:

- Gas sensors and the color sensor measure the characteristics of the meat's condition.
- Arduino receives data from the sensors, processes them, and transmits them to Raspberry Pi.
- Raspberry Pi receives data from Arduino, inputs them into the trained neural network, and conducts analysis to identify the level of meat freshness.
- The identification results are displayed on the screen or can be transmitted for further processing.

This integration allows for the creation of an automated system that ensures accurate identification of meat freshness using neural networks and modern technologies.

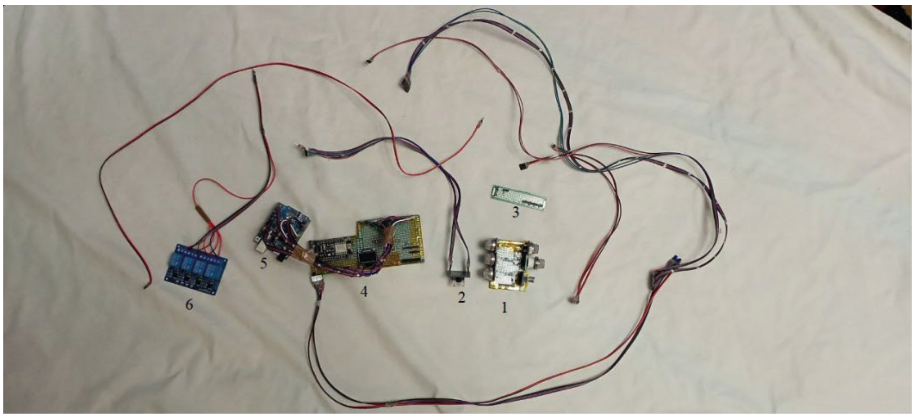

Fig. 3. Prototype of smart system for meat quality control: 1 - Array of gas sensors, 2 - Color sensor. 3 - Power supply board for elements connected through relays, 4 - Main board (Wi-Fi + server), connectors, and display, 5 - Arduino connected to the main board and sensors through it accordingly, 6 - Array of relays.

4 Conclusion

The article addresses the pertinent issue of meat freshness identification, justifying the relevance of employing neural networks in a smart quality control system. An analytical investigation of existing control systems has been conducted, highlighting their shortcomings related to a limited range of solved tasks, low reproducibility of key sensor characteristics, slow processing speed, and the absence of decision-making apparatus. It has been demonstrated that neural networks have significant potential in addressing the meat freshness identification problem. The architecture of the employed neural network is presented, and the features of training and optimization are explored. The hardware component involves a successful combination of a sensor network for data collection, a neural network for decision-making, a microcontroller for data acquisition and transmission, and a single-board computer for information processing. The project is suitable for continuous improvement, specifically in optimizing the neural network architecture, diversifying control objects, real-time deployment, and ensuring system stability in changing operational conditions.

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References

1. Yatsuk, V., Bubela, T., Pokhodylo, Ye., Yatsuk, Yu., Kochan, R.: Improvement of data acquisition system of objects physic-chemical properties. In: Proceedings of the 9th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications 2017, IDAACS ‘2017, pp. 41–46. Bucharest, Romania (2017)

2. Haddi, Z.: Instrumental assessment of red meat origins and their storage time using electronic sensing systems. Anal. Methods **7**(12), 5193–5203 (2015)
3. Kirsching, A.: Classification of meat with boar taint using an electronic nose. Acta Agriculturae Slovenica **3**, 99–103 (2012)
4. Amari, A.: Potential application of the electronic nose for shelf-life determination of raw milk and red meat. AIP Conf. Proc. **1137**, 457–460 (2009)
5. Längkvist, M.: Fast classification of meat spoilage markers using nanostructured ZnO thin films and unsupervised feature learning. Sensors **13**(2), 1578–1592 (2013)
6. El Barbri, N.: Electronic nose based on metal oxide semiconductor sensors as an alternative technique for the spoilage classification of red meat. Sensors **8**(1), 142–156 (2008)
7. Panigrahi, S.: Neural-network-integrated electronic nose system for identification of spoiled beef. Food Sci. Technol. **39**(2), 135–145 (2006)
8. Balasubramanian, S.: Independent component analysis-processed electronic nose data for predicting Salmonella typhimurium populations in contaminated beef. Food Contr. **19**(3), 236–246 (2008)
9. Wang, D.: Prediction of total viable counts on chilled pork using an electronic nose combined with support vector machine. Meat Sci. **90**(2), 373–377 (2012)
10. Panigrahi, S.: Design and development of a metal oxide based electronic nose for spoilage classification of beef. Sens. Actuators, B Chem. **119**, 2–14 (2006)
11. Xiao, Y.: Determination of the freshness of beef strip loins (M. longissimus lumborum) using electronic nose. Food Analytical Methods, pp. 1–7 (2014)
12. Tian, X.: Analysis of pork adulteration in minced mutton using electronic nose of metal oxide sensors. J. Food Eng. **119**(4), 744–749 (2013)
13. Assessment of safety risks using qualimetric methods: Trishch, R., Nechuiviter, O., Hrinchenko, H., Riabchykov, M., Pandova, I. MM Sci. J. **10**, 6668–6674 (2023)
14. Chen, J., Su, J., Kochan, O., Levkiv, M.: Metrological software test for simulating the method of determining the thermocouple error in situ during operation. Measure. Sci. Rev. **18**(2), 52–58 (2018)
15. Rudavskyi, I., Klym, H.: Smart indoor air quality monitoring system: implementation and analysis. In: 24th International Conference on Computational Problems of Electrical Engineering, CPEE 2023 (2023)
16. Diachok, R., Klym, H.: Monitoring trust status during fog level data analysis of the sesnor network. In: Proceedings of the 2022 IEEE 12th International Conference on Dependable Systems, Services and Technologies, DESSERT 2022 (2022)
17. Fedyshyn, T., Przystupa, K., Bubela, T., Petrovska, I.: Data Acquisition System for Monitoring Soil Parameters Lecture Notes on Data Engineering and Communications Technologies **181**, 499–513 (2023)
18. Guo, L.: Portable food-freshness prediction platform based on colorimetric barcode combinatorics and deep convolutional neural networks. Adv. Materials **32**(45), 2004805 (2020)
19. Jiang, K., Zhang, C., Wei, B., Li, Z., Kochan, O.: Fault diagnosis of RV reducer based on denoising time–frequency attention neural network. Expert Syst. Appl. **238**, 121762 (2024)
20. Liu, X., Qi, P., Siarry, P., Kochan, O., Li, Z.: Mining security assessment in an underground environment using a novel face recognition method with improved multiscale neural network. Alexandria Eng. J. **80**, 217–228 (2023)
21. Bubela, T., Bohush, B.: Preconditions for the creation of a meat freshness control and identification system. Measur. Equip. Metrol., Measur. Equip. Metrol. **84**(3), 59–65 (2023)
22. Bubela, T., Bohush, B.: Identification of freshness of meat using a sensor network. In: Proceedings of the 2th International Scientific and Practical Conference «Information and Measurement Technologies IMT-2022» 2022, IMT-2022, p. 42. Lviv, Ukraine (2022)

The Software Engineers Student-Centered Learning

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Abstract. This paper proposes a method for constructing individualized educational trajectories for software engineering students at Ukrainian universities, supporting student-centered learning (SCL). The method is based on the European e-Competence Framework (e-CF), mapping competencies to standard ICT professional profiles. It uses graph theory to model relationships between e-CF profiles, required competencies, and work products. Profiles are clustered into groups with strong internal connections. Possible trajectories between profile levels are evaluated by a "reachability" metric based on the new competencies required. The method is applied to create trajectories spanning junior bachelor to doctoral levels in software engineering. Results show the bachelor-level "Developer," "Digital Media Specialist," and "Test Specialist" profiles have the most vital connections. At the master's level, the "DevOps Expert," "Systems Architect," and "Systems Analyst" profiles are built most directly on the bachelor profiles. For the doctoral level "Digital Transformation Leader" profile, only the "Systems Architect" master trajectory has sufficiently strong links. This methodology and analysis guide students in selecting educational paths based on their software engineering career goals. Planned future work includes an interactive assistant recommending disciplines along trajectories from current to target proficiency levels.

Keywords: competence · curricula · student-centered learning · graph theory · software engineering · standards

1 Introduction

Education in the 21st century requires a student-centered approach to create training programs tailored to the needs and abilities of students. Through their curricula, universities must harmonize the needs of the world of work with the practice of studying at the university. It will allow the student to gain experience in cooperation and develop relevant competencies necessary for rapid adaptation to the labor market and will expand employment opportunities after graduation.

The work of M. Knowles, the creator of the concept of Self-Directed learning, significantly influenced the use of a student-centered approach in educational institutions. M. Knowles showed that all people, by nature, can be self-reliant, even if they need help

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to get started [1]. J Dewey [2] and S. Rogers [3] criticized the outdated education model, in which the teacher is assigned a central role, and the learner is a passive participant in the learning process. Researchers have proven that learners are equal partners in the academic community, and the co-production of knowledge is essential to giving learners ownership and responsibility for their learning.

Within the European Higher Education Area, for countries participating in the Bologna Process, the student-centered approach was formulated as a priority trend in developing higher education in Europe [4], which should apply to all elements of higher education.

Further development of the concept of a student-centered approach was reflected in the Communiqué of the Bologna Ministerial Conferences in Bucharest (2012) [5], in Yerevan (2015) [6], in Paris (2018) [7], and in Rome (2020) [8].

The Bologna Conference in Yerevan defined student-centered learning as a process of qualitative transformation for students and other learners in the learning environment aimed at improving their autonomy and critical ability through an impactful approach [6].

The student-centered approach to learning is the subject of study by the European Students Union (ESU) [9], which has developed a new project called Peer Assessment of Student-Centered Learning, in which the concept of learning outcomes forms the conceptual core of the SCL higher education system [10].

The Bologna reforms led to a paradigm shift in education - the emphasis shifted from teaching to learning, leading to reform in educational programs. There has been a transition from a curriculum based on the description of course content to higher education focused on learning outcomes, which are considered not the sum of information learned but the ability to act successfully in various problem situations. According to the standard [11], institutions should ensure that educational programs that motivate students to take an active role in co-creating learning are developed, and student performance assessments should reflect this approach.

One of the main categories of the student-centered approach is competencies. Competency covers the entire software development process. It involves the knowledge, skills, and attitudes of software engineering professionals that effectively solve problems and perform tasks that arise in professional work in the fast-paced environment of this industry. Thus, the competencies of specialists in the field of software engineering are a necessary condition for the successful development of software products [12].

There are five main reasons why educational institutions use the Competency-based education (CBE) approach to learning: firstly, CBE supports lifelong learning; secondly, it promotes an empowered and inclusive learning culture; third, it provides appropriate training and support on a timely and individual basis; fourth, it uses instructional ideas that align with students' needs and goals, and lastly, CBE emphasizes transparency and sets clear expectations [13].

In accordance with the law of Ukraine on higher education, competence is the ability of an individual to socialize, learn, and carry out professional activities successfully, arising based on a dynamic combination of knowledge, abilities, skills, ways of thinking, views, values, and other personal qualities [14].

In work [15], the team of authors defines competence as "Personal qualities causally related to performance indicators in one or another field of work", where individual

competence integrates knowledge, skills, and inclinations in the professional context. This formulation of competence offers a unified view of the integration of knowledge, skills, and dispositions (willingness to work) and clearly presents the professional context as an element that must remain unchanged. Thus, competence is more than the sum of its components.

Sedelmaier, Y., Landes, D argue that competence is the comprehensive ability to act appropriately in complex situations. The ability to act includes technical knowledge (hard skills), also called factual knowledge. The ability to cope with complex and new situations also requires additional soft skills, often divided into social, personal, and methodological competence [16]. Hard competencies are the skills necessary to perform the tasks of a professional activity and are acquired mainly through formal training [17]. These are competencies defined in research as "core competencies" [18], "the only skills required to perform the job functions" [19], "a person's ability to perform a specific task" [20] and "technical skills that can be measured quantitatively" [21].

The labor market study conducted by Kautz et al. (2014) [22] reflects a noticeable trend of significant employer interest in the "soft skills" of job seekers. Most employers consider them as important as professional knowledge and skills. Ahmed et al. define soft skills as the personal characteristics that primarily influence an individual's behavior when interacting with others in a work setting [23]. The authors analyzed soft skill requirements in the software industry for various software development positions such as systems analyst, designer, programmer, and tester. The authors include soft skills: communication skills, interpersonal skills, analytical and problem-solving skills, team player, organizational skills, ability to work independently, openness, and adaptability to change [23].

Competence is central to the SWECOM (Software Engineering Competency Model), in which knowledge and technical (computer) skills are integrated with behavioral characteristics. The model is designed to define the set of knowledge, skills, and qualities necessary for the effective development and modification of software systems. The model defines the skill areas and work activities for each skill. Activities occur at five levels of skill development. SWECOM suggests that competence combines knowledge, skills, and abilities. A competent person has the knowledge and ability to perform a work activity (i.e., skills) at a given competency level. The competency model includes cognitive attributes, behavioral attitudes, and technical skills. The model also defines life cycle skill areas, cross-cutting skills (e.g., quality, safety, security), and associated activities. It also defines competency levels: Technician (able to follow instructions), Entry Level Practitioner (can assist in performing activities with some supervision), Advanced Practitioner (able to perform activities with little or no supervision), Tech Lead (able to lead and guide members) and senior software developer able to create new processes and change existing ones [24]. The model is aimed at software developers, including programmers, architects, testers, and other specialists.

The model allows us to standardize the assessment of competencies in software systems development, providing a more objective understanding of the level of skills,

planning the training that employees need, and helping determine career paths and qualifications for employees. However, the model requires modification due to the rapid evolution of software systems development. The software development industry is rapidly evolving, and models may become outdated or not consider new trends.

These approaches are consistent with the Global Computing Education paradigms outlined in the latest CC2020 release of the Computing Curricula series of reports from the Association for Computing Machinery (ACM) and the IEEE Computer Society (IEEECS) [25]. After a long break with the release of SE 2014 (Software Engineering Curricular Volume), international organizations have returned to reviewing the guidelines for bachelor's degree programs in computer science professions, particularly software engineering. One of the four core principles that the task force adhered to in developing CC2020 related to the need to incorporate future trends and industry vision into the educational process, tracking changes in technology and research across the sociological spectrum. The CC2020 authors believe that professional and scientific communities should lead in supporting higher education in various ways, mainly by formulating teaching guidelines.

The constant increase of the information load in the field of education in software engineering is explained by the multifactorial nature of the subject area. The CC2020 report provides details of current industry trends in IT and software engineering. These areas, which either already exist or are expected shortly, are determined based on analyzing various business intelligence sources and considering the data provided in CC2020. Universities should consider the research findings in the report when developing software engineering curricula.

The report Software Engineering 2014: Curriculum Recommendations for Undergraduate Software Engineering Programs, also known as SE2014, was developed to guide academic institutions and accrediting agencies on what undergraduate software engineering education should be like [26]. The SE2014 report identifies a set of student outcomes that characterize the qualities of an SE graduate. These include professional knowledge, technical knowledge, teamwork, end-user awareness, design decisions in context, performance trade-offs, and ongoing professional development. Likewise, the report provides a list of principles "that covers both general principles of computing and those that reflect the special nature of software engineering and distinguish it from other computing disciplines".

The European e-Competence Framework (e-CF) is a standard that classifies 40 competencies for ICT professionals, establishing a common language for competencies, skills, and proficiency levels across Europe. It is organized into five ICT business areas related to the European Qualifications Framework (EQF). The e-CF is developed and maintained by "CEN/TC-428 ICT Professionalism and Digital Competences" and is used by organizations, individuals, and public authorities to assess, certify, and manage ICT competencies. https://itprofessionalism.org/

The e-CF is also used to develop new professional roles and map them to the European Skills, Competencies, and Qualifications (ESCO) framework. This process involves identifying relevant e-competences for specific roles and ensuring that the roles are aligned with the European Qualifications Framework (EQF) [27].

The European ICT Professional Role Profiles are closely related to the European e-Competence Framework (e-CF, providing a shared European reference language for developing, planning, and managing IT professional needs. These profiles complement the e-CF and contribute to a common European reference language for planning and managing IT professional needs in a long-term perspective [28].

The European ICT Professional Role Profiles are built on the e-CF and provide a Europe-agreed set of typical profile descriptions from an ICT organizational viewpoint. They illuminate and structure each ICT Professional Profile with some components, using the e-CF as the basis for competence identification. Integrating the e-CF competencies into the ICT Professional Role Profiles provides a tool and entry point for e-CF application to individuals and organizations [29].

Educational standards and programs often lack harmony, using incompatible competency systems that hinder program continuity, duration reduction, and support for individual student trajectories. Extensive competency lists complicate tool and method development for assessing student proficiency.

In forming the Student-Centered Learning (SCL) university curricula for software engineering training in universities, each higher education level and corresponding professional standard must ensure consistency. SCL relies on individual educational trajectories for software engineers, starting from Junior bachelor's programs. Bachelor's programs should build on, not repeat, Junior bachelor's, and each subsequent education level should increasingly emphasize individual learning trajectories.

In this paper, we adapt our previously developed general approach [30] to the changes in educational and professional spheres over the past 1–2 years. We solve the task of constructing educational trajectories for training software engineers at Ukrainian universities. These trajectories must fit the qualifications framework and must support the SCL conception.

The paper is structured as follows. Section 2 presents the theoretical basis for choosing individual educational student trajectories according to the European e-competence framework. Section 3 presents the results of the proposed method according to the European e-competence framework for the Software Engineering specialty.

2 Method of Curricula Construction According to Student-Centered Learning

2.1 Input Assumptions and Limitations

Target competencies for Software Engineering (SE) specialists should include training for "Developer" and "Test Specialist" profiles from e-CF, aligning with the qualifications for a "Specialist in the development and testing of software" in the National Classification of Professions Ukraine. Considering the similarity of the "Digital media specialist" profile, these three profiles form the core of the Software engineering specialty.

Competencies for Developers, Digital Media Specialists, or Test Specialists are limited to the third level of E-CF, equivalent to a bachelor's level in the European Qualifications Framework and the Law on Higher Education of Ukraine. Pursuing master's or doctoral levels is deemed pointless.

Choosing further educational paths should be justified based on the desired target profile. Validity hinges on minimal difficulty in acquiring new competencies and enhancing existing ones. The complexity can be quantified by assessing the number and level of new competencies and deliverables.

Recommended training paths are those with sufficiently low difficulty, measured qualitatively and relatively, aligning with the student-centered learning concept. The goal is to provide recommendations regarding ease, difficulty, and attainability rather than numerical comparisons between profiles. This approach allows students to personalize and adjust their educational path.

2.2 The Formal Statement of the Problem

The initial data are the interrelations matrixes of the "ICT profiles – E-competences" and "ICT profiles – Deliverables." In the mathematical representation, these tables define two bipartite graphs (mappings):

$$\Phi_1 : P \to C, \Phi_2 : P \to D, \tag{1}$$

where $P = \{P_1,\ P_2,\ \ldots\ P_{30}\}$– the profiles set,

$C = \{C_1,\ C_2,\ \ldots\ C_{40}\}$ – the competences set,

$D = \{D_1,\ D_2,\ \ldots\ D_{76}\}$ – the deliverables set.

The mapping of the profiles set to the competencies set we present as $G = \langle P, C, E\rangle$, where E denotes the weighted edges set of the bipartite graph. The weight of each edge $e_{p,c}$ we define as the level of competence with number c, which is needed to profile with number p. Similarly, the mapping of the profiles set to the deliverables set is $H = \langle P, D, K\rangle$, where K denotes the edges of the bipartite graph, and each edge $K_{p,d} \in \{0, 1\}$.

The proximity function between any two profiles s and t we define as distance in an undirected graph:

$$\Pr(s, t) = \alpha \sum\nolimits_{\forall c, c \in C} \min(e_{s,c}, e_{t,c} + (1 - \alpha) \sum\nolimits_{\forall d, d \in D} k_{s,d} k_{t,d}, \tag{2}$$

where α - coefficient allows controlling the importance of proximity metric according to common competencies relative proximity metric according to shared deliverables. The complexity function of the transition to a new profile t in the presence of competencies of the existing profile s we introduce as a distance in a directed graph:

$$Dif\,(s, t) = \alpha \sum\nolimits_{\forall c, c \in c \cap (e_{t,c} > e_{s,c}} (e_{t,c} - e_{s,c}) + (1 - \alpha) \sum\nolimits_{\forall d, d \in D \cap (k_{t,d} = 1)} (k_{t,d} - k_{s,d}) \tag{3}$$

The assumption that training is carried out in consistent progress through the educational levels leads to a search of all possible pairs s and t within a stepwise education system with the suggestion that these pairs must satisfy the following condition:

$$\max_{\forall c, c \in C} (e_{t,c}) - \max_{\forall c, c \in C} (e_{s,c}) = 1 \tag{4}$$

We introduce the reachability matrix of the following target profile, starting with the existing one. In graph theory, reachability is the ability to get from one vertex to another within a graph. A vertex s can reach a vertex t, and t is reachable from s if a sequence of adjacent vertices (i.e., a path) starts with s and ends with t.

Taking into account constraint (4), the reachability matrix we present as:

$$Reach(s,t) = \left\{ \begin{array}{c} \frac{1}{Dif(s,t)}, \, if \; condition(4) \; true \\ 0, \; otherwise \end{array} \right\} \tag{5}$$

2.3 The Construction of Individual Educational Trajectories and Curricula Set

The method of constructing individual educational trajectories set and curricula set as a result is a sequence of following steps.

Step 1. Clustering profiles is ordering profiles' graph structure into relatively homogeneous groups, where the proximity function between any two profiles is calculated according to (2). We used the modularity metric proposed in the paper [31] for clustering. The metric value lies between 0.5 and 1, calculated by the formula:

$$Q = \frac{1}{2m} \sum\nolimits_{s,t} \left(\Pr(s,t) - \frac{d_s d_t}{2m} \right) \delta(k_s, k_t), \tag{6}$$

where di is the degree of the i-th node, Ki is the cluster in which the i-th node is located, m is the number of edges in the graph. $\delta(k_s, k_t) = 1$, if $k_s = k_t$, otherwise 0.

Using the modularity metric (6) allows us to split the initial list of profiles into profile clusters, which are characterized by a strong connection of profiles within classes and weak for profiles located in different clusters (strong link inside and weak ones among groups). A change in the coefficient makes it possible to evaluate the stability of the clustering result when changing the evaluation criterion from proximity by competencies to proximity by deliverables.

Step 2. The reachability graph describes the ability to get from the obtained profile to the next one by educational level with quantity estimation of this step complexity. The reachability graph is constructed using (5) and becomes a background for building individual educational trajectories.

Step 3. The curriculum set is constructed using individual educational trajectories. The starting point for each curriculum building is the need for competencies for goal profile, knowledge, and skills examples, cataloged in the e-CF.

3 Individual Educational Student Trajectories According to the European E-Competence Framework

We performed a profile's clustering from e-CF with $\alpha = 1$ from (2), considering only the quantity of common competencies required for each pair of profiles. As a result, we got seven closely related groups (Fig. 1). Each group has its own color, and the line thickness between each pair of profiles is proportional to the number of shared competencies. Grouping of profiles by Deliverables/Outcomes proximity principle $\alpha = 0$ from (2) gives a partially different result (Fig. 2). A comparison of these results is given in Table 1.

Table 1. Comparison proximity of the profiles by competencies and deliverables/outcomes

Profile's	Proximity by common	
	Competencies	Deliverables/Outcomes
Developer	+	+
Digital Media Specialist	+	+
Test Specialist	+	+
DevOps Expert	+	+
System Administrator	+	-
Network Specialist	+	-
Systems Analyst	-	+
Systems Architect	-	+
Digital Transformation Leader	-	+

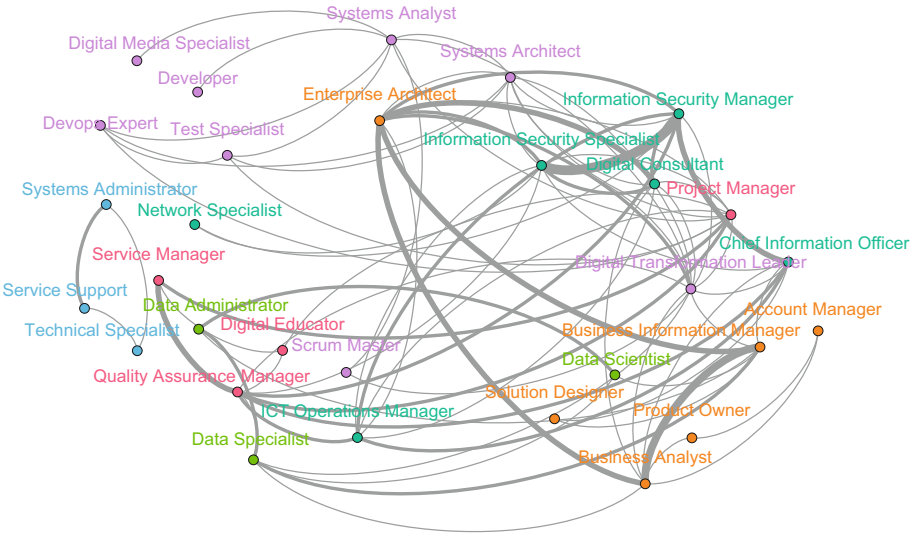

Fig. 1. Seven profiles groups (highlighted by different colors) which are closely related by the list of required competence

All recommended trajectories for achieving the desired profiles for software engineering are presented in Fig. 3. The line thickness characterizes the number of competencies achieved at the previous level that will be claimed at the next one; that is, the thicker the connecting line, the easier it will be to achieve the target profile.

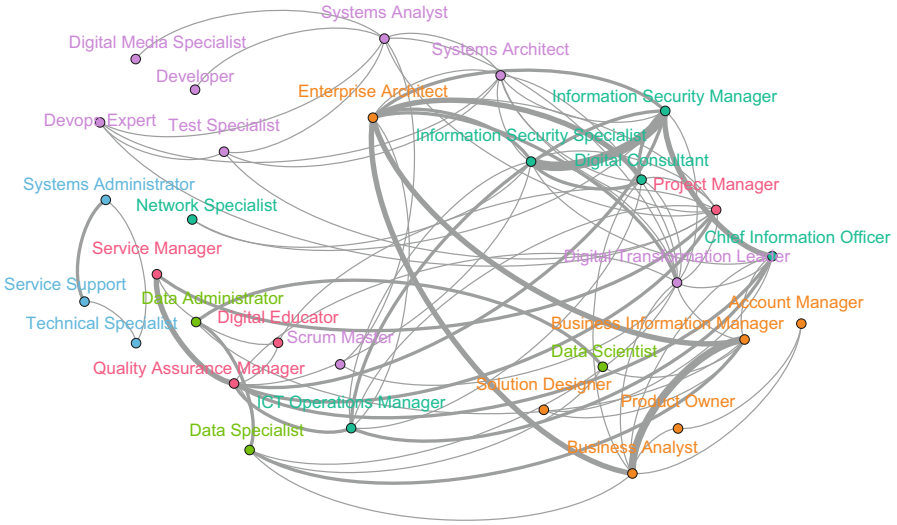

Fig. 2. Seven profiles groups which are closely related by the deliverables

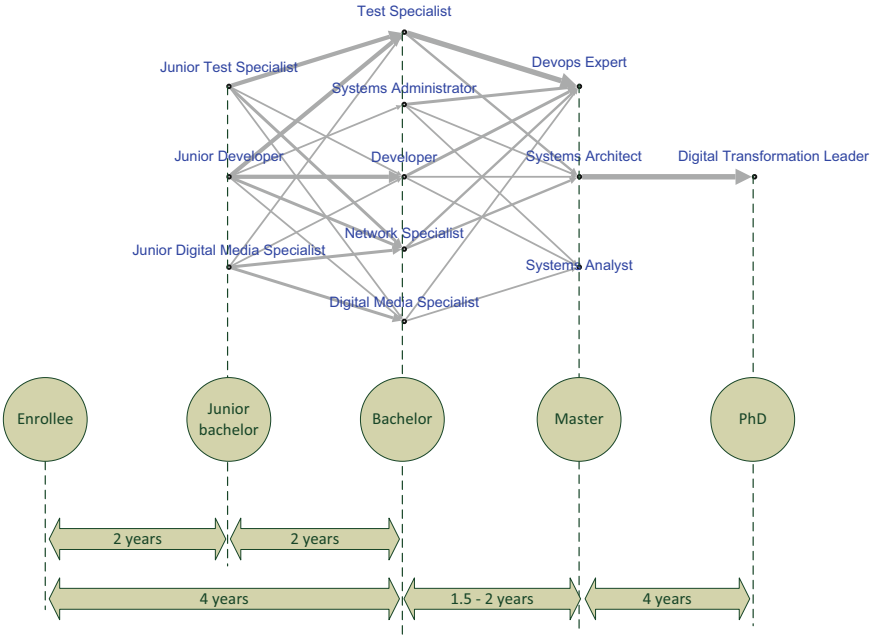

Fig. 3. Trajectories (possible paths) for achieving the desired profiles for software engineering with accounting common competencies and deliverables (the line thickness characterizes the number of competencies achieved at the previous level that will be claimed at the next, that is, the thicker the connecting line, the easier it will be to achieve the target profile)

4 Conclusions and Future Work

The key performance indicator for SCL is student satisfaction with incorporating sustainable curricula. The e-CF has proved to be very useful in the process of curricula design because one of the critical challenges of effective curricula design is managing how different stakeholders communicate and cooperate in designing curricula that meet educational and employer objectives.

The article proposes a partial formalization of the method of constructing educational trajectories for training software engineers at Ukrainian universities. Improving student knowledge, skills, and competence without a clear plan and goal as to how that future Bachelor, Master, or Ph.D. will correspond to the organizational needs of an employer generally has minimal effect.

The following features of software engineering and higher education in Ukraine are taken into account. The target competencies that Developers, Digital Media Specialists, or Test Specialists must possess are limited to the third level of E-CF, corresponding to the bachelor's level in the European Qualifications Framework and the Law on Higher Education of Ukraine.

The proposed method for the set construction of the software engineers' educational trajectories in Ukrainian universities uses graph theory. The nodes of the weighted graph are the roles proposed by the European e-Competence Framework, and the weights of the edges characterize the number of competencies achieved at the previous level of education that will be necessary to achieve the next level.

The article presents the result of synthesizing educational trajectories for software engineering from a junior bachelor level. It is shown that the subsequent levels of education should be oriented toward acquiring the competencies necessary for the DevOps Expert Role, Systems Architect Role, or Systems Analyst Role at the master's level.

Further development of the work is planned in the practical implementation of an interactive online assistant, which will formulate recommendations for the student on the choice of disciplines, forming a set of trajectories from the already achieved level to the target one the student will choose.

References

1. Knowles, M.: Self-Directed Learning: A Guide fsor Learners and Teachers. Association Press, New York (1975)
2. Dewey, J.: Democracy and Education: An Introduction to the Philosophy of Education. WLC Books, New York (2009)
3. Rogers, C.: Freedom to Learn for the 80's. Charles E. Merrill Publishing Company, A Bell & Howell Company, New York (1983)
4. Communiqué of the Conference of European Ministers Responsible for Higher Education, Leuven and Louvain-la-Neuve, 28–29 April 2009 https://www.ehea.info/Upload/document/ministerial_declarations/Leuven_Louvain_la_Neuve_Communique_April_2009_595061.pdf. Accessed 16 Nov 2023
5. Communiqué 2012: Bucharest Communiqué 2012. Conference of Ministers responsible for higher education. https://www.ehea.info/Upload/document/ministerial_declarations/Bucharest_Communique_2012_610673. Accessed 16 Nov 2023

6. Communiqué 2015: Erevan Communiqué, Conference of Ministers responsible for higher education. https://www.ehea.info/media.ehea.info/file/2015_Yerevan/70/7/YerevanCommuniqueFinal_613707.pdf. Accessed 16 Nov 2023
7. Communiqué 2018: Paris Communiqué. https://www.ehea.info/Upload/document/ministerial_declarations/EHEAParis2018_Communique_final_952771.pdf. Accessed 16 Nov 2023
8. Communiqué 2020: Rome Ministerial Communiqué. https://www.ehea.info/Upload/Rome_Ministerial_Communique.pdf. Accessed 16 Nov 2023
9. European Students' Union. https://esu-online.org/. Accessed 16 Nov 2023
10. Student-Centred Learning -Toolkit for Students, Staff and Higher Education Institutions, Eu-ropean Students' Union and Education International. https://www.esu-online.org/wp-content/uploads/2016/07/Overview-on-Student-Centred-Learning-in-Higher-Education-in-Europe.pdf. Accessed 16 Nov 2023
11. Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG). https://www.britishcouncil.org.ua/sites/default/files/standards-and-guidelines_for_qa_in_the_ehea_2015.pdf. Accessed 16 Nov 2023
12. Assyne, N., Ghanbari, H., Pulkkinen, M.: The state of research on software engineering competencies: a systematic mapping study. J. Syst. Softw. **185**, 111183 (2022). https://doi.org/10.1016/j.jss.2021.111183
13. Malhotra, R., Massoudi, M., Jindal, R.: Shifting from traditional engineering education towards competency-based approach: the most recommended approach-review. Educ. Inf. Technol., 1–31 (2023)
14. Law of Ukraine About the search for light (Videomosti Verkhovna Radya (VVR) 2014, No. 37–38, Art. 2004). https://zakon.rada.gov.ua/laws/show/1556-18#Text
15. Frezza, S., et al.: Modeling competencies for computing education beyond 2020: a research based approach to defining competencies in the computing disciplines. In: Proceedings Companion of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education (ITiCSE 2018 Companion), pp. 148–174. Association for Computing Machinery, New York, NY, USA (2018). https://doi.org/10.1145/3293881.3295782
16. Sedelmaier, Y., Landes, D.: Software engineering body of skills (SWEBOS). In: IEEE Global Engineering Education Conference. EDUCON, pp. 395–401 (2014). https://doi.org/10.1109/EDUCON.2014.6826125
17. Soft skills for the engineering students Synergy **9**(2), 137–142 (2013). https://pdfs.semanticscholar.org/fbf4/0a9446331b41d3f11ef3b7035fe33e2b452f.pdf. Accessed 16 Nov 2023
18. Assyne, N.: Hard competencies satisfaction levels for software engineers: a unified framework. In: Hyrynsalmi, S., Suoranta, M., Nguyen-Duc, A., Tyrväinen, P., Abrahamsson, P. (eds.) Software Business. LNBIP, vol. 370, pp. 345–350. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-33742-1_27
19. Setiana, S.M., Setiawati, L., Mustaqim, M.: Hard skills versus soft skills: how do they affect different job types of Japanese language graduates? Int. J. Learn. Teach. Educ. Res. **18**(11), 176–192 (2019)
20. Florea, R., Stray, V.: A global view on the hard skills and testing tools in software testing. In: 14th International Conference on Global Software Engineering (ICGSE), Montreal, 24–26 May 2019. IEEE, New Jersey (2019)
21. DeLong, D., Elbeck, M.: An exploratory study of the influence of soft and hard skills on entry level marketing position interviews. Mark. Educ. Rev. **28**(3), 159–169 (2018)
22. Kautz, T., Heckman, J.J., Diris, R., Ter Weel, B., Borghans, L.: Fostering and measuring skills: improving cognitive and non-cognitive skills to promote lifetime success (2014). http://www.oecd.org/education/ceri/Fostering-and-Measuring-Skills-Improving-Cognitive-and-Non-Cognitive-Skills-to-Promote-Lifetime-Success.pdf
23. Ahmed, F., et al.: Soft skills and software development: a reflection from the software industry, pp. 179–187. arXiv preprint arXiv:1507.06873 (2015)

24. IEEE Computer Society (2014) Software Engineering Competency Model: Version 1.0, SWECOM 2014. https://www.coursehero.com/file/94899251/SWECOMpdf/. Accessed 16 Nov 2023
25. https://users.cs.fiu.edu/~prabakar/ugc/ACM_Reports/2020_ACM-IEEE_CC_Draft.pdf. Accessed 16 Nov 2023
26. Software Engineering 2014 Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering A Volume of the Computing Curricula Series, 23 February 2015. https://www.acm.org/binaries/content/assets/education/se2014.pdf
27. https://esco.ec.europa.eu/en/about-esco/escopedia/escopedia/european-e-competence-framework-e-cf. Accessed 16 Nov 2023
28. https://itprofessionalism.org/about-it-professionalism/competences/ict-profiles/. Accessed 16 Nov 2023
29. https://www.ics.ie/news/ICT_Job_Profiles_eCF_Version2. Accessed 16 Nov 2023
30. Turkin, I., Kirilenko, O.: A roadmap for implementing the sustainable software engineering curricula in Ukraine according to European E-competence framework and student-centered learning conception. In: ICTERI Workshops (2020)
31. Girvan, M., Newman, M.: Community structure in social and biological networks. PNAS **99**(12), 7821–7826 (2002)

Analysis of Technologies for Reconfiguration of IoT Systems at Level of Software Modules and Bootloaders

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Abstract. The analysis of existing components of a smart home as part of the entire range of Internet of Things (IoT) is performed. The analysis of possible ways of reconfiguration of IoT components is performed. The ways of reconfiguration at the network level and partial node reconfiguration are considered. The ways of flexibility of the components of IoT are analyzed and classified. Comparative analysis of summarized parameters of bootloaders is performed. The possibility to use the software components as unchangeable blocks of the code for modification of microcontroller program as the way of reconfiguration is analyzed. The idea to use the replaceable software modules for representation of microcontroller program at higher level of abstraction with modified bootloader is proposed. Elements of programming method for microcontroller reprogramming with replaceable software modules as middleware is proposed. The practical example of the use of results of the research is provided.

Keywords: software reconfiguration · reconfigurable nodes · Fog computing · bootloader · Edge-IoT · replaceable software modules

1 Introduction

Due to intensification of the growth in the demand of modern systems for computing power, there is a need for their constant expansion and modification. For embedded systems running in solid enclosures or in a fixed volume of space, there is a limit beyond which modification and hardware additions become impossible. In reason of communication capabilities expanding and increasing the number of ready-made components for creating complex computing systems increases the variety of approaches to their construction. Depending on the available resources and basic development conditions, it is possible to adjust the type of executable solution to them.

Manufacturers of modern executive modules present a wide selection of chips of different price categories and workmanship. Depending on its purpose, the module can be made either in the form of a component, which is a board with basic interaction interfaces and a set of pins for free use, or in the form of a finished device in a monolithic housing with a set of specialized interaction interfaces and minimal frills. This contrast

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is due to the scope of application of the module and the size of the series within which it was produced.

Despite the variety of manufactured computing modules and devices for building embedded systems, their resource and time resources remain limited [1]. In view of this, for long-term systems, engineers are developing ways to provide their maintenance and support, allowing them to complement and modify already deployed systems. Unfortunately, the ability to expand systems can also be limited due to dimensions and power consumption. There is also a limit to the complexity of systems, when the number of devices involved in it reaches values at which effective resource management becomes difficult, which affects the speed and quality of performing the tasks assigned to the system.

In reason of that, there is a need for an alternative approach to modernizing embedded systems based on multiple devices interacting with each other. Taking into account the fact that serial devices are produced in a standardized manner, in a form compatible with common solutions and interfaces, when used in practice, part of the resources embedded in them may not be used [2]. In this regard, standard modules have a natural resource redundancy, which, with the right approach, can be used for the needs of the overall system.

Taking into account all of the above, there emerges an idea to formulate an approach leveraging the inherent to controllers natural redundancy for the purpose of enhancing both the reliability and longevity of integrated systems [3]. This approach involves taking into account and using redundant components of both the architecture and the constituent components of the system, which will make it possible to avoid failures or turn them into smooth degradation.

Due to the fact that the main consumer of hardware resources is the program executed by the controller, a task arises related to managing the contents of the internal memory and firmware. A component included in many microcontrollers called a bootloader is well suited for this task.

A bootloader serves as an application designed primarily to facilitate the enhancement or alteration of system software without the need for specialized firmware upgrade tools. While bootloaders can perform various functions, their primary role is in overseeing the application. They can employ diverse protocols such as UART, CAN, I2C, I2S, Ethernet, or USB to initiate communication and commence a firmware upgrade process [4].

However, in its standard form, the bootloader does not allow reprogramming the microcontrollers it serves without the use of third-party devices and programs. For this reason, it is considered advisable to use a modified bootloader to enable remote programming or reconfiguration [4].

The purpose of this work is to increase the flexibility of components of IoT systems by means of simplification of reconfiguration process of remote reconfiguration of individual nodes and components.

To reach this goal it is necessary to perform following tasks: analyze existing approaches for building configurable systems, analyze and describe existing solutions, which realize common approaches; analyze tools for implementing the selected

approaches, describe a method for building survivable system, based on analyzed approach, purpose a technical example for proposed programming method.

2 Analysis of Possibilities for IoT Components Reconfiguration

2.1 Analysis of Ways for Reconfiguration at Network Level

For Industry 4.0, it is proposed to change the approach to managing Internet of Things devices, where a large number of Internet of Things devices interact with each other with ensuring effective interaction between machines. In case that traditional management methods are ineffective due to problems of distributed management and ineffective resource allocation. It is proposed to use software-defined networking (SDN), which separates network management and data transfer between devices [5].

Software-defined networking offers the opportunity to optimize the management of traditional networks. Especially the SDN controller has a global view of the network of sensors and actuators, which allows dynamic reconfiguration of network nodes and data flows in real time. This is especially true for devices with limited communication and computing resources. The proposed SDN-IoT architecture focuses on developing a controller that dynamically optimizes the delivery of end-to-end streams in real time. The basis for this is the adaptation of dynamic routing policies based on continuous assessment of the network state, which allows them to jointly minimize delays and energy consumption, thereby increasing the network lifetime [6].

The ITEA 2 Project "Network of Objects" proposes solution aimed at collaboration of Internet for Things-based devices in the context of emergency management. In this solution, messaging is semantically enriched. A solution to three interrelated problems is proposed: ensuring compatibility of device management based on appropriate distributed architecture; setting up workflows to allow together work of devices while ensuring autonomy; establishing the optimal format for data exchange for devices [7].

A Smart Objects (SObjs) concept provides an approach for configuring and management for smart devices as network objects. SObj object management plays a critical role in preventing potential IoT network congestion issues and reducing latency. The proposed method, known as MbDSAS, is an approach to reconfiguring network blocks or gateways without requiring software updates or changes to manage and discover SObjs and maintain IoT network dynamicity. Using this method, gateways are configured to efficiently manage SObjs through software updates or reconfigurations, followed by a warm start. MbDSAS has undergone pilot testing to confirm its suitability as a solution for managing IoT scenarios and to determine the best combination of technologies for its successful implementation [8].

In other solution it is proposed to move computing operations from Edge to IoT by changing the behavior of its nodes according to the requirements of the application or system. To allow it, a Multi-Hop-Over-The-Air update technology is implemented, which automatically configures microcontroller-based IoT devices. With IoT nodes connected to a mesh network in mind, distributed ecosystem is developed to promote collaboration and to enable rapid code deployment to heterogeneous Edge-IoT mesh network nodes. Thus, system automatically deploys new services when necessary [9].

Industrial Internet of Things (IIoT) systems provide a variety of services at edge nodes to improve efficiency and automate system operation. The concept of service hosting emerges, where edge nodes are dynamically reconfigured to host the latest requested services from sensor nodes. Given the limited storage and computing resources at edge nodes, a reconfiguration function is introduced that can expand the number and types of services hosted on these nodes [10].

In case of collecting real-time data using wireless sensors connected to the Internet of Things it presents issues to ensure sufficient coverage, network longevity, and maintaining wireless connectivity. For global remote monitoring (WARM) applications, a lightweight, dynamic, and automatically reconfigurable communication protocol (LDAP) is proposed. This protocol includes a mobile data sink to provide wider wireless sensor network (WSN) coverage and automatic reconfiguration capability to adapt to dynamic network topologies. Improved WSN coverage and service life are also achieved through the use of Long Range (LoRa) wireless interface [11].

According to the proposed solutions, it is possible to conclude that in conditions of limited space and access, it is possible to increase system performance indicators by changing the internal structure of the network. Due to this net reconfigurability for this type of network, it becomes possible to assign roles and rights to participating devices, which in turn affects the distribution of computing and traffic load. In this case, it can be assumed that adjustment, redistribution and control of devices can act as tools to ensure system reliability. In other words, by distributing the computing and traffic load, it will reduce the wear and tear of devices involved in the network, and thanks to device management at the network level, it becomes possible, if necessary, to remove defective or failed network participants without rebooting or updating it. In the described case, downtime can be reduced and system service life can be increased.

2.2 Analysis of Partial Node Reconfiguration

Reconfigurable computing architectures are successfully used in safety-critical areas. As the target architecture evolves, it becomes necessary to update it remotely on the appropriate platform. This process is subject to the risk of remote tampering, where an attacker can maliciously change the configuration of reconfigurable target hardware. Architecture is proposed that includes the trusted hardware using cryptographic coprocessors and trusted platform modules (TPMs), as well as implementing updates over the wireless network. The platform under development implements a secure boot protocol on field programmable gate array (FPGA) with use of Xilinx technology. The project demonstrates successful bitstream configuration, integration of the boot process with TPM, and secure over-the-air updates for hardware reconfiguration [12].

Some IoT systems provide remote dynamic partial reconfiguration (DPR) capabilities for modern FPGAs. These capabilities allow changes to be made to the circuit mapped on the FPGA to modify or expand the functionality of the device without having to take it off the network, through use of remote network communication [13].

For such solutions requires a secure and reliable update system. It is a critical element for successful implementation of the Internet of Things, especially at the scale of large commercial solutions. When analyzing the specific challenges of infrastructures

designed to remotely deploy and manage applications, the management challenges associated with IoT sensor systems are highlighted. A mathematical model and methodology for solving these problems is proposed. To evaluate the effectiveness of the model, it was implemented in the form of software infrastructure for full-fledged commercial products in the field of Internet of Things [14].

Another example proposes a solution that includes the lightweight cryptographic algorithms Espresso and Grain 128 to ensure data confidentiality in projects based on FPGA technology in IoT, as well as the CRC32 algorithm to verify data integrity. This solution is designed for use on Digilent's Basys 3 Artix-7 boards using Vivado. To optimize performance, partial reconfiguration is provided to allow switching between algorithms depending on the flow of IoT traffic and security conditions [15].

The use of partial difference-based reconfiguration, although easier to implement due to the absence of the need for pre-planning the floor, is recommended to be limited to small changes due to its unpredictable nature. This paper proposes a mechanism that prevents this problem by saving the global state of the system. Thus, it does not matter how the partial bitstream based on the differences will affect the hardware configuration. This means that designing a partially reconfigurable system-on-chip requires less effort in the development process [16].

Based on the proposed solutions, it is possible to conclude that with limited expansion capabilities of the system, it is possible to use the computing power of the devices presented in it by rethinking their roles in the system and methods of interaction. By representing devices as peer nodes of the system, it becomes possible to requalify them as needed for the current task. Due to this nodal reconfigurability, it becomes possible to optimize the workflow of the system as a whole, as well as adjust the accuracy and speed of the calculations performed. In this case, it can be assumed that optimization of the work process will lead to an even and feasible distribution of the load between the executive nodes. In other words, due to optimization, the number of operations performed by the system is reduced, which reduces the wear of devices acting as nodes. Due to the reconfiguration of devices at the level of the executable program, it becomes possible to bypass hardware defects due to the permitted reduction in the accuracy or speed of calculations. In the described case, it is possible to increase the survivability and service life of the system.

2.3 Analysis of Cases of Use of Bootloaders

The bootloader is an important component of an embedded ARM system, and the implementation of this bootloader is closely related to the hardware characteristics. It provides a brief description of the S3C2440 development board and its launch mode. The focus is on the initialization of each functional module in the S3C2440 during system startup, and a diagram of a simplified bootloader for this board is presented. After testing, this loader demonstrated high efficiency and portability [17].

The bootloader receives the application from the host via the communication interface and writes it into the controller's program memory. Each bootloader host follows a specific file transfer protocol, which is usually unique to the chip vendor. This paper presents a self-contained and portable microcontroller host (PIC18F66K80). This host is capable of receiving an image from a PC via the Xmodem protocol, storing it in external

flash memory, parsing the Intel hex representation of the stored image, and programming the target controller (another PIC18F66K80) using unified bootloader protocol. Communication between host and target is carried out through a controller area network (CAN). The main advantage of this implementation is the ability to use portable and convenient host controller to program individual targets in question [18].

The description of the development and implementation of a built-in bootloader for ARM uCOS covers the following aspects: the use of self-adaptive boot technology, the use of Memory Management Unit (MMU), interrupt handling, direct installation of interrupt vectors, working with large flash pages, programming for UART, etc. The article also provides a concrete example illustrating the real-life impact of an embedded bootloader when porting ARM uCOS [19].

The approach uses a modular code structure and specific instructions to reduce the migration workload, and uses macros in the definition file for real-time updates. In parallel, backup copies of the flash memory area are configured to improve reliability. The development of this bootloader on the universal PowerPC platform reduces the migration process by more than 60% compared to U-Boot. The probability of successfully launching the bootloader from the backup area is 92.5% or higher [20].

Designed for the Atmel AVR family of microcontrollers, ATmega is superior to Optiboot in terms of smaller size and faster speed, giving programmer more available flash memory and reducing the time required to download or update microcontroller firmware. Bootloader concept played a key role in popularizing Arduino, eliminating the need for specialized programming devices during prototyping phase. However, original purpose of bootloader was to provide the end user or less experienced service personnel with ability to update the firmware of the product or embedded device [21].

In view of the above examples of using the bootloader, it can be assumpted that this component of microcontroller-based systems is a fairly flexible and accessible tool for managing the microcontroller. Due to the presence of this component as part of programmable devices in role of manager for recording and executing programs, it becomes possible to control the contents of the device's memory. And due to the availability of this component, it becomes possible to modify it to suit the needs of the system. The result of using such a tool can be provision of partial or complete reconfiguration of devices as part of an already deployed system.

The idea of a system where all nodes are configurable is the direction to increase the flexibility of the system. The possibility to perform remote reconfiguration over network allows the cooperation of nodes with ability of reconfiguration of one node by another using special software tools or preprogrammed bootloaders [2, 4].

Thus, there are different cases of the use of the Internet of Things and bootloaders applications. It is possible to highlight IoT Medicine as the class that includes both the production of equipment, automation of laboratory activities, and diagnostics, surgery and rehabilitation. This class, for its purpose, requires reliable and uninterrupted operation of the systems used, which fits with the topic of research. Another class can be considered applications of the industrial IoT. It can include both applications for monitoring and controlling production processes, as well as applications for ensuring the safety and security of the manufactured product during its storage and transportation.

Another example is e-commerce applications for logistics and communication tasks. They can be described as applications for automated communication systems for commercial enterprises, transport infrastructure management and smart cities.

3 Analysis of Reconfiguration and Programming Method

3.1 Software Reconfiguration Analysis

In the course of analyzing methods for organizing and constructing systems based on multiple devices and their interaction, approaches were identified that best suit the conditions of limited resources and capacity. These approaches are aimed at improving the speed and reliability of a system by increasing the complexity of its structure and rethinking traditional methods of interaction and behavior.

The first approach that can be considered is a *Software-defined network*. It is based on the idea of introducing an arbiter into a classical network of interaction between devices, which has the ability to regulate traffic and redirect data and computation flows to less loaded devices in real-time mode, thereby optimizing the overall load on the network and its participants. In reason of the described above, network viability and its responsiveness are greatly increased.

Another approach that should be considered is a *Network of Object*. It represents each devise of the network as smart objects with kit of basic operations and functions for management. This type of organization significantly increases the maintainability of the entire system due to the fact that each object can be removed from the system without completely stopping and restarting it. Moreover, making changes to system settings does not require updating the system, eliminating downtime and increasing scalability.

One more method of organization that should be noticed calls *Edge-to-IoT*. It represents each member of the network as node, which could be reconfigured by another node, according application requirements. By using the properties of microcontrollers to repeatedly rewrite the executable program, it becomes possible to reconfigure the node containing this controller. This makes it possible to fine-tune the devices used by the network and create cooperation based on them for a balanced and optimized computing process.

Summarizing the results of the analysis, the resulting data obtained were entered into the resulting Table 1.

Thus, it is possible to conclude that all described methods had a number of similar characteristics, such as increasing the system's resilience to failures and extending the service life of the system. Two of described methods require significant modifications from the system where they are applied, both at the device and infrastructure levels.

3.2 Bootloader Comparison Analysis

To achieve the described effect of increasing the quality characteristics of the system by complicating its internal structure, a method was considered to provide the function of reconfiguring individual elements of the system. A method using a bootloader as a reconfiguration tool was chosen. In this case a search was carried out for options of a custom bootloader implementation for microcontrollers of various manufacturers.

Table 1. Comparison of parameters for three construction approaches.

Architecture	Essence	Advantages
Software-defined network	Adaptation of dynamic routing policies of the network state	– minimize delays – workload optimization – real-time delivery
Network of Objects	Configuration and management for smart devices as network objects	– reduce latency – provide maintainability – ensuring scalability
Edge-to-IoT	Changing the behavior of nodes according to the system requirements	– ensuring autonomy – reconfiguration capability – device collaboration

The case of using a modified bootloader for the S3C2440 microcontroller manufactured by Samsung was considered. Despite the prudently large amount of data memory of the microcontroller, to implement a device based on it with the possibility of reconfiguration using a bootloader, it took approximately 30% of the total size of its built-in memory. Thus, this modification reduced the controller resource by a third.

For the PIC18F66K80 series microcontrollers from the manufacturing company Microchip, the situation looks much better. When using a modified bootloader, it was possible to fit it into 6% of the total volume of the microcontroller's built-in memory. It should be noted that the controller has a significantly smaller amount of memory.

In case of ATMega series microcontrollers, manufactured by Atmel Corporation it can be noticed, that due to the community development of these controllers, the number of modification variations for bootloaders is much greater than that of the previously considered analogues. In view of this, there is a tendency for the size of the bootloader to depend on the functions embedded in it. Considering the most common version of the bootloader, it was found that the size of the memory it occupies does not exceed 3% of the total amount of built-in memory.

Based on the above data, a Table 2 was generated to compare the internal resources of the considered controllers with the requirements necessary for modification.

Based on the results, it should be noted that all the described bootloader implementations have a number of disadvantages associated with the features of the microcontroller. In one case, the loader may be implemented with limited capabilities, in another it may be redundant for its scope of application. The analysis showed that the quality of the modification largely depends on the device used.

Table 2. Comparison of parameters of bootloaders for different microcontrollers.

Manufacturer	Microcontroller	Program/Data memory, Pins	Bootloader requirements
Samsung	S3C2440	47 KB/16 KB, 289 pins	16 KB of Program Memory(34%)
Microchip	PIC18F66K80	64 KB/3648 B, 64 pins	4 KB of Program Memory(6%)
Atmel	ATmega	32 KB/1 KB, 32 pins	1 KB of Program Memory(3%)

4 Proposed Programming Method of Bootloader as Middleware

As a separate element can be the possibility of using an intermediate level to organize the execution of calculations as part of such bootloaders. In other words, it can be called as an intermediate level within the bootloader. It is proposed to use a preset in the case when it is not possible to reflash the bootloader using its resources to perform the operation. This implies creating a bootloader with a primitive API to implement everything else. The idea is that when developing a bootloader, it should be possible to reconfigure it using some higher level, some software interface that allows to execute these commands within the microcontroller, in order to, based on these commands within the microcontroller, perform more complex sequences of actions, without direct access to this microcontroller. It is also proposed to implement the idea of the possibility of reconfiguring and flashing the microcontroller based on such solutions. In this case, it becomes possible to carry out remote reprogramming of the microcontroller using built-in APIs or certain pre-installed capabilities as part of such a bootloader in order to carry out reprogramming at a higher level of the module.

An example of this could be sending a request from a set of high-level commands to such a bootloader, he can write these commands into the EEPROM, and then after receiving a complete set of such a sequence of commands, he can simply begin sequentially executing them using built-in elements and based on this sequence, according to Essentially, reflash parts of the behavior.

Another example would be the use of commands in EEPROM as a direct program for execution by the microcontroller. In this case, there is the possibility of using such a microcontroller or a set of microcontrollers with the main idea, when such, in fact, specialized commands and tasks that must be implemented using these microcontrollers can be written directly not to flash memory, but to the EEPROM of the microcontroller. In this case, absolutely all nodes must initially be flashed using a bootloader specialized for such tasks, which provides a set of such calls, and then after that it is possible, using standard interfaces for interaction between microcontrollers, including remote ones, to directly implement programs into each individual node, in order to later record it in EEPROM.

In this case, EEPROM can act as memory for the program, and initially all controllers can contain the same bootloader, but the actual set of instructions that need to be executed

can be contained in EEPROM. In this case, the bootloader itself and the program written to the controller can act as some basic mechanism and basis for executing instructions written in the EEPROM. In this case, there is a ban on using a larger amount of flash memory as part of the microcontroller in order to write these programs there, among other things.

An API or some basic set of functions included in such a bootloader may allow this to be done. At the same time, the rewriting resource should also allow the use of flash memory for such tasks. If such a mechanism is provided, it will significantly increase the flexibility of microcontroller-based solutions and provide reconfigurability at the hardware level.

5 Practical Example of Use of Proposed Programming Method

Based on the proposed programming method of the use of higher level of abstraction with the replaceable software modules for microcontroller programming the practical example for infrared communication system was created based on ATmega328P chip. This device is the component of smart home that allows remote control of different devices over infrared channel. To fit the requirement of convenient process of adding the support of control for new home electronics the ability of reconfiguration of the created component was implemented. The use of text format of communication with this device over the central coordinator allows to perform updating the content of EEPROM with stored set of commands without reprogramming directly in-system. The possibility of communication between few instances of such devices is implemented with the prototyped own stable protocol of message encoding.

The example of representation of the package of dataset 0x02 for transmitting with use of created implementation contains the start pulse package of 2 ms and rest pulse packages of 1 ms (see Fig. 1). To improve stability in noisy environment and simplify the decoding process the bit value is encoded by duration between ends of packages.

The existing microcontroller-based solutions for communication over the infrared channel assume the possibility to assign the set of commands at the stage of compilation of the project or with use of programmer to store the data with set of commands in EEPROM. The created implementation use the fixed set of commands in created bootloader to perform the assignment and updating the set of commands with use of serial interface UART. The proposed implementation allows the modification of the set of commands without the connection of the programmer to microcontroller.

Additional modification of program or bootloader of microcontroller allows to use the flash memory to store more commands or to involve the chips without EEPROM.

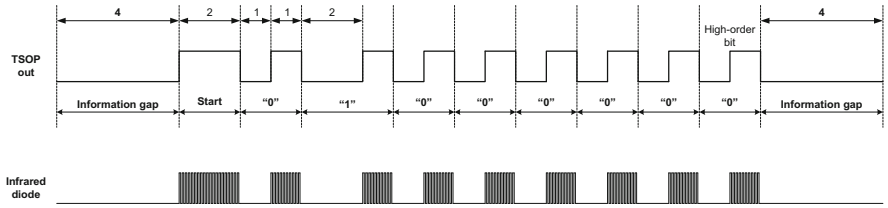

Fig. 1. A representation of the encoded informational package as an example of high level configuration data stored in EEPROM for transmitting over infrared channel by created system.

6 Conclusions

In the work the tools, technologies and methods of reconfiguration of IoT components were analyzed. Subsequently, considering the existing types of systems that are predisposed to changing the internal structure for the needs of the system, they were classified according to the level of organization for their reconfigurable part.

According to obtained preliminary classification, a number of practical solutions for improving performance characteristics using various types of reconfiguration were considered. For the examples considered, a number of qualitative characteristics inherent to these classes of organization of the reconfigurable part of the systems were identified. An initial analysis of them was also given in relation to task of increasing service life of systems and bypassing defects that lead the system to a state of failure.

To solve the problem of providing a reconfiguration function for microcontroller-based systems, the analysis of practical solutions was carried out for modification of built-in components of microcontrollers for managing and updating their firmware.

The performed practical implementation of the proposed way of reconfiguration with representation of bootloader as the set of API of controller shows the possibility of dividing a program by informational part and mechanisms for updating of this part. The informational part can be places in both EEPROM or in flash memory. For the considered examples, a number of quantitative characteristics have been identified that demonstrate a dependence of involved resources on its model and configuration. Initial analysis is also given in terms of accessibility and complexity of modification.

Main contribution of this work is the proposed programming method with replaceable software modules for microcontroller and the obtained results of competitive analysis of ways of modification of components and the features of bootloaders.

The improvement of ways of communication and reconfiguration of IoT components are the main direction of the further research. As part of further development of the topic, it is planned to study the cybersecurity aspects of a reconfiguration channel. It is planned to study the topic of existing threats to IoT systems, and to analyze the vulnerabilities for these threats, and to consider methods and means of protection.

In addition to cybersecurity aspects, the approaches to implementing of access and control of nodes in reconfigurable systems can be considered as important field for research, as well as the control abstraction levels, structural and logical specifications.

References

1. Vdovichenko, O., Perepelitsyn, A.: Technologies for building systems of remote lining of communication lines: a practical example of implementation. Radioelectronic Comput. Syst. **2**(98), 31–38 (2021)
2. Perepelitsyn, A., Duzhyi, V., Vdovichenko, O., Zheltukhin, O.: Technologies of embedded systems prototyping using reconfigurable nodes: technical solutions. In: 12th International Conference on Dependable Systems. Services and Technologies (DESSERT), pp. 1–6. Greece, Athens (2022)
3. Plakhteyev, A., Perepelitsyn, A., Frolov, V.: Edge computing for IoT: an educational case study. In: 2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies (DESSERT), pp. 130–133, Kyiv, Ukraine (2018)
4. Vdovichenko, O., Perepelitsyn, A., Duzhyi, V., Zheltukhin, O.: Method of remote diagnostics, reprogramming and reconfiguration of nodes of embedded system. Aerosp. Tech. Technol. **6**(184), 66–75 (2022)
5. Dhananjay, P.M., Chaudhari, B.S.: Design and performance analysis of IIoT topologies using SDN. In: International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering (ICRIEECE), Bhubaneswar, India, pp. 2547–2551. IEEE (2018)
6. Bonanni, M., Chiti, F., Fantacci, R., Pierucci, L.: Dynamic control architecture based on software defined networking for the Internet of Things. Future Internet J. **13**(5), 1–15 (2021)
7. Brut, M., et al.: When devices become collaborative: supporting device interoperability and behaviour reconfiguration across emergency management scenario. In: IEEE World Forum on Internet of Things (WF-IoT), Seoul, Korea (South), pp. 259–264. IEEE (2014)
8. Marotta, M.A., Carbone, F.J., Cardoso-Santanna, J.J., Rockenbach-Tarouco, L.M.: Through the Internet of Things – a management by delegation smart object aware system (MbD-SAS). In: IEEE 37th Annual Computer Software and Applications Conference, Kyoto, Japan, pp. 732–741. IEEE (2013)
9. Carnevale, L., Ruggeri, A., Martella, F., Celesti, A., Fazio, M., Villari, M.: Multi hop reconfiguration of end-devices in heterogeneous edge-IoT mesh networks. In: IEEE Symposium on Computers and Communications (ISCC), Athens, Greece, pp. 431–438. IEEE (2021)
10. Rahman, T., Xuanxia, Y., Gang, T., Huansheng, N., Zhangbing, Z.: Efficient edge nodes reconfiguration and selection for the Internet of Things. IEEE Sens. J. **19**(12), 4672–4679 (2019)
11. Rahman, G.M.E., Wahid, K.A.: LDAP: lightweight dynamic auto-reconfigurable protocol in an IoT-enabled WSN for wide-area remote monitoring. Remote Sens. J. **12**(19), 1–21 (2020)
12. Siddiqui, A.S., Gui, Y., Saqib, F.: Secure boot for reconfigurable architectures. Crypt. J. **4**(4), 1–15 (2020)
13. Johnson, A.P., Patranabis, S., Chakraborty, R.S., Mukhopadhyay, D.: Remote dynamic clock reconfiguration based attacks on internet of things applications. In: Euromicro Conference on Digital System Design (DSD), Limassol, Cyprus, pp. 431–438. IEEE (2016)
14. Radovici, A., Culic, I., Rosner, D., Oprea, F.: A model for the remote deployment, update, and safe recovery for commercial sensor-based IoT systems. Sens. J. **20**(16), 1–34 (2020)
15. Bîrleanu, F.G., Bizon, N.: Lightweight cryptography for Internet of Things using FPGA-based design with partial reconfiguration. In: 12th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), Bucharest, Romania, pp. 1–7. IEEE (2020)
16. Albuquerque, R.T., Fröhlich, A.A.: Operating system support for difference-based partial hardware reconfiguration. In: IEEE/IFIP International Symposium on Rapid System Prototyping, Paris, France, pp. 75–80. IEEE (2009)
17. Chen, S., Zhu-Ying, L.: Design optimization and implementation of bootloader in embedded system development. In: International Conference on Computer Science and Applications (CSA), Wuhan, China, pp. 151–156. IEEE (2015)

18. Priyanka, P.S., Gnanadas, M., Supriya, P.: Standalone portable host for unified bootloader in PIC devices using CAN interface. In: 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT), Kharagpur, India, pp. 1–4. IEEE (2020)
19. Bo, Q., Zhaozhi, W.: Design of built-in boot loader for ARM uCOS. In: IEEE International Conference on Computer Science and Automation Engineering (CSAE), Zhangjiajie, China, pp. 429–433. IEEE (2012)
20. Yanbo, K., Jiaxu, C., Bing, L.: Generic bootloader architecture based on automatic update mechanism. In: IEEE 3rd International Conference on Signal and Image Processing (ICSIP), Shenzhen, China, pp. 586–590. IEEE (2018)
21. Lewandowski, M., Orczyk, T., Porwik, P.: Dedicated AVR bootloader for performance improvement of prototyping process. In: MIXDES - 24th International Conference Mixed Design of Integrated Circuits and Systems, Bydgoszcz, Poland, pp. 553–557. IEEE (2017)

Security Analysis of Meteorological Support Software for UAS Flight Planning

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Abstract. The unmanned aircraft system (UAS) operation depends on the weather significantly. This was the motivation to develop the decision support system that analyzes the range of factors including general and operative weather, type of aircraft, mission sensors, and area of flight to help remote pilots in their decision-making at the pre-flight stage and during the flight operation. Taking into account the cyber-physical nature of modern UAS it is important to evaluate the possible cyber risks that can be encountered during the operation of developed software. In this paper, the attack trees are built to understand how and for what reasons attacks on the software environment, database, or drone used to carry out the mission occur. The consequences of the cyber hazards are analyzed and some decisions on risk mitigations are made.

Keywords: UAS · Air Navigation · Weather hazards · Software · Cyber threats · Decision Support · Risk analysis

1 Introduction

Unmanned aircraft nowadays are considered and used as a promising tool for many civilian and military applications [1–3]. In turn, unmanned aircraft is a component of a cyber and physical system that includes the aircraft itself and the set of equipment that is required for unmanned aircraft operation and mission realization. According to [4], UAS is the aircraft and other components that can be operated with no pilot on board. This equipment and components are used for unmanned aircraft control, communication and navigation. It also can include the components for mission realization. The range of modern new technologies operated remotely can appear to be unlawful interferences prone to a larger extent than manned by on-board pilot aircraft [5]. The wide range of sensors, communication, and navigation solutions from one side helps to enlarge the operational scope of the UAS application. From another side, this opens the way for malicious actions and cyber-attacks. Moreover, modern UAS information and cyber systems operate with data during the whole lifecycle of information for reliable and successful operations. This fact proves the importance of understanding, identifying, estimating, mitigating and managing the safety risks connected with cyber-attacks for ensuring the safety operations performed by UAS.

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1.1 State-of-the-Art

The overview of the general vulnerabilities, cyberattacks and approaches to mitigation are considered in [6, 7]. The analysis and events reported during the last years and connected with drone-powered cyber-attack events are discussed in [8–10]. The discussion shows the possibility to use drone for cyber-attack design and realization.

The overview of cyber incidents against drones is given in [11]. In this paper the potential cyber threats are considered from the position of possible spoiling confidentiality, integrity and availability to the data for successful operations. In paper [12] the security vulnerabilities and connected cyber threats to modern UASs were analyzed and assessed with consideration of possible mitigation measures. In paper [13] the risks to control systems that should be taken into account at the state of sensors development are investigated. The paper focusing on possible cyber-attacks to the aircraft attitude sensors and considers the fault data injection (FDI) attacks. In paper [14] the system for cyber-attack detection as intrusion using the leveraging deep learning is presented. Analysis of such cyber-attacks as jamming and spoofing is presented in [15]. In papers [16–19] the solutions for spoofing suppression are presented array. In paper [16] the design of antenna array for spoofing detection and suppression from arbitrary direction is presented. In paper [17] a method for spoofing detection using Inertial Navigation Systems based on temporal behavior of spoofed signals is presented. In paper [18] the approach for separation of GNSS spoofing from authentic signals based on relative positioning is proposed and simulations using the Monte Carlo method is done. In paper [19] a method and algorithm for GNSS spoofing suppression with a five-element antenna array from four directions are shown and discussed. In this paper the developed methods of interference and spoofing suppression to the simultaneously working GPS, GLONASS, GALILEO, BEIDOU, and QZSS systems is discussed. More Unmanned Aerial Vehicle Attacks and Neutralization Techniques are analyzed in [20]. The technical risks to UAS flight and mission performance as well as discussion on cyber risk management is presented in [21]. In this work the functional models of different potential attacks at the pre- and in-flight stages are shown and discussed including software attacks. In work [22] the preflight software attacks as fault injection and authentication bypass are considered.

Obviously, the target for cyber threats is the software that can be used for preflight preparation and during the flight. The examples of the software that are used during the pre-flight stage are the firmware of autopilot or different applications for flight planning and management. The examples of the software that can be used in flight software for control and monitoring onboard sensors, flight controllers as well. Some cyber risks to the UAS software are discussed in [11]. The survey of the challenges to autonomous flights due to cyber risks including UAS software is presented in [23]. In work [22] the categorization of the attacks is made and recommendation mitigative measures are proposed. Many current countermeasures and recommendations to mitigate risks for software include intrusion detection, software patching, authorization as well as installation of different anti-malware software. Papers [23, 24] considers the decision to the intrusion systems detection. Papers [25–28] consider the application of artificial intelligence for intrusion detection and mitigation. Papers [29, 30] considers the approaches to identity authentication when communication between unmanned aircraft and ground stations.

1.2 Motivation

As it was mentioned, the UAS is an information-based system that can use communication, navigation, control computer-based systems and networks with corresponding software. In papers [31, 32] it was proposed the software solution for decision-making automation of remote pilots under different weather conditions. The proposed software and decision-support system (DSS) [33] short overview is presented in the next paragraph of this paper. Then, the motivation was to investigate the vulnerabilities and cyber threats that can arise during the DSS operation and assess the possible cyber risks. The risk mitigation strategies are also discussed in the paper.

2 The Software Architecture for Decision-Making Support when UAS Flight Planning

Atmosphere characteristics and weather phenomena influence the aircraft including remotely piloted aircraft significantly. A lot of UAS flights of general applications perform their flights in the lower layer of the atmosphere and have rather small dimensions and low weight. These facts underline the importance of considering additional weather hazards formed in the so-called boundary layer of the atmosphere. For example, wind-related phenomena appear because of the presence of obstacles on the ground. The obstacles can be of natural origin (hills, ravines, etc.) or manmade (buildings, bridges, houses, etc.). The overview of the weather-related hazards for UAS flights and is presented in [34–36]. The DSS was developed to help the pilot in their decision-making when flight planning under different weather conditions. The interface of the DSS is shown in Fig. 1. It is possible to see from Fig. 1 that decision-making is based on the next information and risk-oriented approach [37, 38]:

- type of aircraft,
- planned mission,
- apparatus and sensors for flight control and mission realization
- peculiarities of the planned area of flight,
- general aviation meteorological information,
- real-time meteorological information for the area of planned flight,
- information on low-level turbulence forecast based on real-time meteorological information in the area of planned flight.

The low-level turbulence forecast is based on the information obtained from the distributed network of stationary wind sensors and mobile sensors. The mobile sensors are unmanned aircraft that perform flight in the particular area as it is proposed in the concept [33]. The model for low-level turbulence forecast is also a separate task for study. In the current version of the developed software, we use the model proposed in [39].

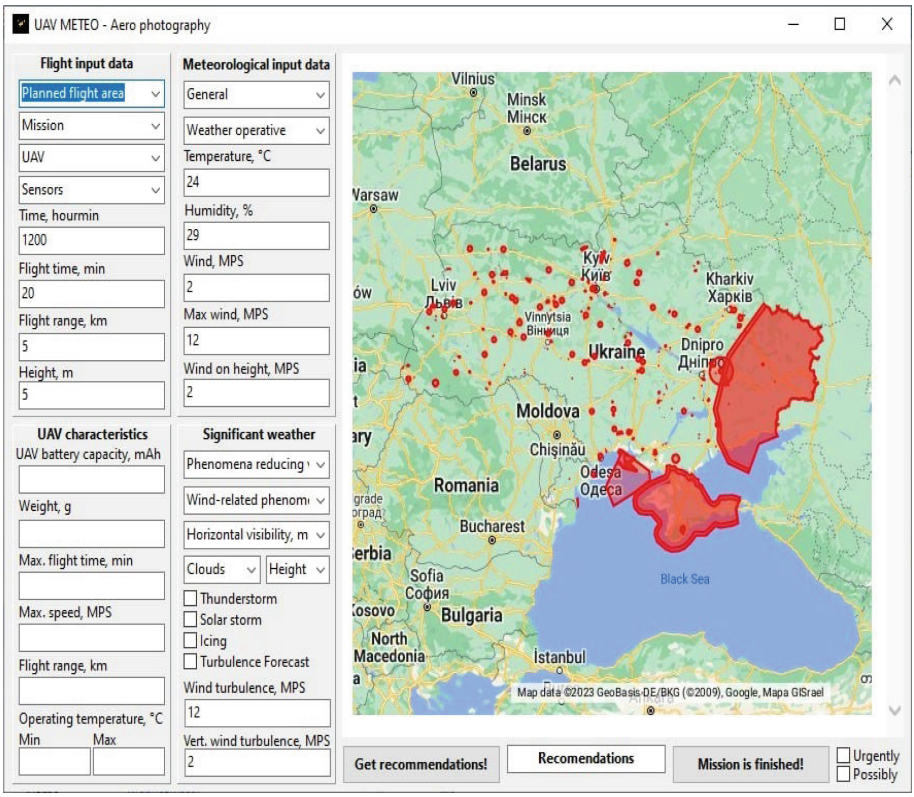

Fig. 1. An Interface of the DSS.

The software uses the map where forbidden UAS flight areas are indicated. It is possible to see red areas in Fig. 1. The approach considered in [32, 33] is aimed at mapping temporary forbidden areas due to the presence of weather hazards. The temporary forbidden areas can be identified during the unmanned aircraft flight, matching the dangerous phenomena position with GPS coordinates and sharing the information to the common database.

The Software architecture for the developed DSS is demonstrated with the deployment diagram shown in Fig. 2.

Figure 2 shows the placement of parts of the system in space. It includes a cloud database with operational weather information flowing from Previous unmanned aircraft, Neighboring unmanned aircraft and Current unmanned aircraft, which requires recommendations from DSS, and from two personal computers (PC) - nodes with installed software. The first PC includes Meteorological support for decision-making by the UAS operator application with a component such as a map forbidden for UAS flight areas. The second PC includes a Weather application with a copy of the database.

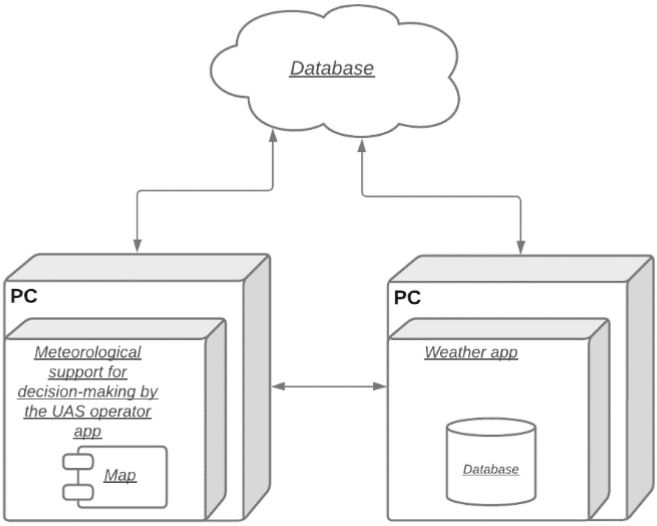

Fig. 2. Deployment diagram.

3 Attack Tree of Cyber Risks to DSS Software

To understand the cyber threats to the developed software and then to assess the risks that can arise during the operation with DSS we consider the cyber threats and vulnerabilities from the position of their influence on confidentiality, integrity and availability. We use this triad as the most important concept for cyber security [40].

To identify, analyze and study the possible cyber threats we have developed the tree attack trees. The attack tree is a relatively convenient tool for understanding the target of the attack, assets that may be attacked and ways or instruments for attack realization [41].

Figures 3, 4 and 5 show the attack trees for collaborative software development. These diagrams provide a clear definition of how and for what reasons attacks on the software environment, database, or drone used to carry out the mission occur. The main impact on the aircraft and on the database that builds the mission route, meteorological data and flight analysis is cyber threats and information intrusion. Unauthorized access to UAV data can lead to the leakage of confidential information.

Each attack tree is a graphical representation of potential attack vectors that may occur in the system.

The privacy attacks shown in Fig. 3 can be aimed at leaking sensitive information. This can include traffic interception, authentication attacks, or physical access to the database or program code. For example, an attacker may use methods to intercept and decode communications between the drone and the control station. Attempts at unauthorized access may include attacks on authentication systems, such as intercepting and exploiting authentic accounts. This can be avoided by applying the latest authentication and two-factor authentication methods.

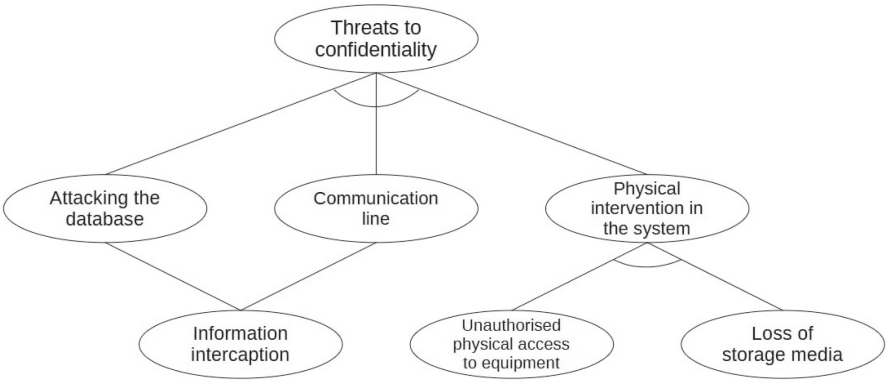

Fig. 3. Attack tree (aim is breaking confidentiality)

The hazards that are presented in Table 1 lead to the unauthorized familiarization with meteorological information. Taking into account the character and sensitivity of the information the consequences are assessed as insignificant and minor. The difference is that interception of information from the database in contrast to interception of operative information deals with the data that does not influence current flight planning. So, the severity of the consequences of the attacks on the database was considered as insignificant.

Table 1. Cyber hazards severity of consequences breaking confidentiality

Hazards	The severity of the consequences
Information interception	Minor
Unauthorized physical access to equipment	Insignificant
Loss of storage media	Insignificant

Figure 4 shows attacks on software integrity. They can include attempts to modify code or data transmitted between systems to cause the system to behave incorrectly. This is a rather complex system in terms of protection against unauthorized persons. The reason for this is public access, where an unscrupulous person can introduce their code or modify existing code to cause incorrect system behavior.

The results of the approach to assess the severity of the hazards that can influence the integrity of the developed software are summarized in Table 2.

The results of viruses and unauthorized modification of the software are considered as catastrophic as the modification of the meteorological information during the unmanned aircraft operation can lead to an aircraft crash and even people injured. An example of such modification is unauthorized putting the data about favorable weather conditions while in reality, hazardous weather situations can be present. The damage during the mission is assessed as a situation with minor consequences because in this

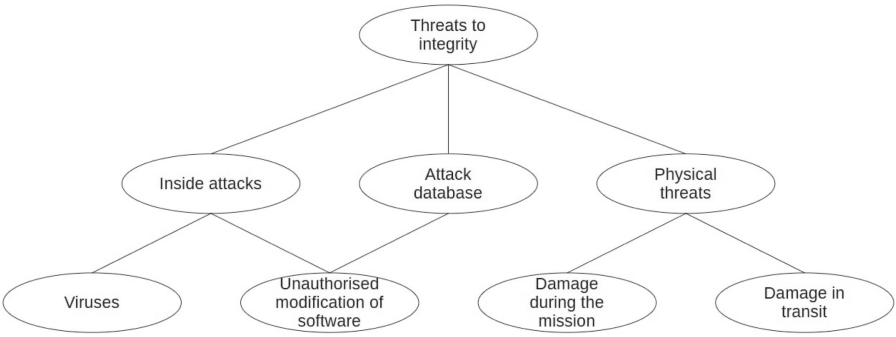

Fig. 4. Attack tree (aim is breaking integrity)

Table 2. Cyber hazards severity of consequences for breaking integrity

Hazards	The severity of the consequences
Viruses	Catastrophic
Unauthorized modification of the software	Catastrophic
Damage during the mission	Minor
Damage in transit	Insignificant

case the operation of the unmanned aircraft will be based on the forecasted and current information that was obtained during the pre-flight stage. Damage in transit can be revealed before the aircraft operation thus the consequences can be considered as minor.

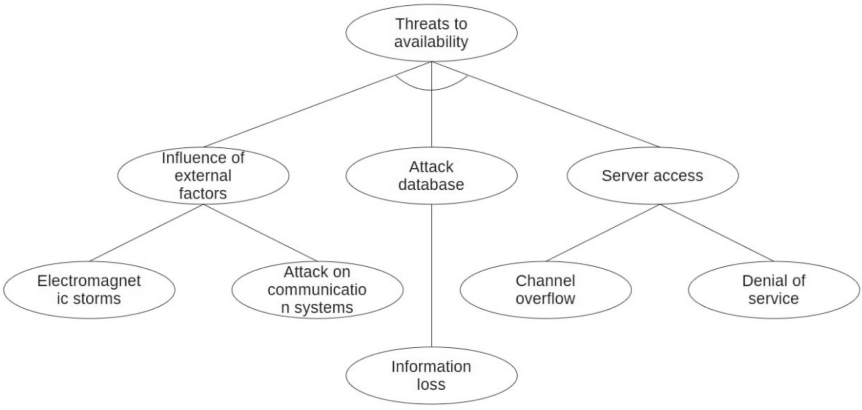

Fig. 5. Attack tree (aim is breaking availability)

Figure 5 shows availability attacks aimed at causing interruptions in the normal functioning of the system. This can include attacks on network traffic or on the processes of the software's internal logic itself. This could include attempts to hack into the software that controls and transmits data from the drone to the server and route management base.

The results of the approach to assessing the severity of the hazards that can influence the availability of the developed software are summarized in Table 3.

Table 3. Cyber hazards severity of consequences for breaking availability

Hazards	the severity of the consequences
Electromagnetic storm	Significant
Attack on the communication system	Minor\Significant
Channel Overflow	Insignificant\Minor\Significant
Denial of service	Insignificant\Minor\Significant

Electromagnetic interferences can affect the GPS signal, thus, the unmanned aircraft can enter the temporary forbidden areas due to weather hazards. The control of unmanned aircraft behavior can help to recover from the potentially hazardous region. Therefore, these hazards were assessed as significant. The other consequences of the attacks from the table are assessed as Minor\Significant Insignificant\Minor\Significant can sufficiently depend on a deviation of the current state of atmosphere from the conditions that were observed and forecasted during the pre-flight stage.

4 Conclusions and Future Plans

In this paper, we discussed the cyber security issues connected with software for meteorological support of UAS operations. The analyzed software realizes the DSS for remote pilots during the different stages of UAS flight. It also can be used as an additional component of the UAS control system that provides meteorological support for unmanned aircraft flights. The attack trees that were analyzed in this study help to understand how and for what reasons attacks on the software environment, database, or drone can be realized. The possible consequences are considered and assessed. The study is intended to understand and choose the best strategies for secure operations of UAS for different missions.

For cyber risk assessment, it is important to make a study on the evaluation of hazard probability. Then our plan is to consider and choose the methods and tools for software security provision.

References

1. Mourtzis, D., Angelopoulos, J., Panopoulos, N.: UAVs for industrial applications: identifying challenges and opportunities from the implementation point of view. Procedia Manuf. **55**, 183–190 (2021)
2. Unmanned Aircraft Systems (UAS) DoD purposes and operational use. https://dod.defense.gov/UAS. Accessed 30 Nov 2023
3. Gargalakos, M.: The role of unmanned aerial vehicles in military communications: application scenarios, current trends, and beyond. J. Defense Model. Simul. Appl. Methodol. Technol. Special Issue **00**(0), 1–9 (2021). https://doi.org/10.1177/15485129211031668
4. ICAO Cir 328-AN/190, Unmanned aircraft system (2011)
5. Cosar, M.: Cyber attacks on unmanned aerial vehicles and cyber security measures. Eurasia Proc. Sci. Technol. Eng. Math. **21**, 258–265 (2022)
6. Averyanova, Yu., Blahaja, L.: A study on unmanned aerial system vulnerabilities for durability enhancement. In: Proceedings of the 5th International Conference on Actual Problems of Un-manned Aerial Vehicles Development, APUAVD-2019, 22–24 October, Kyiv, Ukraine (2019)
7. Alexandre, R., Martins, L., Gorschek, T.: Cybersecurity risk assessment for medium-risk drones: a systematic literature review. IEEE Aerosp. Electron. Syst. Mag. **38**(6), 28–43 (2023)
8. The drone cyberattack that breached a corporate network. https://blogs.blackberry.com/en/2022/10/the-drone-cyberattack-that-breached-a-corporate-network. Accessed 30 Nov 2023
9. Bressler, M.S., Bressler, L.: Beware the unfriendly skies: how drones are being used as the latest weapon in cybercrime. J. Technol. Res. **7**, 1–12 (2018)
10. Scott, C.: Corporate Espionage by Drone: Why Corporations Need Better Physical and Legal Protections. SSRN. https://ssrn.com/abstract=3772434. https://doi.org/10.2139/ssrn.3772434. Accessed 30 Nov 2023
11. Oruc, A.: Potential cyber threats, vulnerabilities, and protections of unmanned vehicles. Drone Syst. Appl. **10**(1), 51–58 (2022)
12. Averyanova, Y., et al.: UAS cyber security hazards analysis and approach to qualitative assessment. In: Shukla, S., Unal, A., Kureethara, J.V., Mishra, D.K., Han, D.S. (eds.) Data Science and Security. LNNS, vol. 290, pp. 258–265. Springer, Singapore (2021). https://doi.org/10.1007/978-981-16-4486-3_28
13. Abbaspoura, A., Yena, K.K., Noeib, S., Sargolzaeic, A.: Detection of fault data injection attack on UAV using adaptive neural network. Procedia Comput. Sci. **95**, 193–200 (2016)
14. Ashraf, S.N., Manickam, S., Zia, S.S., et al.: IoT empowered smart cybersecurity framework for intrusion detection in internet of drones. Sci. Rep. **13**, 18422 (2023)
15. Nascimento Aquilar Pey, J., Daniel Amvame Nze, G., de Oliveira Albuquerque, R.: Analysis of jamming and spoofing cyber-attacks on drones. In: 17th Iberian Conference on Information Systems and Technologies (CISTI), Madrid, Spain, pp. 1–4 (2022)
16. Konin, V., Averyanova, Y., Ishchenko, O.: Aircraft antenna array for spoofing suppression from upper and lower hemispheres. In: 2022 IEEE 2nd Ukrainian Microwave Week (UkrMW), Ukraine, pp. 596–599 (2022)
17. Kujur, B., Khanafseh, S., Pervan, B.: Detecting GNSS spoofing using temporal behavior of spoofed signals. In: Proceedings of the 34th International Technical Meeting of the Satellite Division of the Institute of Navigation, ION GNSS+ 2021, St. Louis, Missouri, pp. 3668–3682 (2021)

18. Chen, Z., Li, H., Ziheng, Z., Lu, M.: An approach to separate GNSS spoofing signals from authentic signals using relative positioning. In: Proceedings of the 34th International Technical Meeting of the Satellite Division of the Institute of Navigation, ION GNSS+ 2021, St. Louis, Missouri, pp. 3642–3652 (2021)
19. Averyanova, Y., Kutsenko, O., Konin, V.: Interference suppression at cooperative use of GPS, GLONASS, GALILEO, BEIDOU. In: Proceedings of the 2020 IEEE Ukrainian Microwave Week, UkrMW 2020, pp. 44–48 (2020)
20. Chamola, V., Kotesh, P., Agarwal, A., Naren, Gupta, N., Guizani, M.: A comprehensive review of unmanned aerial vehicle attacks and neutralization techniques. Ad Hoc Netw. **111**, 102324 (2021)
21. Fiondella, L., Baker, C. D., Polito, K. E., Pollack, S.: The application of unmanned aerial. In: Surface Transportation - Volume II-F: Drone Cyber Security: Assurance Methods and Standards. Report No. 19-010, December 2019
22. Durfey, N., Sajal, S.: A comprehensive survey: cybersecurity challenges and futures of autonomous drones. In: 2022 Intermountain Engineering, Technology and Computing (IETC), Orem, UT, USA, pp. 1–7 (2022)
23. Condomines, J.-P., Zhang, R., Larrieu, N.: Network intrusion detection system for UAV ad-hoc communication: from methodology design to real test validation. Ad Hoc Netw. **90**, 101759 (2019)
24. Straub, J.: Development and testing of an intrusion detection system for unmanned aerial systems. In: 2017 IEEE/AIAA 36th Digital Avionics Systems Conference (DASC), St. Petersburg, FL, USA, pp. 1–9 (2017)
25. Whelan, J., Almehmadi, A., El-Khatib, K.: Artificial intelligence for intrusion detection systems in unmanned aerial vehicles. Comput. Electr. Eng. **99**, 107784 (2022)
26. Pérez-Cutiño, M.A., Gómez Eguíluz, A., Martínez-de Dios, J.R., Ollero, A.: Event-based human intrusion detection in UAS using Deep Learning. In: International Conference on Unmanned Aircraft Systems (ICUAS), Athens, Greece, pp. 91–100 (2021)
27. Abu Al-Haija, Q., Al Badawi, A.: High-performance intrusion detection system for networked UAVs via deep learning. Neural Comput. Appl. **34**, 10885–10900 (2022)
28. Rahman, M.A., Rahman, M.T., Kisacikoglu, M., Akkaya, K.: Intrusion detection systems-enabled power electronics for unmanned aerial vehicles. In: 2020 IEEE CyberPELS (CyberPELS), Miami, FL, USA, pp. 1–5 (2020)
29. Xia, T., Wang, M., He, J., Lin, S., Shi, Y., Guo, L.: Research on identity authentication scheme for UAV communication network. Electronics **12**, 2917 (2023)
30. Michailidis, E.T., Vouyioukas, D.: A review on software-based and hardware-based authentication mechanisms for the internet of drones. Drones **6**, 41 (2022)
31. Averyanova, Y., Znakovska, Y.: Optimizing UAS missions with advanced weather monitoring and analysis software. In: Ortiz-Rodríguez, F., Tiwari, S., Usoro Usip, P., Palma, R. (eds.) Electronic Governance with Emerging Technologies, EGETC 2023. CCIS, vol. 1888, pp. 12–23 (2023). https://doi.org/10.1007/978-3-031-43940-7_2
32. Znakovska, Y., Averyanova, Y.: Simulation of UAS operator's decision-making under different weather conditions. In: Proceedings of the 4th International Conference on Modern Electrical and Energy System (MEES), Ukraine, pp. 1–4. IEEE (2022)
33. Averyanova, Y., Znakovska, Y.: Decision-making automation for UAS operators using operative meteorological information. CEUR Workshop Proc. **3468**, 139–149 (2023)
34. Averyanova, Yu., Znakovskaja, E.: Weather hazards analysis for small UASs durability enhancement. In: Proceedings of the 6th International Conference on Actual Problems of Unmanned Air Vehicles Developments (APUAVD), Ukraine, pp. 41–44. IEEE (2021)

35. Larin, V., Kuzmenko, N., Ostroumov, I., Zaliskyi, M., Solomentsev, O., Sushchenko, O.: Turbulence detection and classification algorithm using data from AWR. In: Proceedings of the 2nd Ukrainian Microwave Week (UkrMW), pp. 518–522. IEEE (2022)
36. Yanovsky, F., Ostroumov, I., Shchebina, O., Kuzmenko, N., Sushchenko, O., Zaliskyi, M.: Model for wind-related phenomena estimation using polarization characteristics of microwave radar signal. In: Proceeding of the 16th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering, pp. 173–177 (2022)
37. Key risk Areas of remotely piloted aircraft systems (RPAS), Safety Intelligence and Performance SM1.1, Report, EASA (2016). https://skybrary.aero/articles/key-risk-areas-remotely-piloted-aircraft-systems-rpas. Accessed 30 Nov 2023
38. Flight Safety Analysis Handbook, FAA, Version 1.0 (2011)
39. Fast Eddy, Model. https://github.com/NCAR/FastEddy-model. Accessed 30 Nov 2023
40. Fenrich, K.: Securing your control system: the "CIA triad" is a widely used benchmark for evaluating information system security effectiveness. Power Eng. **112**(2), 44+ (2008)
41. Vitkus, D., Salter, J., Goranin, N., Čeponis, D.: Method for attack tree data transformation and import into IT risk analysis expert systems. Appl. Sci. **10**(23), 8423 (2020)

Approaches to Structuring Control in an Automated Mobile System

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Abstract. The management of unmanned technology is becoming increasingly important in various fields, including the aviation industry, geodesy, the agricultural sector, and many others. To ensure efficient and safe management, most robots require the use of various remote-control systems, which can be complex and overly costly. However, the Cascade DataHub method offers a new approach to organizing the management of unmanned technology, based on integrating real-time data from various sources into a single platform. This method provides fast and convenient access to important data for decision-making, improves the accuracy and efficiency of unmanned aerial vehicle management, and reduces remote control costs. In this article, we will delve deeper into the Cascade DataHub method and its application for organizing work management, as well as analyse its advantages and disadvantages.

The Cascade DataHub method allows for creating a unified platform for collecting, processing, and analysing data from unmanned aerial vehicles. This method enables the integration of various data sources, such as GPS, cameras, sensors, other control, and monitoring systems, into a unified system that allows monitoring, analysis, and real-time management of the devices.

The key feature of the method is the ability to create various connections between data, allowing the analysis and control of robots from different perspectives. Thanks to real-time data processing technology, operators can instantly respond to dangerous situations, enhancing the safety and reliability of management.

Furthermore, the Cascade DataHub method helps reduce drone management costs by enabling control and monitoring of agents remotely from a convenient location, reducing the need for a large amount of specialized equipment and personnel.

Despite the advantages of the Cascade DataHub method, it also has its drawbacks. One of the biggest drawbacks is the need for high-speed internet connection to transmit a large amount of data in real-time. There may also be issues with system stability in unforeseen situations, such as the disconnection of one of the data sources.

Keywords: Unmanned Technology Management · Cascade DataHub Method · Real-Time Data Integration · Artificial Neural Networks · Fuzzy Hybrid Systems

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1 Introduction

In recent decades, robotics has seen increasing prevalence across various sectors, including military, public, and industrial domains. However, managing robots entails handling vast amounts of data, analyzing it, and making real-time decisions. Effective robot management necessitates a system capable of collecting, storing, processing, and analyzing data in real-time. Consequently, methods and algorithms for robot management have become subjects of active research and development. Recent years have witnessed a surge in interest in machine learning methods, particularly deep learning, which has found successful applications in numerous fields [1].

One such method is the Cascade DataHub - a neural network architecture that boosts learning speed and reduces the volume of training data. The Cascade DataHub method proves to be an effective approach to organizing unmanned technology management. This article presents a system for managing unmanned vehicles capable of controlling a group of robots (a swarm). The aim of this article is to explore the possibilities of employing the Cascade DataHub method for organizing the management of an automated mobile system.

2 Analysis of Methods for Controlling an Automated Mobile System

Analyzing methods for managing an automated mobile system is a crucial component in the creation and operation of such systems. The primary stages of managing any system involve state measurement, comparing the current state with the desired one, and developing influence systems to compensate for the deviation from the desired state [2, 3].

Robot management typically occurs through an onboard navigation and control complex, incorporating an integrated navigation system with a satellite navigation receiver, a sensor and signal system, various antennas and sensors, an autopilot module, and a data storage and transmission system [1].

The onboard navigation and control system offer various capabilities such as movement along a specified route with precision to coordinate and height waypoints, altering route tasks, or returning to the starting point upon command from a ground control station. It also includes auto-tracking of a selected target, stabilization of the robot's orientation angles, maintaining prescribed flight heights and speeds, gathering and transmitting necessary flight information and parameters, and programming control of target equipment devices [3].

The general scheme of a drone control system (Fig. 1) displays the relationships between the ground-based hardware-software complex and the robot itself, exchanging information via a secured communication line. When processing input data, the programmer must consider various data formats and types to interpret them correctly and use them in further processing. For instance, when receiving textual data, it's essential to verify their accuracy, correctness, and ensure they contain necessary information for subsequent processing [6]. When receiving numerical data, it's crucial to check their value ranges and account for possible rounding errors or incorrect formatting. Thus, proper

handling of input data is a critical component of the effective software implementation of any task.

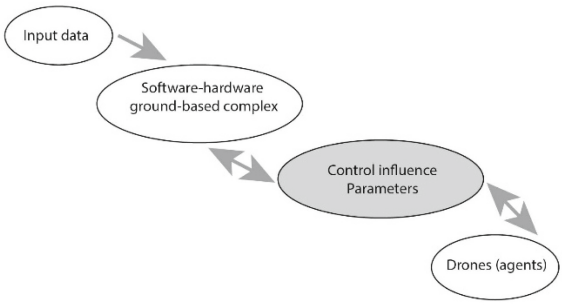

Fig. 1. General scheme of robot control system.

The information transmission and communication system between the robot and the ground hardware-software complex can operate through various communication channels, such as radio channels, communication networks, and via infrared and laser data transmission means. Additionally, data transmission can occur through satellite communication means, enabling data transfer over long distances [4, 8].

When groups of robots interact among themselves and with the ground hardware-software complex, there arises a need to employ communication protocols and action coordination algorithms. These protocols allow addressing tasks related to information gathering and operations within a group [5].

Moreover, to ensure safety during movement and robot management, a remote control and emergency shutdown system can be employed. This system allows operators from the ground complex to remotely interact and manage the robots in unforeseen situations.

Communication between robots and manned objects can be established through communication networks and specialized devices facilitating data exchange between these entities. Such interaction can be beneficial for coordinating and fostering collaboration between manned and unmanned objects. Additionally, data transmission and communication between robots can occur through radio channels or other communication channels, enabling action coordination among a swarm of robots with a shared task, as well as interaction between them and the ground hardware-software complex.

Beyond direct information exchange between robots and the ground hardware-software complex, data transmission through satellite links is also possible. This enables remote control over the unmanned vehicle, for instance, when the robot is at a considerable distance from the operator.

In scenarios where robots are utilized for missions in special conditions such as adverse weather or high radiation intensity, specialized communication channels can be employed to transmit information under those specific circumstances.

Therefore, the robot management system can be quite complex and dynamic. To ensure its effective operation, diverse information transmission technologies and communication methods between system components need to be employed [4, 7] (Fig. 2).

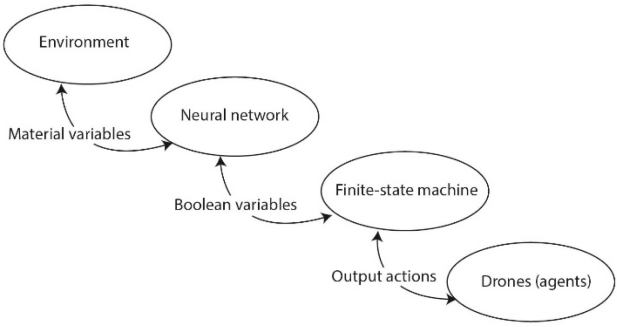

Fig. 2. Structural diagram of the swarm robot control system using genetic programming.

On Fig. 3, the structure of the neural network and its interaction with the finite automaton is depicted. Symbols 'S' denote neurons with sigmoid-like activation functions, while 'L' represents neurons with threshold activation functions. Nearby are the neuron numbers utilized in describing the cross-operation of the neural network. Each of the three neural network neurons receives a value that can be either zero or one. Consequently, there exist eight possible combinations of the neural network's output signals (000, 001, 010, 011, 100, 101, 110, 111) which are fed into the input of the finite automaton. This neural network structure and its interaction with the finite automaton can be utilized to address various tasks in the fields of machine learning and robotics [7].

The genetic programming algorithm used by the control system comprises the following stages:

1 - Creating an initial generation.
2 - Mutation.
3 - Crossover.
4 - Selecting individuals to form the next generation.
5 - Computing the fitness function.

Advantages of this system include its clarity, relative simplicity of implementation, lack of high hardware performance requirements, and its potential for various input variables.

Disadvantages include the practical inability to control a swarm as interactions with "neighbours" are evaluated based on past events only. Despite considering numerous parameters, simplifying them in the used system cannot provide a correct and objective evaluation of results. For instance, it does not account for changes in the surrounding environment and the robot's parameters dependent on it [9].

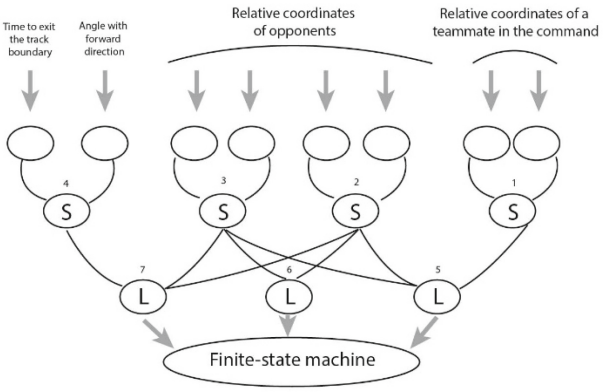

Fig. 3. Neural Network and Its Interaction with a Finite Automaton.

The analysis and synthesis method used involves reverse feedback linearization combined with fuzzy logical inference systems. Compared to "regular" linearization, applying this algorithm allows its use for significantly nonlinear control objects.

It is anticipated that reverse feedback linearization alongside fuzzy logical inference systems can be employed for managing diverse objects demonstrating substantial nonlinearity. This includes systems with variable parameters, systems affected by disturbances, or systems exhibiting nonlinear functions. Implementing this method enhances control precision and diminishes the impact of measurement errors on control quality.

Compared to conventional linearization, the reverse feedback linearization method enables the consideration of nonlinear effects within the system, thereby preserving a more accurate model of the system. Through this method, system behaviour can be effectively modelled, allowing for more accurate prediction of its response to various input signals [10].

Therefore, the application of reverse feedback linearization combined with fuzzy logical inference systems represents an efficient approach to managing complex systems exhibiting a high degree of nonlinearity (Fig. 4).

Typically, the use of a knowledge base results in limiting the application scope of control systems employing it to the target function of the controlled object. This can be both an advantage and a drawback of the control system.

Advantages of the control system for robots based on reverse feedback linearization and fuzzy logic inference include significantly reducing the impact of uncertainty on control system quality and improving identification quality by optimizing the parameters of the fuzzy model. Additionally, the structure of the fuzzy control system model used allows rectifying deficiencies found in fuzzy systems, such as the inability to complement the initial rule set of the knowledge base and the possibility of incomplete, conflicting, or identical rules due to human factors during the formation of the knowledge base rules.

Disadvantages of unmanned aerial vehicle control systems include computational complexity and the difficulty in forming a knowledge base when training the fuzzy

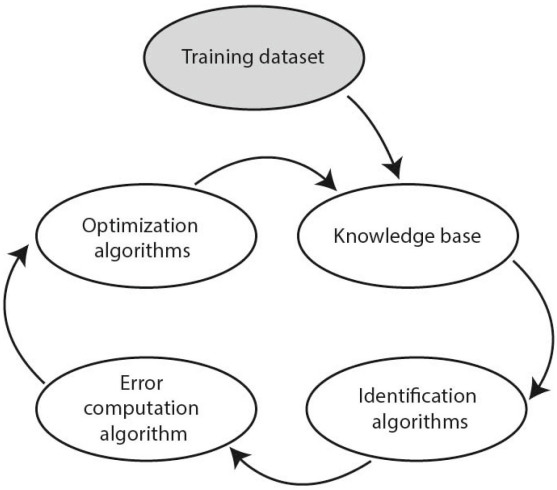

Fig. 4. General Structure of the Fuzzy Control Model for Automated Unmanned Technology Based on Reverse Feedback Linearization Using Fuzzy Logic Inference.

model. Dependency on the quality of training and tuning the fuzzy knowledge base can affect the control system's quality.

Control of automated technical systems based on a distributed system involves one person controlling a swarm and issuing commands to agents for executing complex tasks. Each device is equipped with a specialized computer enabling autonomous operation in the absence of communication with the control system [7, 11].

Controlling unmanned aerial vehicles based on a distributed system is more efficient than traditional control methods, ensuring more precise and faster task execution. Control can be exercised from anywhere in the world via the Internet network.

Software for managing robots based on a distributed system may include functions such as route planning, automatic object tracking, video and photo capture, data analysis, and decision-making based on this data.

Control of automated unmanned systems based on a distributed system is applied in fields such as agriculture, forestry, environmental protection, road and infrastructure monitoring, military applications, and others.

The interaction scheme of processes through the Cascade DataHub is depicted in Fig. 5.

The presented system has a distinct advantage in swarm management. Additionally, the interaction scheme of processes utilized helps to avoid many issues associated with managing process data and organizing access of one process to another's data.

However, significant drawbacks include the complexity in implementing control algorithms and software, as well as insufficient security in the overall control system. Attention should also be paid to the equipment used in the distributed control system and possible difficulties in software integration [12].

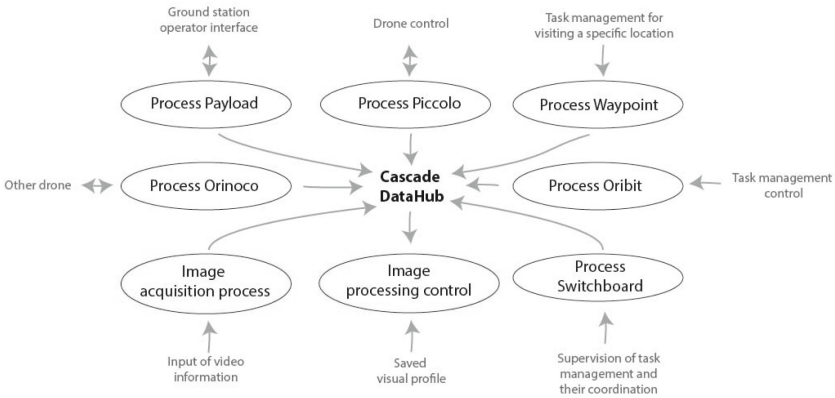

Fig. 5. Interaction Scheme of Processes through Cascade DataHub in a Drone Distributed Control System.

When ensuring swarm management of robots, it's crucial to consider aspects such as interaction within the group, ensuring information retrieval and transmission, and overall group control. Group interaction involves managing agents' actions and overseeing their execution, ensuring flight safety, and collision avoidance.

Information retrieval and transmission encompass establishing communication among objects within the robot control system, the ground complex, and trusted third-party entities. Group control involves determining the group and its elements' location, accounting for the number of objects in the system, and defining group scales. It's noteworthy that during the development and design of robot control systems, determining safety requirements according to specific mission needs and its execution conditions is a crucial step. Potential threats that may arise during the mission should be considered, and measures should be developed to prevent and/or mitigate them.

Moreover, the development of control algorithms allowing for effective system operation and goal achievement is a critical stage. These algorithms should consider the characteristics of the robots, used sensors, and other components of the control system.

Additionally, when developing control systems, technical limitations of robots, such as limited maximum speed and travel distance, battery capacity, among others, should be considered. All these factors must be considered during system design to ensure its effective operation and achieve maximum productivity.

Lastly, system support and maintenance are crucial aspects. Ensuring access to necessary resources for effective system operation and developing procedures and instructions for its operation and technical maintenance are essential [8].

3 Method Cascade DataHub

Method Cascade DataHub is an innovative approach to managing unmanned vehicles, enabling reliable, efficient, and safe control of agents in real-time conditions. The main idea of the method is to consolidate various information sources that facilitate the functioning of unmanned vehicles into a single system for control and monitoring.

The primary components of the method are:

Sensors: They gather information about the status of the unmanned vehicle and its operating environment. Among the sensors used in the Cascade DataHub method are GPS navigators, accelerometers, gyroscopes, pressure sensors, temperature, humidity sensors, etc.
Data transmission network: This network ensures the transmission of information from the sensors to the central control system of unmanned vehicles. Various data transmission networks are used depending on the conditions, such as Wi-Fi, Bluetooth, 3G/4G, LoRaWAN, NB-IoT, and others.
Central management system: It processes and analyzes the data received from the sensors and makes decisions.

Thus, the collection and analysis of data from the sensors and decision-making based on this data are vital components of unmanned vehicle management. However, effective execution of these tasks requires support from appropriate software tools.

The core concept of the Cascade DataHub method lies in gathering data from sensors at one location, where they are processed and analyzed. After this, the processed data is transmitted to other management systems that utilize this data to control and manage the automated unmanned system.

The second stage of utilizing Cascade DataHub involves teaching the network the finer details of unmanned vehicle management, such as precise positioning and spatial orientation, obstacle avoidance, and more. At this stage, the network learns to execute more accurate and complex maneuvers, enabling better control of the robot in complex conditions.

Training for Detailed Control

The third stage of using Cascade DataHub involves teaching the network detailed control of the automated unmanned system. At this stage, the network learns to perform high-precision maneuvers and movements, achieving greater accuracy and efficiency in management. For instance, the network can learn to execute precise shots from a certain height and angle to obtain high-quality images. Additionally, the network can be trained to differentiate specific objects in images, aiding in the construction of more accurate maps.

However, the Cascade DataHub method can be utilized not only to enhance the autonomous operation of unmanned vehicles but also in various other fields requiring the resolution of complex tasks with vast amounts of data.

For example, the method can be used in medicine to improve the disease diagnostic process based on image analysis or in the financial sector for analyzing financial risks and forecasting.

Therefore, the Cascade DataHub method is a powerful tool for solving complex tasks that demand a large amount of data and high precision in results. It can be applied in various fields, including the aviation industry and diverse scientific research. With the increase in data volume and the improvement of machine learning technologies, the Cascade DataHub method becomes an even more effective and powerful tool for achieving high results in different fields of activity.

One of the main advantages of the Cascade DataHub method is its high data processing speed. Thanks to this speed, data can be analyzed in real-time, allowing operators to carry out quick and effective unmanned aerial vehicle management.

Another advantage of the Cascade DataHub method is its high precision and reliability. This method enables precise determination of flight parameters such as speed, altitude, direction, and more, enabling operators to execute precise and efficient management of automated unmanned systems.

4 Overview of Cascade DataHub Architecture

Cascade DataHub is a deep learning method that reduces the amount of training data while increasing the speed of learning. This is achieved by sequentially connecting several neural networks, each responsible for determining different aspects of system control.

The architecture of Cascade DataHub involves several stages:

The first stage utilizes a neural network trained on general data to determine overall system control.
The second stage involves connecting the next network to the first one, focusing on defining more detailed aspects of system control.

Therefore, at each subsequent stage, a new network is added, identifying finer details of system management. Thus, by using Cascade DataHub, a more precise and efficient management of automated drone systems can be ensured [13].

5 Cascade DataHub Software

Cascade DataHub consists of the following components:

DataHub Manager: A program that manages drones and collects data from them.
DataHub Analytics: A program that analyzes and visualizes data from drones.
DataHub Connectors: Components enabling the connection of DataHub with various data sources like sensors, databases, and other systems.
DataHub API: An interface allowing integration with other systems and developing applications based on DataHub.

The DataHub Manager allows remote control and management of drones via internet access. It facilitates setting flight parameters, monitoring batteries, controlling the camera, and performing other actions.

DataHub Analytics enables the analysis of data collected from drones using various data analysis tools such as graphs, tables, maps, etc. Additionally, it allows users to create custom reports and dashboards for data visualization.

DataHub Connectors are additional software tools that acquire data from various sources and real-time data streams. They gather data from sensors, networks, databases, video streams, and audio sources. These connectors can be configured to collect data from different sources and stream them to analytical tools developed using Cascade DataHub.

In summary, DataHub Connectors enable connections to various data sources and real-time transmission protocols like MQTT, OPC UA, REST API, among others. Furthermore, Connectors can be expanded to connect to new data sources through software extensions.

The DataHub API allows developers to access and manipulate data within the DataHub system. It uses standard REST API protocols, making it easy to integrate applications with DataHub. The API is designed for scalability and flexibility, supporting programming languages like Python, JavaScript, Java, Ruby, PHP, and C#.

The Cascade DataHub method enables the creation of a unified platform for collecting, processing, and analyzing data from unmanned aerial vehicles. This method integrates various data sources such as GPS, cameras, sensors, and other control and monitoring systems into a single system for real-time monitoring, analysis, and control of drones.

A key feature of this method is the ability to create various data connections, allowing the analysis and control of devices from different perspectives. Real-time data processing technology enables operators to respond instantly to dangerous situations, thereby enhancing control safety and reliability.

Moreover, the Cascade DataHub method reduces the cost of managing drones by enabling remote monitoring and control, reducing the need for extensive specialized equipment and personnel [14].

Despite the advantages of the Cascade DataHub method, it also has its drawbacks. One of the significant disadvantages is the requirement for high-speed internet connectivity to transmit a large amount of data in real-time. Additionally, system stability issues may arise in unforeseen situations, such as the disconnection of one of the data sources.

6 Practical Implementation of the Cascade DataHub Method for UAV Management

The Perdix project stands out as one of the most prominent projects employing the Cascade DataHub method in unmanned aerial vehicles (UAVs). Developed jointly by the U.S. Department of Defense and the Massachusetts Institute of Technology (MIT), Perdix is a small UAV capable of operating in a swarm mode, executing missions in complex conditions.

One of the key aspects of the Perdix project lies in the ability of these UAVs to act as a distributed network, communicate, and collaborate to achieve a common goal. The Cascade DataHub method is utilized for these UAVs to interact and exchange data in real-time, significantly enhancing mission execution efficiency and reliability.

The advantages of employing the Cascade DataHub method in the Perdix project are evident. This method allows synchronized operation and real-time data exchange among UAVs, leading to higher accuracy and mission execution speed. Moreover, the Cascade DataHub method enables UAVs to respond to environmental changes and make necessary corrections in real-time.

Overall, the Perdix project serves as an excellent example of employing the Cascade DataHub method in UAVs. It demonstrates the power and effectiveness of this method in solving complex tasks.

Perdix represents the use of the Cascade DataHub method in organizing the management of UAVs. These small drones, capable of working in groups of up to 20 units, interact with each other and execute complex tasks such as reconnaissance, collecting intelligence about military objects, and transmitting it based on high-quality maps.

The Perdix project serves as a good example of how employing the Cascade DataHub method reduces the number of people needed to manage UAVs, ensuring more efficient operations. Deep learning networks were utilized in the Perdix project to enable drones to learn from each other and make real-time decisions. The application of the Cascade DataHub method allowed drones to work as a unified system and perform tasks more efficiently and accurately [11, 13].

Moreover, the Perdix project demonstrates that the Cascade DataHub method can be successfully used in military operations. Launched under the Strategic Capabilities Office program, the Perdix project aims to develop technologies that make the U.S. more effective and protected in military operations. The use of the Cascade DataHub method in the Perdix project created a system that efficiently executes reconnaissance tasks on military objects.

Another successful example of employing the Cascade DataHub method in UAVs is the Solar UAV project. This project was developed to research atmospheric conditions and climate change.

To execute research missions, Solar UAV uses unmanned aerial vehicles with solar batteries, enabling them to fly at heights of up to 20 km for several months without interruption for refueling. However, operating drones at such heights requires high precision in control and navigation.

For this purpose, the Solar UAV project utilizes the Cascade DataHub method to train deep learning networks to perform more precise navigation and control of drones at altitude.

A large amount of data is collected from sensors during the operation of aerial vehicles, providing information about atmospheric conditions and climate changes. This data is used to train a deep learning network that performs more accurate data processing and management of aerial vehicles at altitude.

With the help of the Cascade DataHub method, high precision control and navigation of aerial vehicles at heights up to 20 km have been achieved, allowing for the collection of important data for researching atmospheric conditions and climate changes at high altitudes.

Thus, the Solar UAV project serves as an example of the successful use of the Cascade DataHub method in UAVs to achieve high precision control and navigation at altitudes up to 20 km.

Another example of using the Cascade DataHub method in UAVs is the Falcon UAV project developed by AeroVironment. This project aims to create UAVs capable of operating in low-temperature and high-altitude conditions, such as in mountainous regions.

One of the key elements of the Falcon UAV project is the data management system based on the Cascade DataHub method. This system allows for the collection, processing, and analysis of data gathered by the unmanned aerial vehicle to enhance its efficiency and achieve maximum control accuracy.

One example of using the Cascade DataHub method in the Falcon UAV project is the collection and processing of data regarding fuel status and the aircraft engine's operation. This system enables real-time monitoring of fuel status and engine operation, allowing for the calculation of optimal flight speed and altitude for the UAV to maintain maximum operational efficiency.

Additionally, the data management system based on the Cascade DataHub method is employed for collecting and analyzing data from satellites and other sources. This allows the UAV to thoroughly analyze the territory it operates in and gather crucial data for further application across various fields.

HALE (High-Altitude Long Endurance) is an unmanned aerial vehicle designed for extended flights at altitudes above 20 km. The main objective of the project is to provide broadband internet access and other communication services in regions where these services are limited or unavailable [2, 15].

One of the primary challenges facing such an aircraft is ensuring flight safety. To address this, HALE is equipped with a range of sensors and measurement systems that monitor flight and system operations. Data collection and analysis from these sensors and systems are facilitated using the Cascade DataHub method.

Cascade DataHub allows for the collection and analysis of data from various sensors and systems, ensuring more precise aircraft control and safety measures. For instance, the system can monitor pressure and temperature at different points on the aircraft, engine status, and power systems, enabling operators to timely identify and address potential malfunctions.

Moreover, the Cascade DataHub method ensures high flight efficiency for the aircraft. For example, the system can study optimal flight trajectories, allowing for fuel savings and increased flight time.

Skydio R1 is an unmanned aerial vehicle equipped with 13 cameras that provide a 360-degree environmental view. The aircraft can automatically follow a user-defined route and avoid obstacles along its path, thanks to detailed environmental scanning. Furthermore, Skydio R1 can perform various tasks like object tracking or fixing specific points in space.

A key component of the Skydio R1's management system is artificial intelligence technology based on the Cascade DataHub method. It enables the aircraft to quickly learn new tasks and situations, making necessary real-time adjustments.

Additionally, the Cascade DataHub method ensures high precision in automatically recognizing objects and obstacles in the aircraft's path, significantly reducing the risk of unforeseen situations and accidents.

In conclusion, the Skydio R1 project is another excellent example of using the Cascade DataHub method in unmanned aerial vehicles. Skydio has demonstrated that this technology can be highly effective in autonomously managing aircraft and performing diverse tasks that were previously accessible only to humans.

Utilizing the Cascade DataHub method in unmanned aerial vehicles opens new possibilities for data acquisition and enhances data processing accuracy. With UAVs equipped with systems built on the Cascade DataHub, tasks like:

Surveying land areas to determine atmospheric pollution levels and identify sources of pollution.

Monitoring the status of forest areas, allowing for quick detection of fires and diagnosis of tree diseases [16].
Monitoring industrial objects and infrastructure. Drones equipped with cameras that measure temperature and other parameters aid in early detection of potential faults.
Researching wildlife and monitoring climate changes. Using drones efficiently collects data on changes in vegetation structure, animal populations, and other indicators, facilitating understanding of environmental conditions and changes occurring.
Search and rescue operations. UAVs can be used to search for deceased or injured individuals and assess post-disaster situations.

Overall, the Cascade DataHub method enables efficient management of UAVs and ensures the accuracy of data collection and processing, allowing for the execution of diverse tasks using these aircraft.

7 Conclusion

This article explored the utilization of the Cascade DataHub method for organizing the management of an automated drone system. The main advantages of integrating this method into swarm management systems were outlined, including increased precision and reliability in control, reduced system training and calibration time, as well as enhanced data utilization efficiency.

Specific examples of Cascade DataHub method application in unmanned aerial vehicles were provided, such as the Solar UAV project, where the system improved autopilot accuracy and navigation in strong wind conditions, and the Perdix project, where the system coordinated actions among a large number of drones in real-time.

Overall, the application of the Cascade DataHub method significantly enhances the quality of managing unmanned aerial vehicles and broadens their capabilities across various industries such as transportation, agriculture, environmental monitoring, and many others. With this method, drones can become more efficient and reliable tools for addressing diverse tasks laid out before them.

References

1. Taye, M.M.: Understanding of machine learning with deep learning: architectures, workflow, applications and future directions. Computers **12**, 91 (2023). https://doi.org/10.3390/computers12050091
2. Rati, B., Rajendra, P., Parvez, F., Jyoti, G.: Blockchain-enabled secure and efficient data sharing scheme for trust management in healthcare smartphone network. J. Supercomput. **79**, 16233–16274 (2023). https://doi.org/10.1007/s11227-023-05272-6
3. Kutsenko, L.M., Semkiv, O.M., Kalinovskyi, A.Y., Piksasov, M.M., Sukharkova, O.I.: Geometric modeling of a mobile installation for launching unmanned aerial vehicles. Tech. Sci. **1**(1), 117–120 (2017). https://doi.org/10.15587/2313-8416.2017.117920
4. Majumdar, A.K.: Fundamentals of free-space optical communications systems, optical channels, characterization, and network/access technology, Chap. 4. In: Majumdar, B.A.K. (ed.) Optical Wireless Communications for Broadband Global Internet Connectivity, pp. 87–118. Elsevier (2019). https://doi.org/10.1016/B978-0-12-813365-1.00004

5. Kabir, H., Tham, M.-L., Chang, Y.C.: Internet of robotic things for mobile robots: concepts, technologies, challenges, applications, and future directions. Digit. Commun. Netw. **9**, 1265–1290 (2023). https://doi.org/10.1016/j.dcan.2023.05.006
6. Gielis, J., Shankar, A., Prorok, A.: A critical review of communications in multi-robot systems. Curr. Robot Rep. **3**(3), 213–225 (2022). https://doi.org/10.1007/s43154-022-00090-9
7. Franchuk, V.I., Kalachov, S.H., Kurylenko, O.A.: Tekhnolohii avtomatyzovanoho proektuvannia v elektronitsi: navchalnyi posibnyk. Vydavnytstvo KhNURE, Kharkiv (2018)
8. Pathak, R., Barzin, R., Bora, G.C.: Data-driven precision agricultural applications using field sensors and unmanned aerial vehicle (UAVs). Int. J. Precis. Agric. Aviat. **1**(1), 19–23 (2018). https://doi.org/10.33440/j.ijpaa.20180101.0004
9. Tahir, A.: Formation control of swarms of unmanned aerial vehicles, Doctoral Dissertation, University of Turku, Turku, Finland, September 2023. ISBN 978-951-29-9411-3. https://urn.fi/URN:ISBN:978-951-29-9411-3
10. Kong, X., Wu, Y., Wang, H., Xia, F.: Edge computing for internet of everything: a survey. IEEE IoT J. **9**, 23472–23485 (2022). https://doi.org/10.1109/JIOT.2022.3200431
11. Papanikolopoulos, N.P., Roumeliotis, S.I. (eds.): Hormone-inspired self-organization and distributed control of robotic swarms: special issue on analysis and experiments in distributed multi-robot systems. Auton. Robot. **17**(1), 93–105 (2004).https://doi.org/10.1023/B:AURO.0000032940.08116.f1
12. Tariq, U., Ahmed, I., Bashir, A.K., Shaukat, K.: A critical cybersecurity analysis and future research directions for the internet of things: a comprehensive review. Sensors **23**(8), 4117 (2023). https://doi.org/10.3390/s23084117
13. Swarnalatha, P., Prabu, S. (eds.): Handbook of Research on Deep Learning Techniques for Cloud-Based Industrial IoT. https://www.igi-global.com/book/handbook-research-deep-learning-techniques/309461
14. Srinivasan, S., Kumarasamy, S., Andreadakis, Z.E., Lind, P.G.: Artificial intelligence and mathematical models of power grids driven by renewable energy sources: a survey. Energies **16**, 45383 (2023). https://doi.org/10.3390/en16145383
15. Elamassie, M., Uysal, M.: Free space optical communication: an enabling backhaul technology for 6G non-terrestrial networks. Photonics **10**(11), 1210 (2023). https://doi.org/10.3390/photonics10111210
16. Georgiades, G., Papageorgiou, X.S., Loizou, S.G.: Integrated forest monitoring system for early fire detection and assessment. In: 2019 6th International Conference on Control, Decision and Information Technologies (CoDIT), pp. 1–6, April 2019. https://doi.org/10.1109/CoDIT.2019.8820548

Creation of Software for Evaluating the Quality of Educational Services Using the QFD Method

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Abstract. The goal is to develop software for obtaining an assessment of the quality of educational services. **The subject** of the article's research is the QFD method, which is visualized in the form of a house of quality. The object is the process of evaluating the quality of educational services at the department. The main **tasks** are the automation of the construction of the house of quality, which aims to speed up the calculations of the assessment of the quality of the educational process and improve the perception of information, the analysis of prototypes of the system, the detailing of the task "Automation of the construction of the house of quality", testing the software on the data obtained through the survey of education seekers, obtaining results The following **results** were obtained: created software that allows the user to enter a maximum of twenty requirements, a maximum of 20 specifications and a maximum of three competitors; visualizes the structure of the house, allows you to enter text data and select symbolic values in the corresponding cells; calculates absolute and relative importance; visualizes quantitative technical data using a petal chart and provides an advisory message on the input data. As a result, education seekers believe that "The possibility of choosing individual disciplines" is the most important factor in the educational process. This requirement is affected by the following technical characteristics "Number of disciplines in the subject field" and "Number of disciplines in the non-subject field. This requirement is rated higher by students than by competitors. The scientific novelty of the obtained results is as follows: a software-visualized house of quality with the possibility of entering various types of data for further recommendations, visualization of quantitative data of technical characteristics using a petal chart. Practical significance. The results of the work make it possible to control the quality of the evaluation of the educational process by consumers in relation to competitors - other departments of the faculty, it makes it possible to structure large volumes of data and visualize the relationships between consumer requirements and technical characteristics that can affect the evaluation of consumers.

Keywords: quality assessment of educational services · QFD method · quality house · petal chart · software

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https://doi.org/10.1007/978-3-031-60549-9_39

1 Introduction

Assessment of the quality of educational services is an extremely important step in shaping the educational process in the 21st century. Ukraine sets itself the task of developing modern education systems and compliance with European standards, and already has an impressive base in this area. The evaluation of the quality of educational services of a higher educational institution undoubtedly affects decisions regarding the improvement of the educational process, which is of great importance for the professionalism of future generations. The labour market is constantly changing, and with the development of technology, new requirements arise. Over the past 30 years, the level of education in Ukraine has grown significantly, especially in the field of higher education. Ukraine has become one of the leaders in the coverage of the population with higher education [1], However, this does not mean that one should stop at what has been achieved and continue to work on improving education.

There are a variety of approaches in evaluating the quality of educational services, but the QFD method can be used as one of the options. The use of this method has its advantages and is considered justified. The main goal of QFD is to overcome three main shortcomings that are characteristic of traditional approaches to development: ignoring the opinion of the consumer/customer, loss of data, and inconsistency of requirements that may arise as a result of different implementation of tasks by different performers [2]. This approach can be seen as a method that can give an assessment of the educational process at different levels of the structure, be it among a group of students, at a department, faculties, etc.

2 Research Problems

Unfortunately, the educational process has its shortcomings, which become more and more noticeable every year. The content of educational programs does not always correspond to modern trends and the latest technologies. New fields of academic disciplines are emerging and the requirements for the quality of education are growing at a remarkable pace. In recent years, the problems of "digital literacy" have become more visible, they are becoming more and more relevant for young people and adults. The problem of monitoring educational services is an important factor for assessing the quality of education and student satisfaction.

The COVID-19 pandemic [3] became one of the reasons for changes in the educational process. During the quarantine, vulnerabilities in distance learning were discovered. Attention was drawn to the difficulty of assimilating a large amount of information without additional presentations or videos, to the insufficient level of organization of the educational process, as well as to the complete or partial lack of communication with the teacher.

Assessment of the quality of educational services is a complex process that depends on many factors that must be considered in the system. There are many approaches that can evaluate certain aspects of the educational process, but not all of them can be 100 percent reliable to take into account all aspects. This software can partially eliminate the contradiction in the sense that the process of providing educational services from

the side of education seekers will be evaluated. This sufficiently narrows the direction of the research and is undoubtedly as important a part of the evaluation of the process as the pedagogical point of view, the opinion of the management, etc.

3 Analysis of System Prototypes

In the article [4], based on the project of quality assurance and accreditation of universities in Egypt, a prototype of the QAES system was described - it is a Web2 system used in the Quality Assurance Unit at Mansoura University in Egypt during the evaluation of institutions. The quality assessment of any higher education institution in Egypt consists of three stages: self-assessment, external/internal assessment, and peer review. The QAES system focuses on the first and second stages.

QAES was created with the goal of automating the assessment process of any institution and providing assistance to anyone involved. The system retrieves all necessary documents, such as university, staff, student and building data, for the evaluation process. The main outputs of the system are the annual self-evaluation report of the institution, the internal/external evaluation report, and the recommendation report. QAES provides many capabilities to the evaluator team, such as assigning tasks, updating reports, and notifying team members. Additionally, the team can agree, disagree, or comment on assignments, print grade reports, and update their data.

The implementation of the prototype is based on the use of PHP and Ajax web technology. MySQL DBMS is used to create the database. The system includes a set of screens for the administrator, institute, and evaluator. The QAMS database refers to the database of the quality management system.

The article [5] proposed a comprehensive approach to quality assurance of online testing in education to meet the needs of all stakeholders, such as test writers, teachers, students, experts, and quality managers. To automate this process, a software application called Test Quality Evaluation was developed, which allows to ensure the quality of educational tests throughout the entire life cycle.

To create evaluation documents in the form of reports, the prototype TQE program contains two panels for each context. This application is written in PHP and uses the functionality of Jasper Soft BI Suite to analyze and create reports by obtaining data from various information sources, as well as to store and organize them in a repository. In addition, the program allows you to display reports in a more user-friendly manner. The user must also set the values of the required local parameters of the report. Alternative parameters and their user-selectable values are obtained from the data source.

The TQE software is an experimental prototype for evaluating the quality of tests used in e-learning courses in three different subject areas: physics, computer science, and foreign languages.

The practical guide [6] contains information on internal quality assurance (IQA) covering all aspects of policies, activities and mechanisms related to quality assessment and improvement that are developed and implemented by and within higher education institutions. University approaches to IQA are improvement-oriented and typically place more emphasis on the quality of teaching and learning aspects, as well as the concept of an organization's quality culture. IQA systems are used for quality assurance, which

may include institutional policies and guidelines. For effective management of quality processes, special departments are created in universities. An important element of IQA systems is the collection and analysis of data, for which performance indicators can be developed in accordance with the standards and aspirations of the institution. Quite often, various institutional surveys are used as a tool that can conduct a systematic assessment.

4 Software Operation Algorithm

The main task of the information system is to automate the process of evaluating the quality of the educational process using the QFD method, which can be visually represented in the form of a quality house (Fig. 1). It aims to speed up calculations and improve information perception. In real practice, various types of this building are used, and all of them have common and distinctive features in the display of information [7].

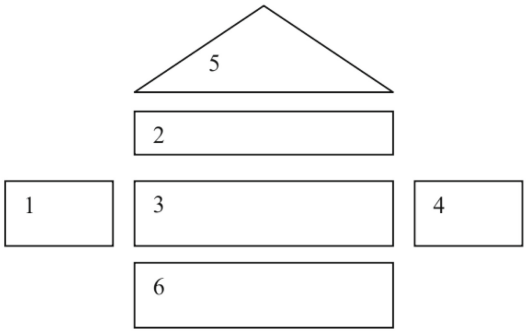

Fig. 1. Structure of the House of Quality

Regarding the blocks: in the middle of the house is block 3, which contains in cells the communication with the technical characteristics located in block 2 and with the customer requirements located in block 1. In the roof of the house (5) information is given about the correlation between the technical characteristics. Block 4 is designed to display the consumer's assessment of one or another requirement. Block 6, the basement, contains the results of the analysis of the technical characteristics of competing products, the target values of the technical characteristics of the products, assessments of the absolute and relative importance of parameters, etc. [8].

Automation of the quality assessment of the educational process using the QFD method can be implemented using the development of computational mechanics and interface development. Below is a sequence of algorithms, which are the main ones for the implementation of the automation process.

First, it is necessary to determine the requirements of consumers and translate them into technical specifications. Each service has a list of qualities by which it can be evaluated, but it is not always possible to do this objectively due to different concepts of convenience, universality, etc. In this case, after receiving a list of opinions and evaluations of the educational process by consumers, they were structured and translated into

specific requirements using the expert method. The list of requirements in this work is: adjustment and updating of methodical manuals; addition of lectures in English/language practice in pairs; the presence of competitions in various directions; provision of educational and teaching-methodical literature; availability of courses/trainings that help take care of mental health; possibility of individual choice of disciplines; the opportunity for students to choose their own direction of course project, calculation graphic work, calculation work; development of SoftSkills/teaching the basics of teamwork; Internet connection; possibility of internship at enterprises/companies; assistance of the department in finding a job; the possibility of access to computer and copying equipment; timely information on the organization of the educational process is available; relationship between teacher and student; the interface of the official website is convenient and has all the information; visual accompaniment of initial classes. Unfortunately, the number of requirements cannot be predetermined or reasonably limited, because each expert independently determines them based on various factors, for example, their own experience. Strictly speaking, it is easier to work with a set that will not exceed two dozen, because with the growth of requirements, the need for new technical characteristics also arises, it is more difficult to establish a connection between all fields, the house becomes bulky and not so clearly defined.

So, after defining the requirements, the process of establishing technical characteristics takes place, which to one degree or another depend on and influence the requirements. In this case, the technical characteristics were determined by an expert, they affect the consumer's requirements. In general, the number of technical characteristics cannot have hard limits, since each expert chooses them based on their own experience and other factors. List of technical characteristics in the work: number of methodical manuals, textbooks, monographs; the number of copyright certificates, patents for inventions; the number of participants (students) in international and other competitions; the number of competitions, Olympiads organized by the department; the number of students who presented reports at conferences; the number of publications in the periodical press abroad (articles, theses); the number of received grants for participation in scientific research; the number of works of students, including together with the teacher; the number of subjects taught in English; number of students per computer; the number of laboratories; the number of students who have successfully mastered the educational programs (at A and B); the number of students who dropped out of the educational process; the number of disciplines in the subject area; the number of disciplines not in the subject field. Numerical data for technical characteristics are taken for a specific time period chosen by the expert.

Then you need to prioritize the requirements, which makes it easier to focus on the most important ones. A priority matrix or consensus method can be used to rank the requirements. In this work, a consumer survey was conducted in order to select the five most important requirements from the list. The percentages of each of the requirements were translated into coefficients corresponding to a generally accepted scale from 1 to 5, where 5 is the maximum importance, and 1 is the minimum. Determining priorities in this work is a simple process that can be carried out even by an inexperienced expert with mathematical skills. The requirement "The possibility of individual choice of disciplines" became the most important among the list of requirements.

Next, for successful work, it is necessary to establish relationships between requirements and technical characteristics. The expert needs to analyze the data, which is a list of requirements, technical characteristics and a scale of relationship, to reveal the strength of the relationship between the lists. The scale consists of symbols, such as an unfilled circle with a relationship of 1 - a weak relationship, a filled triangle (3) - a medium relationship, a filled square (9) - a strong relationship. The expert determines the strength of the relationship between each requirement and each technical characteristic at his discretion. The process of establishing connections depends on the correctness of the expert's establishment of lists of requirements and technical characteristics. In the QFD method, not all relationships between requirements and technical characteristics can be established. The expert is responsible for the correctness of establishing connections since there is no universal check for this process.

Often, together with symbolic marks, numerical assessments of the significance of the relationship are calculated. These values can be obtained using formula 1:

$$Significance\ of\ relationship = Strengths\ of\ interconnection \times Weight, \% \quad (1)$$

The numerical values of the "Strengths of Interconnection" weighting coefficients (9, 3, 1) are used in the calculations, and the value of the "Weight, %" indicators can be calculated at the stage of establishing satisfaction with one's own and competing services.

At this stage, problems may arise, for example, that there are situations where a requirement or technical characteristic is not related to any characteristic or requirement, respectively, or a situation where there is no strong relationship between them, or when almost all cells are filled (it is most likely that this need (characteristic) refers to a higher level of abstraction, so it is necessary to return to the procedure of affine structuring. It is also possible that a specific need in a row refers to such a specific category as economy, reliability, or safety) etc.

After that, relationships between technical characteristics are established. The expert analyses the list of technical characteristics and the scale of the connection between them. Analogous to establishing relationships between requirements and technical characteristics, a scale is used to determine the strength of the relationship - 9, 3, 1. Symbolic designations are used to denote relationships. The expert analyses and establishes connections, leaving some technical characteristics unconnected. The quality of marking depends on many factors, such as the experience of the expert, so it cannot be universally verified.

At the next stage, the complexity of implementing technical characteristics is established, which aims to determine the company's capabilities. The estimate may vary depending on whether the company has the necessary equipment, technology, and specialists. It is based on a scale from 1 to 5, where 1 means easy implementation of the requirements, and 5 - difficult. The expert analyses the established list of technical characteristics and the scale of implementation complexity and determines the level of implementation complexity at the moment. This process is quite subjective and different experts may have different opinions.

After that, it is necessary to establish satisfaction with own and competing service. For this, there is a scale from 1 to 5, where 5 is the highest rating and 1 is the lowest. The user survey method using Google Forms and the expert method were used to

assess satisfaction. A survey was conducted among students of the "Information Design Technologies" department and two other departments of the faculty. Further, based on the results of the survey, bar charts were constructed regarding satisfaction with various requirements of department users. Experts recorded the highest scores and resolved controversial issues, such as choosing a higher score among equal scores.

Based on the determined target values, the "degree of improvement" value can be calculated according to formula 2:

$$\text{Degree of improvement} = \frac{\text{Target value}}{\text{Product evaluation}} \tag{2}$$

After that, the weight of each consumer expectation or product characteristic should be established as part of defining the project goals. At the same time, the weight is calculated according to formula 3:

$$\text{Weight coefficient} = \text{Importance of consumer expectations} \times \text{Degree of improvement} \tag{3}$$

The sum of all weights (expressed as a percentage) must equal 100%.

After that, it is necessary to carry out a technical analysis of own and competitive services, comparing quantitative indicators of technical characteristics. The expert must have access to data on the technical characteristics of the product/service for a selected period, which can be collected using methods such as surveys, literature analysis or technical documentation. Restrictions can be set if the data is negative because the technical characteristics must be chosen from the counter digit. At the stage of technical analysis, units of measurement of technical characteristics are established, for example, percentages, hours, or items.

Next comes the calculation of absolute and relative importance. To calculate the absolute importance, the numerical values of the technical characteristics and the importance coefficients of each requirement are used, which are multiplied and added by each technical characteristic. Relative importance is calculated as the ratio of absolute importance to the sum of all absolute importance, multiplied by one hundred percent. Thus, the values of the technical characteristics are determined, which allow to satisfy the requirements of consumers.

After forming the main data, it is necessary to structure them in a visually acceptable form. It is necessary to fill in the quality house with the correct data, the main steps are: filling in the left part of the house - the consumer requirements and coefficients are entered, the correctness of entering each field is checked; in the upper part of the building (except for the roof), technical characteristics are entered, the correctness of entering each field is checked; in the central part, connections between requirements and technical parameters are established, but there may be cases when some fields do not have connections between each other, in the roof, connections are established between technical characteristics, but in some fields they may be absent; in the right part of the house, an assessment of consumer satisfaction with own and competitive services is carried out, as well as a check of filling in all fields; in the basement, the complexity of the implementation is entered, the quantitative data of the technical characteristics of own and competitive services are entered, and the filling of all fields is checked, the

absolute and relative importance of the technical characteristics are derived, and the filling of all fields is checked.

This data is then used to display a petal chart. After collecting quantitative data on the technical characteristics of own and competitive services, selecting the characteristics to be displayed on the petal chart, a classic version of the chart is created. The angle between the rays of the chart is 360/n degrees, and the area of the polygon reflects the contribution of the indicators to the final result. The area of a polygon can be determined by dividing it into separate triangles and determining the area of each of them [9].

Next, the rating and recommendations are displayed. The coefficients of consumer requirements are compared and the highest priority requirements are determined, the technical characteristics that have the strongest impact on the most important requirements are analysed, the relationships between technical characteristics are analysed so that their influence on each other can be taken into account, the satisfaction with own and competitive services is compared and those requirements are determined, where satisfaction with one's own product/service is less than that of competitors, the difficulty of implementing the required technical characteristics is analysed and those that are easiest to implement at the moment are selected, quantitative data on own and competitor services are compared, values of absolute and relative importance are compared, necessary values are displayed in the form of a message with recommendations.

5 Software Design

The source code editor Visual Studio Code [10] was chosen to perform the assigned tasks. It was decided that a "house of quality" could be created using JavaScript [11], HTML [12] and CSS [13], which would allow the user to enter the required data quickly and easily. JavaScript is now supported by all modern web browsers and is used by most sites on the Internet for complex and powerful functions.

The software architecture (Fig. 2) consists of an HTML directory (main_page.html, charts.html, help.html), a CSS directory (main.css) and a JS directory (house_builder.js, charts.js).

The html directory:

- main_page.html: before launching the page, certain scripts are launched: own house_builder.js script and Bootstrap framework scripts; the file has a head tag that contains information about the html page, namely: connecting Bootstrap styles, custom styles, page title and meta tags, page header is created, page markup for the future home is done, and display markup is also laid in this file modal window used to display results;
- charts.html: scripts are activated before starting the page, namely: own scripts charts.js, scripts of the Bootstrap framework and scripts of the Chart.js framework, the file similarly to the main_page.html file has a head tag, which contains information about the page, in the body there is a block with the names of technical characteristics and a petal chart. The block is created using a div html element to which the container m-5 border p-3 class is added. Chart.js forms a certain petal chart;
- help.html: before starting the page, the Bootstrap framework script is activated. The file, like the files listed above, has a head tag, which contains information about the page.

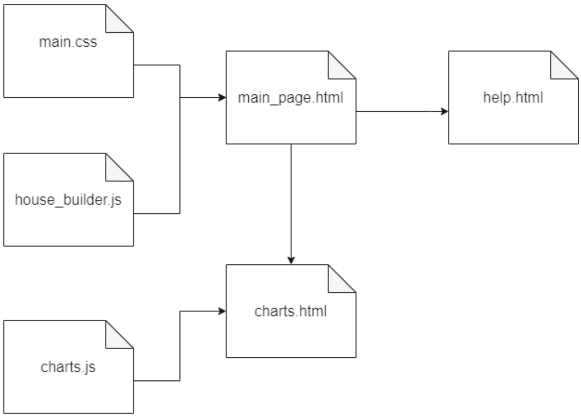

Fig. 2. Software architecture

The css directory:

– main.css: basic css properties were used to style page elements: height – sets the height of the element; width – sets the width of the element; padding – internal indentation of the element; margin – external indentation of the element; visibility – displays or hides the element; position – indicates how the element is positioned in the document; display – defines the display type of the element; border – creates borders for the element; text-align – positions the text relative to the block; z-index – determines the position of the positioned element and its child elements along the z-axis.

The js directory.

– house_builder.js: scripts that activate the functioning of the application are superimposed on the buttons in the header of the main page. The addTable script was created to display the frame of the house. This script is associated with the "Build a house" button in the header of the main page. The fixData script is associated with the "Fix Data" button in the header on the main page. Local storage web storage is used to transfer data to various html pages. Data is stored in the form of "key-value" pairs, only strings can be stored in it, if it is necessary to store arrays and objects in this storage, then before doing so, they must first be converted into strings. The representData script is associated with the "Result" button. It collects data from tables: names, priorities, ratings, etc., and displays it in a structured form in a textual recommendation form in a modal window;
– charts.js: contains a script that allows you to retrieve data from local storage. This data is required to display the petal chart. Two arrays are created - the names of the characteristics are entered in the first array, and the quantitative data of the characteristics are entered in the second. These arrays are passed to the petal chart.

6 The Result of the Software Operation

Currently, the interface is aimed at Ukrainian-speaking users. The main page of the "house of quality" initially has only a header with fields and buttons, without any frame of the house, so as not to confuse users who are not familiar with this form of evaluation. To get more information about the application or to get hints about unclear fields, the user can click the Help button, which will open a comprehensive reference for the functionality of the buttons and the amount of data required.

Since there are four phases in QFD, and each of them builds its own quality house, the number of requirements and characteristics was limited to 20 and the number of competitors to 3. These values are sufficient for any deployment phase.

The existing buttons have clear labels, differ in colour for better perception of information (Fig. 3).

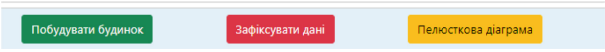

Fig. 3. Functional buttons

To build a house, user need to click on the "Build a house" button, after which a frame will appear, which the user must fill in for effective work. Most of the cells have a simplified version that is easy to fill out for users who are familiar with the help. These are cells with limited scales for weight evaluation, matrix of interrelationships, evaluation of satisfaction and complexity of implementation. The only area where you can get confused is when filling in the information about the basement of the house, since the user must enter the names and data himself.

After filling in the priorities and matrix of relationships between requirements and technical characteristics, after clicking on the "Capture data" button, the data appears in the basement.

If the user wants to analyse the quantitative data and visualize them in the form of a petal chart, then after filling in the fields with technical characteristics and entering data about his own and competing products in the basement, he can click on the "Fix data" and "Petal chart" buttons. After that, a page with visualized data will open. A visualization option can be seen in Fig. 4.

Due to multidimensionality and the impossibility of a universal assessment of data, the correct analysis and structuring of data by an expert are decisive factors for achieving results.

In this work, quality assessment was carried out by evaluating educational services at the department, using a survey to collect part of the necessary information. This example will be illustrated by comparing the department of "Design Information Technologies" with other departments at the faculty.

Figure 5 shows the data that was obtained through the survey and expert analysis (relationships between requirements and technical characteristics). It is already clear that processing a large amount of data is not entirely convenient.

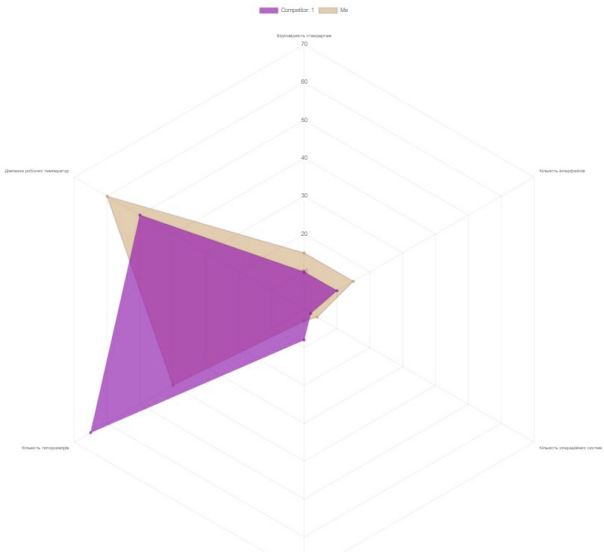

Fig. 4. An example of a petal chart

	Вага	Оцінка споживачів: Конкурент 0	Конкурент 1	Конкурент 2
Коригування та оновлення методичних посібників	3	2	4	3
Додавання лекцій англійською мовою/мовна практика на парах	3	2	3	1
Наявність конкурсів на різні напрямки	1	2	4	3
Забезпечення навчальною та навчально-методичною літературою	1	5	4	4
Наявність дисциплін/тренінгів, які допомагають подбати про ментальне здоров'я	1	3	4	1
Можливість індивідуального вибору дисциплін	5	4	3	5
Можливість для студентів обирати власний напрямок КП, РР, РР	4	2	3	5
Розвиток SoftSkills/Навчання основ командної роботи	3	2	2	1
Доступ до Інтернету	3	3	4	5
Можливість проходження практики на підприємствах/в компаніях	3	4	4	3
Допомога кафедри у пошуку роботи	3	3	4	4
Можливість доступу до комп'ютерної та копіювальної техніки	3	2	3	5
Доступна і своєчасна інформація з питань організації навчального процесу	2	2	3	4
Взаємовідношення між викладачем та студентом	3	3	3	4
Інтерфейс офіційного сайту зручний і є вся інформація	2	3	4	3
Візуальне супроводження навчальних занять	2	3	4	4

Fig. 5. Basic data of the assessment of the quality of the educational process

Figure 6 shows the data that was entered into the basement of the house over a period of time. This input structure should be preserved for traditional visual representation.

The software automatically calculates absolute and relative importance to simplify the calculation process and user input.

Складність реалізації	2	4	4	3	3	4	4	2	3	1	1	1	1	1	1
Одиниці вимірювання	шт.	шт.	чол.	шт.	чол.	шт.	шт.	шт.	шт.	чол.	шт	чол.	чол.	шт.	шт.
Конкурент 1	237	75	150	50	20	33	10	38	5	1	4	213	56	60	14
Конкурент 2	400	46	102	63	31	35	8	50	8	3	3	219	43	64	12
Власний продукт	305	58	118	48	45	42	4	69	5	1	5	200	45	58	16
Абсолютна важливість	63	12	21	18	30	18	12	42	60	79	81	38	20	129	129
Відносна важливість	8.38	1.60	2.79	2.39	3.99	2.39	1.60	5.5	7.97	10.50	10.77	5.05	2.65	17.15	17.15

Fig. 6. Data from the basement When an expert analyses the interrelationships and the influence of one technical characteristic on another, filling the roof is a necessary component. Figure 7 shows that the connections are established correctly, and 15 characteristics can be taken into account.

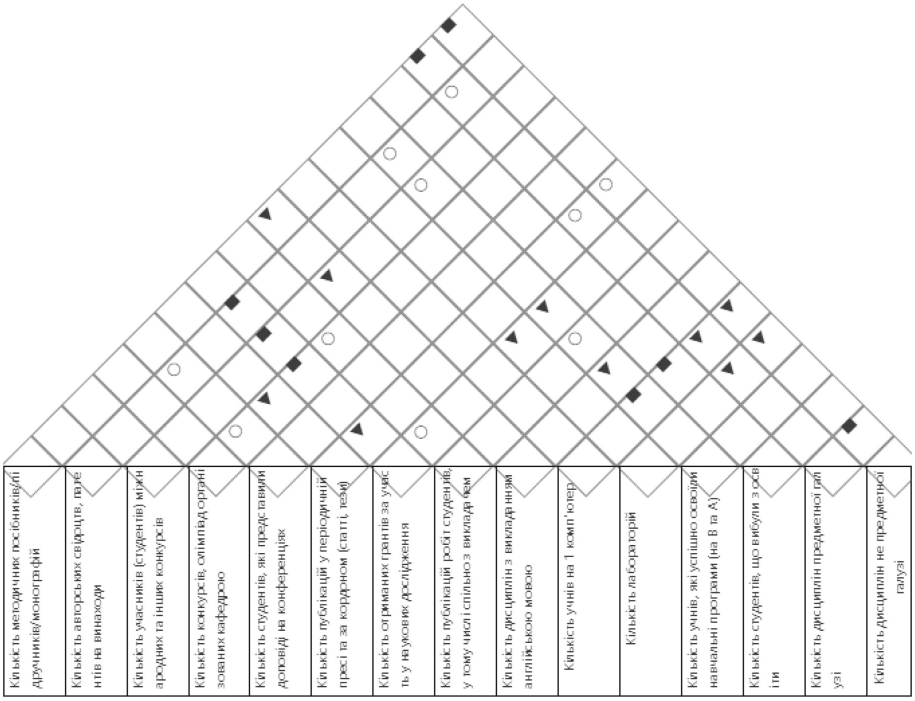

Fig. 7. The filled roof of the house

If you click on the "Petal chart" button, the page with the chart shown in Fig. 8 opens.

In this chart, it is possible to hide any of the participants and compare the values of the remaining technical characteristics of the product or service. When you hover the cursor over any vertex, you can see the value and characteristics of this point. In

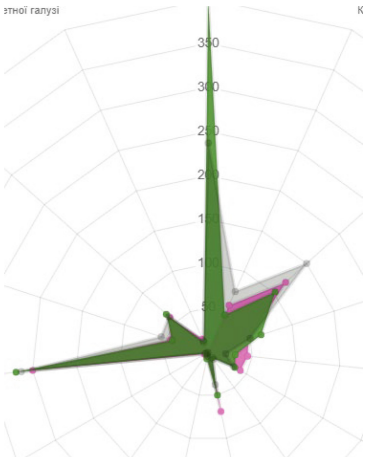

Fig. 8. Petal chart based on input data

addition, it is possible to leave only one participant in the chart, depending on the goals of the analysis.

Based on the entered data, you can get a general result (Fig. 9), which does not contain clarifications, since the quality assessment has many nuances that cannot be predicted. However, preliminary work shows that this approach to evaluation is very convenient, as all information can be entered and output on one page instead of being spread over many files and folders, which can cause confusion. This structure has its advantages and makes it possible to visualize data.

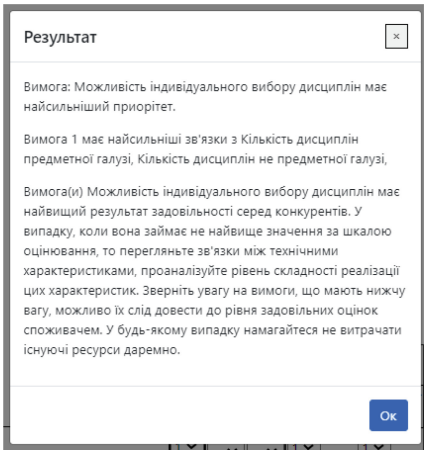

Fig. 9. The result of the program

After the analysis of the departments, it can be concluded that “The possibility of individual choice of disciplines” is the most important requirement for students. This

requirement has the greatest impact on characteristics such as "Number of Subject Area Disciplines" and "Number of Non-Subject Area Disciplines". In addition, it also has a more satisfactory consumer rating than its competitors.

After testing the software on other examples, you can make a list of the main weaknesses of the software that can be improved in the future:

- entering fractional quantitative data in the basement is incorrectly displayed in the future on the petal chart;
- if two or more of the most important requirements have the same ratings and consumer satisfaction, then the recommendation message is duplicated;
- inability to save data to a file to prevent data loss for any reason;
- it is necessary to form a more complex structure of the house for more accurate analysis of relationships, for example, form the columns "Target value", "Degree of improvement", "Weight", "Weight %" for requirements;
- add the ability to dynamically change columns and rows.

7 Conclusions

So far, the QFD quality function deployment methodology has been analysed. This method makes it possible to transform the general requirements of the consumer into the established characteristics of the final products and provides process management. As with any method, there are advantages and disadvantages that have been analysed in the course of literature research and software development.

The main task is to automate the process of evaluating the quality of education using the QFD method and its visualization using the "house of quality". This task was broken down into two subtasks: "Development of computational mechanics" and "Development of the interface", each of which consists of smaller subtasks. Most of these sub-tasks require an expert panel to ensure efficiency and accuracy of the assessment.

The main files used to create the application's functionality and interface are described. With the help of HTML, CSS and JS, the frame part of the house, which is a key component of the project, was successfully visualized. Simplified visualization is a feature of this method. The interface of the pages was also described and some solutions regarding their visualization were substantiated.

Using a petal chart to visualize quantitative technical data is an effective tool in this case. Some basic data adjustments have been made and there is also a restriction on data entry, the user can enter relevant data in the relevant fields. Filling out the connection matrices and quantitative data in the basement is at the discretion of the user.

As a result, education seekers believe that "The possibility of choosing individual disciplines" is the most important factor in the educational process. This requirement is affected by the following technical characteristics "Number of disciplines in the subject field" and "Number of disciplines in the non-subject field. This requirement is rated higher by students than by competitors. The result of the work is successful due to the achievement of the main goal and the solution of the main task.

The software can be developed in the following directions, for example, in the matrix of relationships between requirements and characteristics, you can include numerical values along with symbolic notations, or form the columns “Target value”, “Degree of improvement”, “Weight”, “Weight %” for requirements.

References

1. Kritskiy, D.N., Druzhinin, E.A., Karatanov, A.V., Kritskaya, O.S.: Content management method of complex technical system development projects. In: Natalya Shakhovska, Mykola O. Medykovskyy, (ed.) Advances in Intelligent Systems and Computing IV: Selected Papers from the International Conference on Computer Science and Information Technologies, CSIT 2019, September 17-20, 2019, Lviv, Ukraine, pp. 293–303. Springer International Publishing, Cham (2020). https://doi.org/10.1007/978-3-030-33695-0_21
2. QFD (Quality Function Deployment). https://support17.com/smk-konspekt-9/
3. Nicola Jones,: The Promise and Perils of Life Lived Online. Knowable Magazine (2021). https://doi.org/10.1146/knowable-060821-1
4. Kandil, M.S.: Prototype of Web2-based system for Quality Assurance Evaluation Process in Higher education Institutions/M. S. Kandil, A. E. Hassan, A. S. Asem, M. E. Ibrahim. Int. J. Electr. Comput. Sci. 10, No. 02
5. Doneva, R., Gaftandzhieva, S., Totkov, G.: Automated Quality Assurance of Educational. https://www.researchgate.net/publication/326190575_Automated_Quality_Assurance_of_Educational_Testing
6. Matei, L., Iwinska, J. Quality Assurance in Higher Education. A Practical Handbook. https://www.researchgate.net/publication/331345390_Quality_Assurance_in_Higher_Education_A_Practical_Handbook
7. Kritskiy, D., Kritskaya, O.: Modification of the quality house method. Int Sci. Tech. Conf. Comput. Sci. Inform. Technol. **2**, 167–170 (2020). https://doi.org/10.1109/CSIT49958.2020.9321922
8. Kivko, S.G., Druzhinin, E.A., Prokhorov, O.V., Kritsky, D.N.: Management of energy saving project and programs at metallurgical enterprises. Int. Sci. Tech. Conf. Comput. Sci. Inform. Technol. **3**, 158–161 (2019). https://doi.org/10.1109/STC-CSIT.2019.8929807
9. Kritsky, D.N., Druzhinin, E.A., Pogudina, O. K., Kritskaya, O.S.: A Method for Assessing the Impact of Technical Risks on the Aerospace Product Development Projects. In: Natalia Shakhovska, Mykola O. Medykovskyy, (ed.) Advances in Intelligent Systems and Computing III: Selected Papers from the International Conference on Computer Science and Information Technologies, CSIT 2018, September 11-14, Lviv, Ukraine, pp. 504–521. Springer International Publishing, Cham (2019). https://doi.org/10.1007/978-3-030-01069-0_36
10. Visual Studio Code. https://bizzapps.ru/p/vs-code/
11. Haverbeke, M.: Eloquent JavaScript. 3rd edition, 472, pp. (2018)
12. McGrath M. HTML in Easy Steps: An Indispensable Guide for HTML Newbies! 192 p. (2020)
13. Meyer, E.A.: Weyl E. CSS: The Definitive Guide: Visual Presentation for the Web, 208 p. (2017)

Transport Systems and Logistics

Engineering Patterns of Changes in the Parameters of Functioning of Intercity Passenger Transportation System

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Abstract. Transport is an important element of the functioning of society and its economic condition. Transport provides the needs of humanity in the transportation of people and goods. Passenger and cargo flows are formed taking into account the complexity, cost, time and speed of travel. Determining regularities in the passenger transportation system is an important task for the research of modern scientists. The study of flows in the passenger transportation system is such a task and arouses interest. The redistribution of passengers between routes of the same transport and the redistribution of passengers between modes of transport leads to changes in transportation indicators. The number of passengers transported by a certain route affects the traffic interval, passenger capacity, cost of rolling stock and all other technical and financial parameters of transportation.

Keywords: Transport system · intercity passenger transport route · main transportation parameters · efficiency · model

1 Introduction

The paper studies the sustainable passenger traffic between cities, the distribution of such traffic between alternative routes among the routes of the same and different modes of transport [1–5].

It is proposed to introduce computer modeling of the formation of passenger flows within the territory of Ukraine. The study proposes a function of route attractiveness, which, unlike the existing ones, takes into account the travel time to the station, station class (level of service at the station), boarding time, interval of movement of vehicles on the route, comfort of vehicles, comfort of the trip, cost of the trip, travel speed between stations, disembarkation time and travel time from the station.

The object of research is the process of functioning of passenger transportation systems within Ukraine.

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https://doi.org/10.1007/978-3-031-60549-9_40

The subject of the research is passenger transport systems, formation of passenger flows, redistribution of passengers between alternative routes in one and many modes of transport.

The purpose of the study is to establish the function of redistribution of passengers between alternative routes, to develop a model of the route network based on the example of Ukraine. In order to obtain the set tasks, the methods of scientific research were used in the work: empirical when observing the operating system, studying the system, measuring its parameters, complex when analyzing the literature, modeling the network, verification when analyzing the obtained results, original methods when studying the sources and mathematical when receiving a function.

2 Literature Analysis

Modern scientific research has studied the attractiveness of public routes [5–10].

In their studies, researchers often look at a single route, or a route for picking up passengers to certain points of passenger concentration. In this paper, we take such points, like all other stops, as nodes for modeling the route network. Researchers [11–20] have added to certain points their attractiveness through a coefficient or in another way.

Scientists [20–28] have not fully determined the network impact of the route on the network, and the influence of route functioning parameters on transportation performance parameters has not been sufficiently established [28–35].

3 Network Modeling

To provide computer modeling, the route network of Ukraine was considered. Bus stations and bus terminals of regional places of Ukraine – places of concentration of passengers are taken as nodes that have certain characteristics of receiving and sending passengers, the path - arcs of communication. A graph-analytical approach to a certain stage of network modeling is proposed. The proposed approach allows calculating the distance matrix and the flow distribution matrix between nodes.

In solving this stage, information was collected on the distances between nodes, absorption rates, and flow generation by nodes. Figure 1 shows the window of the developed computer model of the passenger transportation system of Ukraine.

The proposed model allows using and changing the parameters of fuel consumption, fuel cost, and vehicle capacity.

This model has the ability to simultaneously distribute passengers between road, rail, air, and water transport networks.

Vehicle capacity is the total passenger capacity; in urban transport, the total passenger capacity is equal to the number of seats (units).

Fuel consumption is measured in liters per hundred kilometers (l/100 km) and kilowatts per 100 km (kW/100 km) when using an electric motor.

The cost of vehicles, fuel prices, and fares are measured in conventional units (*c.u.*), while the cost of travel in the simulation is measured in conventional units per kilometer (*c.u. * km*).

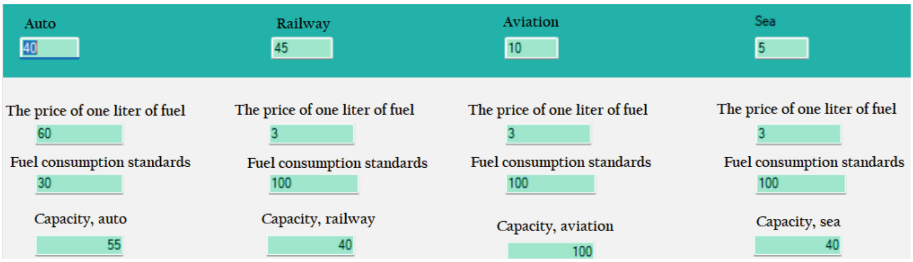

Fig. 1. The developed computer model of the passenger transportation system of Ukraine

A total of 25 nodes and arcs between certain nodes were obtained. Figure 2 shows the map of Ukraine with nodes on it.

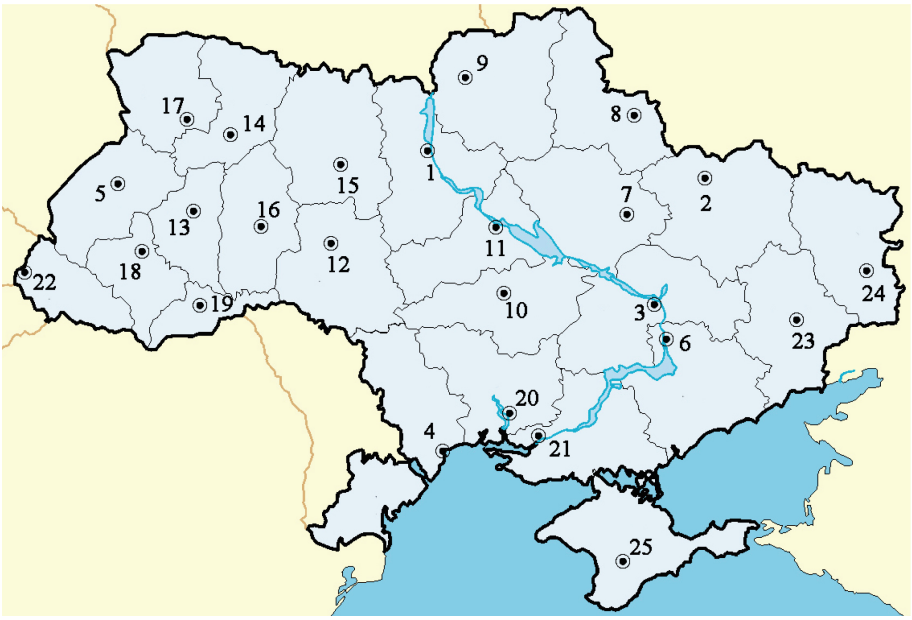

Fig. 2. Map of Ukraine with nodes of the graph model of the route network of Ukraine

The study assumes that the nodes of the graph model are located in regional centers. Kyiv is assumed to be node 1, Kharkiv – 2, Dnipro – 3, Odesa – 4, Lviv – 5, Zaporizhzhia – 6, Poltava - 7, Sumy – 8, Chernihiv – 9, Kropyvnytskyi – 10, Cherkasy – 11, 12 – Vinnytsia, 13 – Ternopil, 14 – Rivne, 15 – Zhytomyr, 16 – Khmelnytskyi, 17 – Lutsk, 18 – Ivano-Frankivsk, 19 – Chernivtsi, 20 – Mykolaiv, 21 – Kherson, 22 – Uzhhorod, 23 – Donetsk, 24 – Luhansk, 25 – Simferopol (Sevastopol for water transport).

The following information was also used in the modeling process: the number of routes of a certain type of transport (units), the speed (*km/h*) of vehicles in a certain network, the value added tax rate, the depreciation rate, the profit rate, interest payments

on the loan body, discount rates, project duration (in quarters), vehicle cost (*c.u.*), travel cost (*km* * *c.u.*), average occupancy rate, trip length resistance coefficient, distance between nodes (km), cost of fixed (salaries, etc.) and variable (tires, etc.) costs, which changes with the cost of fuel.

The results of the calculations were obtained. Figure 3 shows the result of the calculations – the net present value of routes 9 and 10. The route number, the quarter of the probable payback period of the project for the purchase of vehicles for this route, the amount of financial resources received from the operation of this route (quarterly in c.u.) were obtained.

```
Route number 9

10 - 1623477.40 1666565.52 1710459.12 1755180.44 1800752.08 1843513.73 1887001.85 19

9 - 1683419.55 1727856.37 1773129.02 1819260.41 1866273.85 1910375.72 1955231.46 200

8 - 1933178.52 1983234.92 2034253.59 2086260.28 2139281.22 2188967.32 2239521.53 229

Route number 10

2 - 31564440.16 32283074.19 33017666.63 33768581.83 34536192.17 35250236.09 35978694
```

Fig. 3. The result of the calculations is the net present value of routes 9 and 10

Figure 4 shows the result of calculating the net discounted profit. The route number (for example, route 9) and the flow of net discounted profit are obtained on a quarterly basis in accordance with the quarters of the probable payback of the project, for example, the payback period is in the 10th quarter, in which case the financial resource in the first quarter will be 1623477,40 c.u., and in the second – 1666565,52 c.u.

```
Route number 9

10 - 1623477.40 1666565.52 1710459.12 1755180.44 1637047.31 1675921.54 1715456.19 1755

9 - 1683419.55 1727856.37 1773129.02 1819260.41 1696612.55 1736705.16 1777483.11 18189

8 - 1933178.52 1983234.92 2034253.59 2086260.28 1944801.06 1989970.25 2035928.62 20826

Route number 10

2 - 31564440.16 32283074.19 33017666.63 33768581.83 31396537.66 32045668.48 32707903.7
```

Fig. 4. The result of calculating the net discounted profit

Figure 5 shows the result of calculating the movement of the financial flow in the road route network, in the part of the calculation of the flows for the payment of certain personnel involved in the operation of a certain route.

Similar calculations were made for the aviation, railway and water networks. Examples are shown in Figs. 6, 7, 8 and 9.

The possibility of the influence of the human factor when entering the network parameters is foreseen, and therefore the presence of connections to the nodes, the maintenance of these nodes is checked. Figure 9 shows an example of testing a car network.

```
Route number 9

10 - 1803863.78 1851739.47 1900510.14 1950200.49 2000835.65 2048348.59 20966

9 - 1870466.17 1919840.41 1970143.36 2021400.45 2073637.61 2122639.68 217247

8 - 2147976.14 2203594.35 2260281.76 2318066.97 2376979.13 2432185.91 248835

Route number 10

2 - 35071600.17 35870082.43 36686296.26 37520646.47 38373546.86 39166928.99
```

Fig. 5. The result of calculating the movement of financial flows in the road route network, in terms of calculating flows for labor payment

```
Route number 4

61 - Route number 4
42170705.14 44525233.51 46897596.58 49289074.18 51700952.99 54028775.24 56372

60 - 42546479.51 44909462.80 47290471.03 49690788.31 52111705.69 54447929.70

59 - 42922253.88 45293692.09 47683345.48 50092502.44 52522458.39 54867084.15

58 - 43673802.62 46062150.68 48469094.39 50895930.70 53343963.78 55705393.07

57 - 44801125.73 47214838.57 49647717.75 52101073.09 54576221.87 56962856.44

56 - 45552674.48 47983297.16 50433466.66 52904501.34 55397727.27 57801165.35

55 - 46304223.22 48751755.75 51219215.57 53707929.60 56219232.66 58639474.26
```

Fig. 6. Net profit in the railway transport network

```
2 - Route number 3
298414821.66 305191005.43 312118107.08 319199560.91 296762609.52 302883565.81 309128453.17

Route number 4

3 - Route number 4
4690844.09 4799199.45 4909922.53 5023068.35 4671539.12 4769402.97 4869210.84 4971003.94 46

2 - 4701622.44 4810220.32 4921191.37 5034590.74 4682249.70 4780332.63 4880364.06 4982385.2
```

Fig. 7. Discount profit in the water transport network

```
Route number 5

2 - Route number 5
731445701.93 747908436.47 764741452.39 781953084.26 799551854.11 815911028.33

Route number 6

2 - Route number 6
353325151.74 361280173.90 369414053.91 377730819.31 386234588.21 394139545.80

Route number 7

2 - Route number 7
261204463.05 267086769.72 273101298.13 279251026.53 285539000.09 291384275.24
```

Fig. 8. Movement of financial flows in the air transport network for personnel payments

```
1  Not serviced
2
```

Fig. 9. An example of a car network check

The inspection did not reveal any nodes with missing links, nor did it reveal any links that are not accessible. Figure 10 shows the results of the aviation network inspection.

```
1  Not serviced       : 1-8 1-9 1-12 1-14 1-15 1-17 1-18 1-19 1-
2
```

Fig. 10. The result of checking the aviation network

According to the results of the inspection, it was found that arcs 1–8, 1–9, 1–12 and so on are not serviced. This is the result of this modeling. The model does not contain airports in nodes 8, 9, 12, 14 and others. It can be concluded that the proposed model correctly verifies the network in terms of connections between nodes.

Let's calculate the correspondence of passengers between nodes within the same mode of transportation. Figure 11 shows the result of the distribution of passengers between automobile routes.

```
1  П1-П2(Hij): ||(П1-П2)|| Route number (Hij-route),..|||
2
3  1-2(271): 1(7.97), 6(49.07), 7(13.73), 82(139.20), 90(61.41)
4  1-3(187): 8(12.72), 22(68.68), 46(14.44), 97(92.01)
5  1-4(103): 33(103.13)
6  1-5(170): 9(85.05), 51(85.05)
7  1-6(68): 22(26.73), 46(5.62), 97(35.81)
8  1-7(156): 1(3.98), 6(24.52), 7(6.86), 22(20.87), 82(69.55), 90(30.68)
9  1-8(0): ||(1-7)||1(3.98), 6(24.52), 7(6.86), 22(20.87), 82(69.55), 90(30.6
10 1-9(238): 33(159.62), 43(0.93), 44(78.24)
11 1-10(91): 28(76.80), 39(0.86), 49(13.40)
12 1-11(162): 8(15.68), 42(130.57), 49(16.51)
13 1-12(210): 44(210.39)
14 1-13(29): 52(29.15)
15 1-14(58): 9(20.86), 22(16.42), 50(0.16), 51(20.86)
```

Fig. 11. The result of the distribution of passengers between car routes

In Fig. 11, we can see that the total *Hij* (passenger correspondence) between nodes 1 and 2 is 271 hundreds of passengers, which corresponds to the data entered into the program and obtained by the empirical method. This flow was divided between the routes, namely: the first route attracted 7.97 hundred passengers; 6–49,07; 7–13,73; 82–139,2; 90–61,41.

Redistribution of passengers was carried out in the proposed way according to dependence (1)

$$F_i = f(T_s) \cdot f(K_s) \cdot f\left(T_p\right) \cdot f(I_i) \cdot f(A) \cdot f(F_k) \cdot f(C_i) \cdot f(V_i) \cdot f(T_v) \cdot f(T_z), \quad (1)$$

where F_i – the volume of passengers on the route i in a particular mode of transport;
$f(T_s)$ – attractiveness of the route, based on the location of the station and the quality of transport accessibility of the station;
$f(K_s)$ – the function of station attractiveness, the state of its development and the provision of station services;
$f(T_p)$ – function of the time of boarding the transport (*hours*);
$f(I_i)$ – function of the interval of vehicle movement on the route (*hours*);
f(A) – function of the comfort of vehicles;
$f(F_k)$ – ride comfort function;
$f(C_i)$ – the cost of driving on the *i-th* route;
$f(V_i)$ – driving speed on the *i-th* route;
$f(T_v)$ – the time of disembarkation on the *i-th* route;
$f(T_z)$ – travel time from the bus station z.

The relevant factors influencing the choice of the route are indicated by passengers during the survey, the importance of such parameters is individual for each society and is established by an empirical method, and mathematical modeling is possible using the Saati method.

The next step is to obtain information about the correspondence between certain network nodes. Figure 12 shows information on passenger flows along the links of the automobile route network, for example, link 1-1 does not provide communication, link 1-2 provides passenger communication by routes1, 6, 7, 82 and 90, routes provide communication of 797; 4907; 1373; 13920 and 6141 passengers, respectively.

```
П1-П2(Hij): ||(П1-П2)|| Route number  (Hij- route),..|||

1-2(271): 1(7.97), 6(49.07), 7(13.73), 82(139.20), 90(61.41)
1-3(187): 8(12.72), 22(68.68), 46(14.44), 97(92.01)
1-4(103): 33(103.13)
1-5(170): 9(85.05), 51(85.05)
1-6(68): 22(26.73), 46(5.62), 97(35.81)
1-7(156): 1(3.98), 6(24.52), 7(6.86), 22(20.87), 82(69.55), 90(30.68)
1-8(0): ||(1-7)||1(3.98), 6(24.52), 7(6.86), 22(20.87), 82(69.55), 90(30.6
1-9(238): 33(159.62), 43(0.93), 44(78.24)
1-10(91): 28(76.80), 39(0.86), 49(13.40)
1-11(162): 8(15.68), 42(130.57), 49(16.51)
1-12(210): 44(210.39)
1-13(29): 52(29.15)
1-14(58): 9(20.86), 22(16.42), 50(0.16), 51(20.86)
```

Fig. 12. Passenger flows through the links of the automobile route network along the routes

The relevant calculation parameters made it possible to calculate variances in the payback period of projects for the purchase of vehicles for the route. Figure 13 shows an example of calculations of the payback period for railway route № 19. According

to the results, the railway route will pay off in the period from 21 to 31 quarters. The probability of project payback in the 24th quarter is 0,2089. The probability of project payback is highest in the 24th quarter, the probability of less than 0,0001 percent is not displayed on the monitor and is not highlighted, it is considered that such a probability is too small and does not require attention. The probability arises as a consequence of the properties of the passenger flow, which is a stochastic variable and can fluctuate according to the normal distribution law [35–41] [42]. At the same time, cleaning up the flow values is not a guarantee of a shorter payback period. The calculations in Fig. 13 show that the payback period of the project T_o is most likely to occur in the 23rd quarter when the values of transportation volumes Q_t. Q_{21} to Q_{31} takes values from 180443 passenger square meters (passengers per quarter) to 144693 passenger square meters, and Q_{24} – the most likely quarter of project payback is 166468 passenger square meters, respectively, the 23rd quarter contains indicators of income (D_t) between the boundary values of the project.

```
:Quarter   - 80, probability     - 0.0009000: Qt - 114473.000000, Income   - 17748733.33
:Quarter   - 79, probability     - 0.0015500: Qt - 114877.000000, Income   - 17748733.33


Route number    19
:Quarter   - 31, probability     - 0.0023300: Qt - 144693.000000, Income   - 35998125.00
:Quarter   - 30, probability     - 0.0088000: Qt - 146968.000000, Income   - 35998125.00
:Quarter   - 29, probability     - 0.0197300: Qt - 149568.000000, Income   - 35998125.00
:Quarter   - 28, probability     - 0.0382000: Qt - 152493.000000, Income   - 35998125.00
:Quarter   - 27, probability     - 0.0651400: Qt - 155418.000000, Income   - 35998125.00
:Quarter   - 26, probability     - 0.1081800: Qt - 158668.000000, Income   - 35998125.00
:Quarter   - 25, probability     - 0.1530400: Qt - 162243.000000, Income   - 35998125.00
:Quarter   - 24, probability     - 0.2089700: Qt - 166468.000000, Income   - 35998125.00
:Quarter   - 23, probability     - 0.1749800: Qt - 170693.000000, Income   - 35998125.00
:Quarter   - 22, probability     - 0.1179600: Qt - 174918.000000, Income   - 35998125.00
:Quarter   - 21, probability     - 0.0729500: Qt - 180443.000000, Income   - 35998125.00
```

Fig. 13. An example of calculating the payback period of railway route № 19

The impact of flow fluctuations on the payback period of the project can have other values and take a larger payback range. Figure 14 shows the results of T_o, Q_t, D_t calculation for another route.

In Fig. 14, we can see that the payback period ranges from the 36th to the 73rd quarter, and it is established by the cost calculations that *To* takes a significant range of values, and this situation may be due to the peculiarities of *To* values from the impact of costs on each route.

The results of the network operation are generated in a separate file. Figure 15 shows the results of the overall operation of route number 4 and number 5. One can get generalized information about the route. Route 5 is laid between nodes 2, 3, 21, 20, and 4 in one direction of travel and between nodes 4, 20, 21, 3, and 2 in the opposite direction of travel. On route 5, the volume of traffic between nodes 2 and 3 is 654 passengers per day, and on route 4, the volume of traffic between nodes 2 and 3 is 8 passengers per day.

This is due to the function of redistribution of passengers between routes, and presumably in this case a significant difference in the interval of movement has a significant impact on the redistribution, and therefore *f(Ii)* – a function of the interval of movement

```
Route number   26
:Quarter   - 73, probability    - 0.0014700: Qt - 93038.000000, Income   - 17959216.67
:Quarter   - 72, probability    - 0.0008600: Qt - 93248.000000, Income   - 17959216.67
:Quarter   - 71, probability    - 0.0019700: Qt - 93668.000000, Income   - 17959216.67
:Quarter   - 70, probability    - 0.0011300: Qt - 93878.000000, Income   - 17959216.67
:Quarter   - 69, probability    - 0.0026000: Qt - 94298.000000, Income   - 17959216.67
:Quarter   - 68, probability    - 0.0031000: Qt - 94718.000000, Income   - 17959216.67
:Quarter   - 67, probability    - 0.0036800: Qt - 95138.000000, Income   - 17959216.67
:Quarter   - 66, probability    - 0.0026200: Qt - 95348.000000, Income   - 17959216.67
:Quarter   - 65, probability    - 0.0047700: Qt - 95768.000000, Income   - 17959216.67
:Quarter   - 64, probability    - 0.0055500: Qt - 96188.000000, Income   - 17959216.67
:Quarter   - 63, probability    - 0.0064400: Qt - 96608.000000, Income   - 17959216.67
:Quarter   - 62, probability    - 0.0074000: Qt - 97028.000000, Income   - 17959216.67
:Quarter   - 61, probability    - 0.0131100: Qt - 97658.000000, Income   - 17959216.67
:Quarter   - 60, probability    - 0.0102100: Qt - 98078.000000, Income   - 17959216.67
:Quarter   - 59, probability    - 0.0114800: Qt - 98498.000000, Income   - 17959216.67
:Quarter   - 58, probability    - 0.0180100: Qt - 99128.000000, Income   - 17959216.67
:Quarter   - 57, probability    - 0.0148000: Qt - 99548.000000, Income   - 17959216.67
:Quarter   - 56, probability    - 0.0250000: Qt - 100178.000000, Income   - 17959216.67
:Quarter   - 55, probability    - 0.0284600: Qt - 100808.000000, Income   - 17959216.67
:Quarter   - 54, probability    - 0.0319200: Qt - 101438.000000, Income   - 17959216.67
:Quarter   - 53, probability    - 0.0353100: Qt - 102068.000000, Income   - 17959216.67
:Quarter   - 52, probability    - 0.0384900: Qt - 102698.000000, Income   - 17959216.67
:Quarter   - 51, probability    - 0.0413600: Qt - 103328.000000, Income   - 17959216.67
:Quarter   - 50, probability    - 0.0588700: Qt - 104168.000000, Income   - 17959216.67
:Quarter   - 49, probability    - 0.0462600: Qt - 104798.000000, Income   - 17959216.67
:Quarter   - 48, probability    - 0.0593200: Qt - 105638.000000, Income   - 17959216.67
:Quarter   - 47, probability    - 0.0677000: Qt - 106478.000000, Income   - 17959216.67
:Quarter   - 46, probability    - 0.0625000: Qt - 107318.000000, Income   - 17959216.67
:Quarter   - 45, probability    - 0.0597700: Qt - 108158.000000, Income   - 17959216.67
:Quarter   - 44, probability    - 0.0688800: Qt - 109208.000000, Income   - 17959216.67
:Quarter   - 43, probability    - 0.0606400: Qt - 110258.000000, Income   - 17959216.67
:Quarter   - 42, probability    - 0.0512800: Qt - 111308.000000, Income   - 17959216.67
:Quarter   - 41, probability    - 0.0398200: Qt - 112358.000000, Income   - 17959216.67
:Quarter   - 40, probability    - 0.0385700: Qt - 113618.000000, Income   - 17959216.67
:Quarter   - 39, probability    - 0.0271500: Qt - 114878.000000, Income   - 17959216.67
:Quarter   - 38, probability    - 0.0180400: Qt - 116138.000000, Income   - 17959216.67
:Quarter   - 37, probability    - 0.0116900: Qt - 117398.000000, Income   - 17959216.67
:Quarter   - 36, probability    - 0.0076900: Qt - 119078.000000, Income   - 17959216.67
```

Fig. 14. Results of *To*, *Qt*, *Dt* calculation for route number 26

of vehicles on the route from dependence *(1)* has such an impact. The calculation also highlights the value of the number of passenger seats on the route – q(pass.), the volume of traffic on the route during the peak, in this case, the value per day Q_{day} (pass.), the length of the route $L_м$ (km), the speed of communication on the route $V_м$ km/h, the design capacity of the vehicle q, the number of vehicle calculations on the route A, the interval of movement in hours and minutes, the static occupancy rate γ_c and the dynamic occupancy rate $\gamma_д$ [20].

All calculations are carried out in the network, for which the calculations of the tables of shorter distances were carried out for each network. Figure 16 shows the result of the calculation of the shortest distances along the railway network.

Figure 15 demonstrates the influence of the passenger flow distribution function between routes. The influence of the traffic interval on the distribution of passengers on alternative routes between nodes 2 and 3 was divided into 8 and 654 passengers per day.

Accordingly, the interval is from 1440 to 102 min. Similar calculations were made for the automobile, railway, and aviation networks. All calculations are carried out in the network, for which the calculations of the tables of shorter distances were carried out

```
Route number       №4
    8       8
2-----3-----2
Passenger seats on the route       : 3 passengers
Volume of transportation on the route  : 8 passengers during the peak
Maximum passenger flow             : 8 passengers during the peak
Route length          :235.00 km
Turnover time  : 7.83 hours
Vehicle speed    : 60 km/h
Bus capacity             : 55 passengers
Number of buses at "peak"          : 1
Movement interval  24.00 hours
Movement interval  1440.00 min
The cabin occupancy rate is dynamic       : 0.05


Route number       №5
   654    536    660     766     766    660     536     654
2-----3-----21-----20-----4-----20-----21-----3-----2
Passenger seats on the route       : 424 passengers
Volume of transportation on the route  : 1403 passengers during the peak
Maximum passenger flow             : 766 passengers during the peak
Route length          :803.00 km
Turnover time  : 26.77 hours
Vehicle speed    : 60 km/h
Bus capacity             : 55 passengers
Number of buses at "peak"          : 16
Movement interval  1.71 hours
Movement interval  102.86 min
The cabin occupancy rate is dynamic       : 0.78
```

Fig. 15. The results of the general operation of route number 4 and number 5

for each network. Figure 16 shows the result of calculating the shortest distances along the railway network.

Distances between nodes are calculated to determine many parameters, namely: route length, delayed trips, variable time period costs, movement interval, trip time and other parameters. Other parameters were also used during programming.

Modeling of the network was carried out with the following parameters: share of road transport 39%; railway 51%; aviation 10%; the cost of automobile fuel C_A 50 c.u.; fuel consumption by road transport Q_{HA}30 l/100 km; bus capacity $q_A = 55$ units; value added tax rate of 0,01; rate of amortization deductions 10; the income tax rate is 10; the value of the discount rate is 10; annual interest payments on borrowed capital; project duration from 60 to 160 quarters; the share of passenger traffic in the railway network is 51%; cost per square hour $C_{ж}$ 3 c.u.; fuel consumption for transportation $Q_{ЗТ}$ 100 kV., wagon capacity $q_{зт}$ 40 units, cost of aviation fuel 3 c.u.; fuel consumption in the Q_{AB} aviation network; aircraft capacity $q_{AB} = 55$ units; the cost of the bus is 10,000,000 c.u.; tariff in the automobile network 1 c.u.; the cost of the wagon is 30,000,000 c.u.; travel fare 2 c.u.; the cost of the plane is 1,000,000,000 c.u.; flight fare 5 c.u.

```
0 485 450 635 551 551 340 335 147 320 180 276 539 342 154 335 415
485 0 235 774 1036 294 145 189 494 476 385 737 1024 827 639 820 90
450 235 0 556 1001 105 182 352 586 241 381 569 989 792 604 699 865
635 774 556 0 1079 480 695 865 782 315 455 560 1067 870 682 690 94
551 1036 1001 1079 0 1102 891 886 698 847 731 519 126 209 397 399
555 294 105 480 1106 0 287 457 691 346 486 674 1094 897 709 804 97
340 145 182 695 891 287 0 170 404 380 240 592 879 682 494 675 755
335 189 352 865 886 457 170 0 305 550 410 611 874 677 489 670 750
147 494 509 782 698 404 475 305 0 467 327 423 686 489 301 482 562
320 476 241 315 847 346 380 550 467 0 140 328 835 638 450 458 711
180 385 381 455 731 486 240 410 327 140 0 352 719 522 334 482 595
276 737 569 560 519 674 592 611 423 328 352 0 507 310 122 130 383
521 1006 971 1049 126 1072 861 856 668 817 701 489 0 179 367 369 2
342 827 792 870 209 893 682 677 489 638 522 310 197 0 188 190 73 3
154 639 604 682 397 705 494 489 301 450 334 122 385 188 0 181 261
335 820 699 690 399 804 675 670 482 458 482 130 387 190 181 0 263
```

Fig. 16. The result of the calculation of the shortest distances along the railway network

To establish connections between the network parameters, the modeling was carried out ten times with a change in the cost of vehicles by 50,000 c.u. The results are presented in Fig. 16 and form the basis for further research.

4 Conclusions

- the payback period of the project depends on the cost of rolling stock;
- the quality of means of transport affects the redistribution of passengers less than the travel interval;
- it is possible to develop a network model by means of computer simulation;
- the function of redistribution of passengers between alternative routes is established within the considered system for the 2012 research year.

References

1. Majid, M.A.A., Pardi, F., Amer, A., Kamdari, N.A.M., Selamat, S.M.: Air passengers vertex curve theorem - evidence from ASEAN countries. Asian Econ. Finan. Rev. **9**(3), 329–338 (2019). https://doi.org/10.18488/journal.aefr.2019.93.329.338
2. Zhang, Y., Findlay, C.: Air transport policy and its impacts on passenger traffic and tourist flows. J. Air Transp. Manag. **34**, 42–48 (2014). https://doi.org/10.1016/j.jairtraman.2013.07.010
3. Bao, Y., Yi, D., Xiong, T., Hu, Z., Zheng, S.: A comparative study on hybrid linear and nonlinear modeling framework for air passenger traffic forecasting. Adv. Inf. Sci. Serv. Sci. **3**(5), 243–254 (2011). https://doi.org/10.4156/aiss.vol3.issue5.28
4. Rodríguez-Doncel, V., Santos, C., Casanovas, P.: A model of air transport passenger incidents and rights (2014). https://doi.org/10.3233/978-1-61499-468-8-55
5. Marie-Sainte, S.L., Saba, T., Alotaibi, S.: Air passenger demand forecasting using particle swarm optimization and firefly algorithm. J. Comput. Theor. Nanosci. **16**(9), 3735–3743 (2019). https://doi.org/10.1166/jctn.2019.8242

6. Jing He, J., Xu, L., Ning Guo, X., Hu, Y.: Air passengers purchasing behavior of specialty products at airport: an empirical study. Paper Presented at the ACM International Conference Proceeding Series, pp. 13–17 (2021). https://doi.org/10.1145/3503491.3503494
7. Liang, X., Guo, Z., Zhang, Q., Yang, M., Wang, S.: An analysis and decomposition ensemble prediction model for air passenger demand based on singular spectrum analysis. Xitong Gongcheng Lilun Yu Shijian/Syst. Eng. Theor. Pract. **40**(7), 1844–1855 (2020). https://doi.org/10.12011/1000-6788-2019-1010-12
8. Huang, F., Peng, J., You, M.: Analyses of characetristics of air passenger group mobility behaviors. Wuli Xuebao/Acta Physica Sinica **65**(22), 228901 (2016). https://doi.org/10.7498/aps.65.228901
9. Ida, Y.: Changes of air passenger distribution patterns in Japan. Japan J. Hum. Geogr. **45**(3), 221–243 (1993). https://doi.org/10.4200/jjhg1948.45.221
10. Afaq, A., Gaur, L., Singh, G., Dhir, A.: COVID-19: transforming air passengers' behaviour and reshaping their expectations towards the airline industry. Tour. Recreat. Res. **48**, 800–808 (2021). https://doi.org/10.1080/02508281.2021.200821
11. Mygal, V., Mygal, G.: Interdisciplinary approach to the human factor problem. Municipal Econ. Cities. **3**(156), 149–157 (2020). https://doi.org/10.33042/2522-1809-2020-3-156-149-157
12. Mygal, V.P., Mygal, G.V.: Cognitive and ergonomics aspects human interactions with a computer. Radioelectron. Comput. Syst. **1**(93), 90–102 (2020). https://doi.org/10.32620/reks.2020.1.09
13. Mygal, V.P., Mygal, G.V., Mygal, S.P.: Transdisciplinary convergent approach – human factor. Radioelectron. Comput. Syst. Model. Digitalization **4**(100), 7–21 (2021). https://doi.org/10.32620/reks.2021.4.01
14. Mygal, V., Mygal, G., Mygal, S.: Cognitive space for online and offline learning: a convergent approach. Educ. Rev. USA **6**(4) 109–123 (2022). https://doi.org/10.26855/er.2022.04.001
15. Dolia, K., Kobrina, N.: Engineering patterns of changes in the parameters of functioning of intercity passenger transportation system. Int. Sci. J. Eng. Agric. **1**(5), 132–138 (2022). https://doi.org/10.46299/j.isjea.20220105.14
16. Mygal, V.P., Mygal, G.V., Mygal S.P.: Actual problems of creative activity and new cognitive possibilities: a transdisciplinary approach. Qeios ID: GIJ3RI (2023). https://doi.org/10.32388/GIJ3RI
17. Mygal, G., Protasenko, O.: Human factors: the problem of man-machine interaction in the digitalization conditions. Sci. J. Polonia Univ. Periodyk Naukowy Akademii Polonijnej (PNAP). **48**(5), 198–210 (2021). https://doi.org/10.23856/4825
18. Huang, F., Xiong, X., Peng, J., Guo, B., Tong, B.: RCA: a route city attraction model for air passengers. Physica A **491**, 887–897 (2018). https://doi.org/10.1016/j.physa.2017.08.081
19. Erjongmanee, S., Kongsamutr, N.: Air passenger estimation using gravity model and learning approaches: case study of Thailand. Paper Presented at the ICAICTA 2018 - 5th International Conference on Advanced Informatics: Concepts Theory and Applications, pp. 36–41 (2018). https://doi.org/10.1109/ICAICTA.2018.8541335
20. Dolya K., Dolya O.: Economic-mathematical modeling influence of environment at the development of systems passenger transport. Науковий вісник Херсонського державного університету **16**, 152–154 (2016)
21. Chang, Y., Liao, M.: Air passenger perceptions on exit row seating and flight safety education. Saf. Sci. **46**(10), 1459–1468 (2008). https://doi.org/10.1016/j.ssci.2007.11.006
22. Santos, C.: Enhancing the decision making process through relevant legal information in consumer law disputes - a case study in air transport passenger rights. Paper Presented at the CEUR Workshop Proceedings, vol. 1296 (2014)

23. Chiang, W.: Establishment and application of fuzzy decision rules: an empirical case of the air passenger market in Taiwan. Int. J. Tour. Res. **13**(5), 447–456 (2011). https://doi.org/10.1002/jtr.819
24. Iacus, S.M., Natale, F., Santamaria, C., Spyratos, S., Vespe, M.: Estimating and projecting air passenger traffic during the COVID-19 coronavirus outbreak and its socio-economic impact. Saf. Sci. **129**, 104791 (2020). https://doi.org/10.1016/j.ssci.2020.104791
25. Seetaram, N., Song, H., Ye, S., Page, S.: Estimating willingness to pay air passenger duty. Ann. Tour. Res. **72**, 85–97 (2018). https://doi.org/10.1016/j.annals.2018.07.001
26. Lv, Z.: Evaluation the quality of air passenger services (2014). https://doi.org/10.4028/www.scientific.net/AMR.971-973.2329
27. Van De Vijver, E., Derudder, B., Witlox, F.: Exploring causality in trade and air passenger travel relationships: the case of Asia-Pacific, 1980–2010. J. Transp. Geogr. **34**, 142–150 (2014). https://doi.org/10.1016/j.jtrangeo.2013.12.001
28. Lyu, Z., Zhu, Y., Li, J., Xu, Y., Li, Z., Wang, X.: Exploring spatiooral characteristics of air passenger flow in the Beijing-Tianjin-Hebei region based on ticket data. Paper Presented at the Proceedings of 2020 IEEE 2nd International Conference on Civil Aviation Safety and Information Technology, ICCASIT, pp. 925–930 (2020). https://doi.org/10.1109/ICCASIT50869.2020.9368855
29. Lin, X., Chiang, C., Shih, T., Jiang, Y., Chou, C.: Foot-and-mouth disease entrance assessment model through air passenger violations. Risk Anal. **29**(4), 601–611 (2009). https://doi.org/10.1111/j.1539-6924.2008.01183.x
30. Do, Q.H., Lo, S., Chen, J., Le, C., Anh, L.H.: Forecasting air passenger demand: a comparison of LSTM and SARIMA. J. Comput. Sci. **16**(7), 1063–1084 (2020). https://doi.org/10.3844/JCSSP.2020.1063.1084
31. Jin, F., Li, Y., Sun, S., Li, H.: Forecasting air passenger demand with a new hybrid ensemble approach. J. Air Transp. Manag. **83**, 101744 (2020). https://doi.org/10.1016/j.jairtraman.2019.101744
32. Cakir, V., Oguz, S.: Forecasting air passenger demand with system dynamics under terrorism threat. Paper Presented at the Proceedings of the International Conference on Industrial Engineering and Operations Management (JUL), pp. 2676–2677 (2018)
33. Gunter, U., Zekan, B.: Forecasting air passenger numbers with a GVAR model. Ann. Tour. Res. **89**, 103252 (2021). https://doi.org/10.1016/j.annals.2021.103252
34. Wu, X., Xiang, Y., Mao, G., Du, M., Yang, X., Zhou, X.: Forecasting air passenger traffic flow based on the two-phase learning model. J. Supercomput. **77**(5), 4221–4243 (2021). https://doi.org/10.1007/s11227-020-03428-2
35. Tsui, W.H.K., Ozer Balli, H., Gilbey, A., Gow, H.: Forecasting of Hong Kong airport's passenger throughput. Tour. Manage. **42**, 62–76 (2014). https://doi.org/10.1016/j.tourman.2013.10.008
36. Kim, S., Shin, D.H.: Forecasting short-term air passenger demand using big data from search engine queries. Autom. Constr. **70**, 98–108 (2016). https://doi.org/10.1016/j.autcon.2016.06.009
37. Nourzadeh, F., Ebrahimnejad, S., Khalili-Damghani, K., Hafezalkotob, A.: Forecasting the international air passengers of Iran using an artificial neural network. Int. J. Ind. Syst. Eng. **34**(4), 562–581 (2020). https://doi.org/10.1504/IJISE.2020.106089
38. Janic, M.: High-speed rail and air passenger transport: a comparison of the operational environmental performance. Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit. **217**(4), 259–269 (2003). https://doi.org/10.1243/095440903322712865
39. Sulistyowati, R., Suhartono, Kuswanto, H., Setiawan, Astuti, E.T.: Hybrid forecasting model to predict air passenger and cargo in Indonesia. Paper Presented at the 2018 International Conference on Information and Communications Technology, ICOIACT, pp. 442–447 (2018). https://doi.org/10.1109/ICOIACT.2018.8350816

40. Hsu, C., Wen, Y.: Improved grey prediction models for the trans-pacific air passenger market. Transp. Plann. Technol. **22**(2), 87–107 (1998). https://doi.org/10.1080/03081069808717622
41. Chen, S., Kuo, S., Chang, K., Wang, Y.: Improving the forecasting accuracy of air passenger and air cargo demand: the application of back-propagation neural networks. Transp. Plann. Technol. **35**(3), 373–392 (2012). https://doi.org/10.1080/03081060.2012.673272

Optimizing Air Traffic Control: Innovative Approaches to Collision Avoidance in UAV Operations

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Abstract. In the modern world, the development of unmanned aerial vehicles (UAVs) is becoming an increasingly relevant and important task. Controlling the traffic of UAVs is a key component to ensure the safety and efficiency of their movement in airspace. This article explores mathematical models and methods that help address the challenges of UAV traffic management. The first section of the article is dedicated to mathematical models of UAV movement in a two-dimensional plane. The use of motion equations allows predicting trajectories and controlling the movement of UAVs, ensuring their safety and accurate location. The second section of the article discusses the important task of collision avoidance for multiple UAVs. The mathematical model of this task helps find optimal paths for each UAV to minimize mutual distances and avoid possible collisions in airspace. The third section discusses dynamic route planning for UAVs. The use of optimization methods allows finding the shortest route and optimizing fuel costs, which are crucial aspects for ensuring the efficiency of UAV operations. This article summarizes the importance of mathematical models and methods in UAV traffic management and emphasizes their role in ensuring the safety and reliability of unmanned aerial vehicles in airspace. The development of these models and methods is an important direction for further research and improvement of UAV traffic management systems.

Keywords: Unmanned aerial vehicles · traffic management · mathematical models · collision avoidance · route optimization · air traffic · air safety · dynamic route planning · UAV movement · trajectory modeling · optimal movement · UAV routing · unmanned system efficiency

1 Introduction

The growing interest in unmanned aerial vehicles (UAVs) in the modern world calls for the improvement of control systems and management of their movement. This is particularly relevant in the face of increasing air traffic and the expanding use of UAVs in various industries, including delivery, monitoring, and research. One key aspect of addressing issues related to UAV movement is the development of effective mathematical

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models, methods, and information technologies for traffic management [1]. This article focuses on the model of UAV movement in a two-dimensional plane and explores its application for collision avoidance, route optimization, and trajectory planning. The continuation of the introduction is the first section, where the equations of movement in a two-dimensional plane are presented, and their use for modeling UAV trajectories is analyzed [2].

One of the most popular formulas for solving these problems is the formula for minimizing mutual distances:

$$min \sum i = 1N \sum j + 1Nd(r_i(t), r_i(t)) \quad (1)$$

This formula involves minimizing distances between each pair of UAVs, where **d(ri(t),rj(t))** is the distance between the vehicles i and j at time t. While this approach is effective, it has its drawbacks [3]. One of the main drawbacks of such a formula is the need for exhaustive computation of distances between all pairs of vehicles, which becomes a significant factor as the number of UAVs increases [4]. This can lead to computational complexity and real-time delays. The research proposes a new approach to collision avoidance based on optimizing the use of airspace and vehicle routes. These mathematical models allow avoiding exhaustive computations and ensuring more efficient traffic management, reducing the risk of collisions, and enhancing overall air safety [5].

2 Mathematical Models of UAV Movement

Motion Equations in a Two-Dimensional Plane: Representation of motion equations. Examples of use for trajectory modeling. In this section, we will examine the motion equations for unmanned aerial vehicles (UAVs) in a two-dimensional plane and their use in modeling movement trajectories [6].

Mathematical models of movement are crucial for accurately predicting and controlling the movement of UAVs. Representation of motion equations: The movement of UAVs in a two-dimensional plane can be described by the following motion equation:

$$r(t) = r_0 + v_0 t + at^2 \quad (2)$$

where r(t) is the position of the UAV at time t, r_0 is the initial position of the UAV, v_0 is the initial velocity of the UAV, a is the acceleration of the UAV.

This equation considers the initial position, initial velocity, and acceleration to model the movement of UAVs at a specific moment in time. Trajectory planning: The motion equation allows for the planning of trajectories for UAVs based on given initial conditions and accelerations. For example, this is useful for planning precise routes for drones or aircraft to perform specific tasks. Movement modeling: The motion equation is used to create realistic simulations of UAV movement. This helps analyze their behavior in different scenarios and conditions without the need for physical experiments. Trajectory control: The motion equation allows real-time control and modification of the UAV's trajectory. By using known values of initial position, velocity, and acceleration, the movement of the device can be adjusted to achieve specific goals. The motion equation

in a two-dimensional plane is a crucial component for modeling and controlling the movement of unmanned aerial vehicles, ensuring accuracy and predictability in their motion [7].

Motion Equations in a Two-Dimensional Plane. Presentation of Motion Equations. Examples of use for trajectory modeling. In this section, we will discuss the motion equations for unmanned aerial vehicles (UAVs) in a two-dimensional plane and their application for modeling movement trajectories. Mathematical models of movement are essential for accurate prediction and control of UAV motion. Presentation of motion equations: The motion of UAVs in a two-dimensional plane can be described by the following motion equation:

$$(t) = r_0 + v_0 t + \frac{1}{2} a t^2 \tag{3}$$

where r(t) is the position of the UAV at time t, r_0 is the initial position of the UAV, v_0 is the initial velocity of the UAV, a is the acceleration of the UAV.

This equation considers the initial position, initial velocity, and acceleration to model the movement of UAVs at a specific moment in time. Trajectory planning: The motion equation allows for the planning of trajectories for UAVs based on given initial conditions and accelerations. For example, this is useful for planning precise routes for drones or aircraft to perform specific tasks.

Movement modeling: The motion equation is used to create realistic simulations of UAV movement. This helps analyze their behavior in different scenarios and conditions without the need for physical experiments. Trajectory control: The motion equation allows real-time control and modification of the UAV's trajectory. By using known values of initial position, velocity, and acceleration, the movement of the device can be adjusted to achieve specific goals. The motion equation in a two-dimensional plane is a crucial component for modeling and controlling the movement of unmanned aerial vehicles, ensuring accuracy and predictability in their motion [8].

3 Collision Avoidance for Multiple UAVs

In this section, we will explore a crucial aspect of unmanned aerial vehicle (UAV) traffic management - collision avoidance in situations involving multiple UAVs. Mathematical models developed to address this task play a significant role in ensuring the safety and efficiency of UAV movement in airspace. 2.1 Mathematical model of collision avoidance. Description of the collision avoidance task. Application to situations with multiple UAVs. The mathematical model of collision avoidance is a tool that helps determine optimal paths for each UAV to minimize mutual distances and avoid potential collisions [9].

This model considers the positions and velocities of all UAVs to ensure their safety in airspace. Description of the collision avoidance task: The collision avoidance task involves finding optimal solutions for each UAV, considering the movement of other UAVs and constraints on their capabilities. The goal is to avoid situations where UAVs are too close to each other, which could lead to potential accidents and collisions. Application to situations with multiple UAVs: Mathematical models of collision avoidance

are particularly useful in situations with multiple UAVs, where manually determining optimal paths for each of them could be challenging.

In such cases, models help automate the process and ensure effective collision avoidance, maintaining safety and order in airspace.

This section underscores the importance of mathematical models of collision avoidance for managing the traffic of unmanned aerial vehicles in complex situations with multiple UAVs, ensuring their safety and coordinated movement in airspace. Minimization of mutual distances model to avoid collisions between N UAVs: Mathematical formula:

$$min \sum i = 1N \sum j = i + 1ND(r_i(t), r_i(t)) \tag{4}$$

This formula is applied to avoid collisions between unmanned aerial vehicles (UAVs) in airspace. It requires the minimization of distances between UAVs to prevent potential conflicts. Mathematically, we calculate the sum of all mutual distances between pairs of UAVs, and our goal is to find positions and movement paths for UAVs that minimize this sum. Logical description: In the real world, where unmanned aerial vehicles are in motion, there is a risk of potential collisions [10].

This formula helps develop collision avoidance strategies by minimizing mutual distances between vehicles. The ability to compute an optimal distribution of positions for each UAV contributes to ensuring safety in airspace.

Dynamic Route Planning Considering Speed and Maneuverability Constraints: In this subsection, we will examine a crucial aspect of unmanned aerial vehicle (UAV) traffic management - dynamic route planning considering constraints on their speed and maneuverability. This approach is essential for ensuring the efficiency and safety of UAV movement in various conditions [11]. Mathematical model of dynamic route planning for route planning of UAVs, taking into account constraints on speed and maneuverability, mathematical models are employed that consider the physical limitations of the aircraft. The model may take the form:

$$min \sum i = 1N \sum J = 1Nc(i, j)x(i, j) \tag{5}$$

where N - the number of route points,

c(i, j) - fuel costs between points i and j,

x(i, j) - binary variables indicating whether to visit point j after point i (Fig. 1).

This mathematical model helps find the shortest route for UAVs while adhering to speed and maneuverability constraints. Considering speed and maneuverability constraints In route planning, it is crucial to consider constraints on the maximum speed and the ability to control UAVs [12]. Mathematical models enable the optimal selection of paths and waypoints, adhering to these constraints, which is important for the safety and efficiency of movement. Application to real-time scenarios Dynamic route planning models considering speed and maneuverability constraints are used in real-time to control UAVs and optimize their routes. This allows for responding to changes in the environment and flight route requirements, ensuring the best movement of the aircraft. This subsection emphasizes the importance of dynamic route planning considering speed and maneuverability constraints for the safe and optimal movement of UAVs in

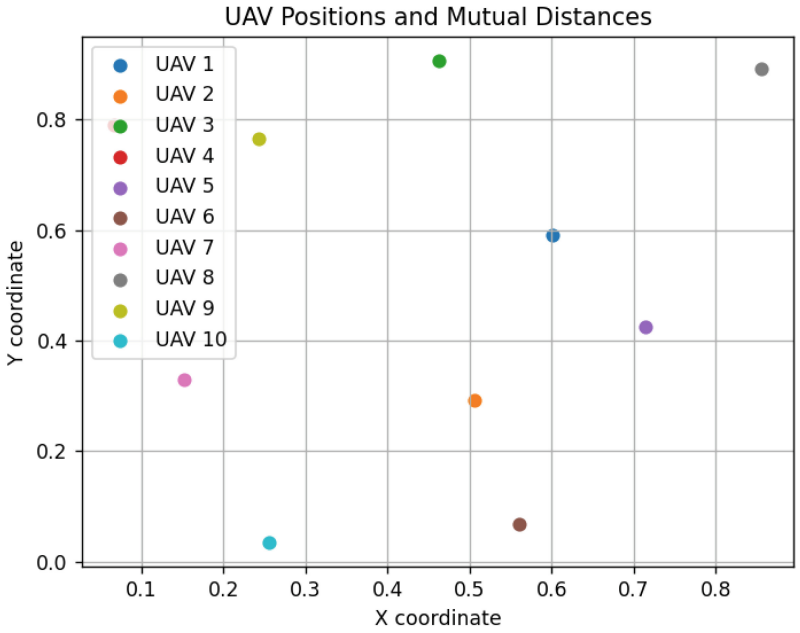

Fig. 1. Modeling the minimization of mutual distances to avoid collisions between N UAVs

various conditions and scenarios. Another way to represent this mathematical model, which allows for considering constraints on the maximum speed and maneuverability of UAVs, is as follows:

$$max \int t_o tf U\,(u(t)dt \tag{6}$$

where: t0 - initial time moment. tf - final time moment. u(t) - UAV control vector at time t. U(u(t)) - utility function of the control.

This formula helps find the optimal route for UAVs, considering their speed and maneuverability. By maximizing the utility function, we can achieve a balance between speed and route efficiency. This formula represents the route optimization problem, taking into account constraints on speed and maneuverability [13]. To derive a more specific mathematical model, it is necessary to define the utility function U(u(t)) and the control constraints. Speed constraints can be expressed as $||v(t)|| \leq Vmax$, where v(t) is the velocity vector, and Vmax is the maximum speed. Maneuverability constraints can be expressed as $||u(t)|| \leq Umax$, where u(t) is the control vector, and Umax is the maximum control. The utility function U(u(t)) can be defined based on the mission's objective, such as minimizing time, fuel, or other factors. It usually takes the form of a time integral, where t0 and tf are the initial and final moments of the mission (Fig. 2).

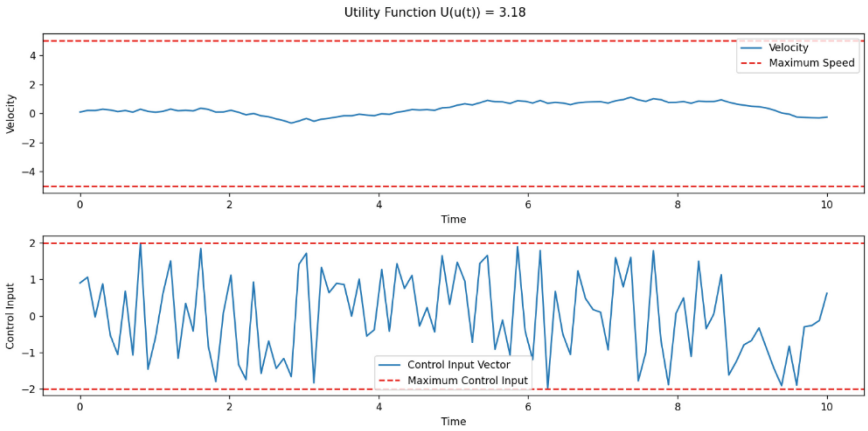

Fig. 2. The mathematical model of the utility function

Route Planning Model Considering Weather Conditions: In this section, we will explore another crucial aspect of unmanned aerial vehicle (UAV) traffic management: the route planning model that considers weather conditions. Weather conditions can significantly impact the safety and efficiency of UAV movement, making it essential to consider them in route planning. For the planning of UAV routes considering weather conditions, mathematical models are employed that incorporate weather-related information. This model may take the following form:

$$min \sum i = 1N \sum J = 1Nc(i,j)x(i,j) + \lambda w(i,j) \tag{7}$$

where N - the number of route points. c(i, j) - fuel costs between points i and j. x(i, j) - binary variables indicating whether to visit point j after point i. w(i, j) - impact of weather conditions on costs between points i and j. λw - parameter considering the importance of weather conditions [14].

This mathematical model helps find the optimal route for UAVs by calculating the impact of weather conditions on fuel consumption. Real-time Weather Consideration In route planning considering weather conditions, obtaining real-time weather information is crucial, allowing adjustments to the UAV's route based on changes in weather conditions. This ensures safety and efficiency during adverse weather conditions. Application in Adverse Weather Situations Route planning models considering weather conditions are particularly important in adverse weather conditions, where weather conditions can change rapidly. They enable the adaptation of UAV routes to hazardous weather conditions while maintaining safety and efficiency. This section emphasizes the importance of considering weather conditions in UAV route planning, ensuring safety and successful mission execution in various weather conditions. Another way to incorporate how weather conditions affect UAV movement is to use a formula to account for this factor:

$$min \sum i = 1N \sum J = 1Nc(i,j,t)x(i,j,t) \tag{8}$$

where c(i,j,t) is the cost of movement between points i and j at time t.

This formula allows for the optimization of UAV routes, considering changes in weather conditions over time. It can be particularly useful for missions where weather conditions may rapidly change. The formula takes into account the costs of movement c(i,j,t) at a given time for all pairs of route points. This model can be further developed by considering weather models that influence the speed and direction of UAV movement over time. For example, changes in speed depending on the wind or other weather factors [15] (Fig. 3).

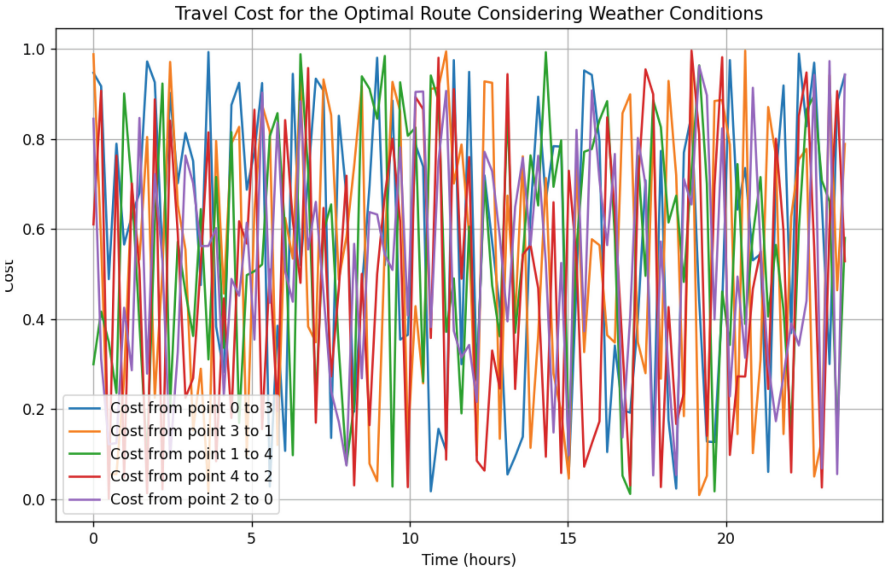

Fig. 3. The cost of movement for the optimal route, considering weather conditions.

4 Dynamic Route Planning

Fuel Cost Minimization. Traveling Salesman Problem as a Model. Route optimization and Fuel Cost Minimization: Optimizing the Placement of Ground Stations for UAV Charging: This formula helps address the placement of ground stations for UAV charging with the goal of minimizing energy and time costs:

$$min \sum i = 1N \sum J = 1Md(i,j)x(i,j) \tag{9}$$

where N - number of UAVs. M - number of ground stations. d(i,j) - distance between UAV i and station j.

This formula allows optimizing the placement of ground stations for maximum coverage and minimizing charging costs. Using these formulas, you can build a more

comprehensive mathematical model that considers various aspects of unmanned aerial vehicle traffic management. It helps optimize UAV movement under constraints and ensures effective and safe traffic control. This formula enables the optimization of the placement of ground stations for UAV charging, requiring the definition of distances d(i,j) between UAV i and station j. This model can be expanded by considering other factors, such as the maximum distance a UAV can travel from the station to its destination or different charging speeds. Please note that specific mathematical models and formula derivations will depend on the situation, conditions, and goals of your research [16] (Fig. 4).

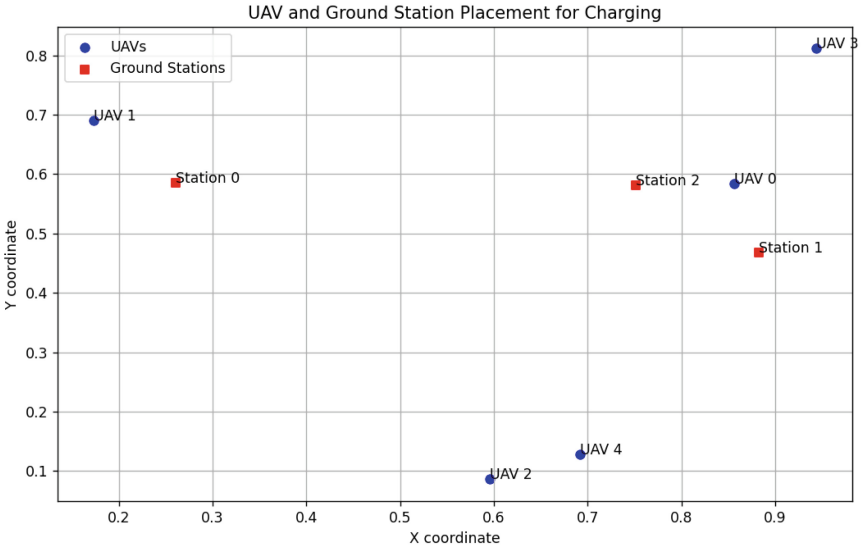

Fig. 4. Potentially logical and beneficial placement of UAVs and indispensable charging stations

Route Optimization for Minimizing Flight Time and Fuel Consumption: In this section, we will explore a crucial aspect of unmanned aerial vehicle (UAV) traffic management – route optimization to minimize flight time and fuel consumption. The optimal route can be decisive in enhancing efficiency and reducing costs [17]. To optimize the UAV route with the goal of minimizing flight time and fuel consumption, mathematical models can be employed. These models may take the form of a mathematical formula:

$$min \sum i = 1N \sum J = 1Nc(i,j)x(i,j) \tag{10}$$

This formula is used to optimize drone routes with the aim of minimizing flight time and/or fuel costs. We determine the cost (either time or fuel) between each pair of points and decide which points should be included in the optimal route. Logical description: In drone traffic management, it's crucial to find optimal routes to reduce time and fuel costs. This formula takes into account the cost of movement between different points and helps

find the most efficient routes for drones [18]. It can be valuable for tasks involving the planning of locations and routes for optimal drone traffic management. An alternative interpretation of the formula could be:

$$min \sum i = 1N \sum J = 1Nc(i,j)x(i,j) \tag{11}$$

where N - the number of route points, c(i, j) - fuel costs between points i and j, x(i, j) - binary variables indicating whether to visit point j after point i (Fig. 5).

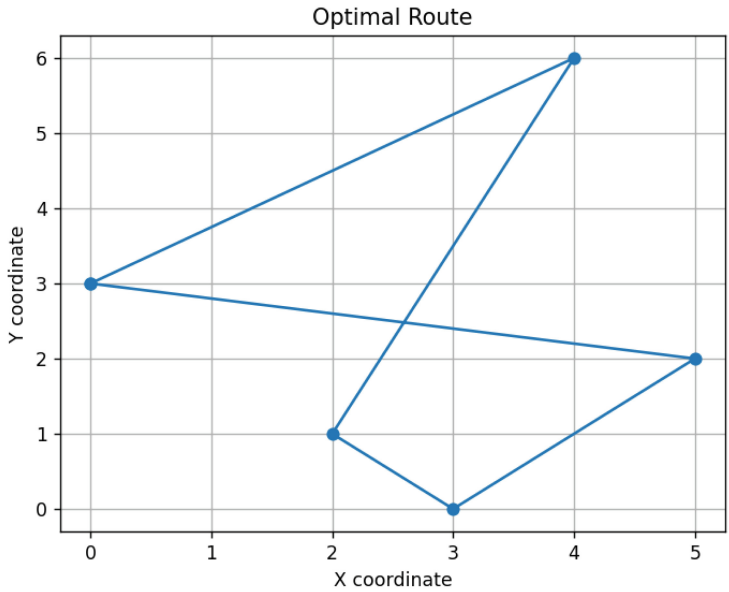

Fig. 5. Optimal drone routes with a focus on ground station placement

This mathematical model helps find the shortest route, saving both time and fuel. Reducing fuel and flight time costs, route optimization lowers fuel costs by selecting the optimal route with minimal fuel consumption between points [19]. Additionally, it allows for a reduction in flight time, which is crucial for efficiency and task completion. Applicability to various tasks, optimization models for minimizing flight time and fuel consumption can be applied to various tasks, from delivery to mapping [20]. They enable the efficient use of drone resources and reduce environmental impact. This section underscores the importance of route optimization for achieving maximum efficiency and fuel savings when using unmanned aerial vehicles.

5 Conclusions

This article explored and presented models, methods, and information technologies for managing unmanned aerial vehicle (UAV) traffic.

We discussed mathematical models and formulas that optimize UAV movement, ensuring safety, efficiency, and fuel savings. The model for minimizing mutual distances was introduced, aiming to avoid collisions between UAVs and based on the mathematical formula:

$$min \sum i = 1N \sum J = i + 1Nd\left(r_i(t), r_j(t)\right) \tag{12}$$

This model helps avoid potential conflicts and ensures the safety of movement in airspace. Equations of motion and route optimization we have studied the equations of motion for UAVs and mathematical models for route optimization, including minimizing fuel costs and flight time. These models are based on the formula:

$$min \sum i = 1N \sum J = 1Nc(i, j)x(i, j) \tag{13}$$

where c(i, j) represents the fuel costs between route points, and x(i, j) denotes binary variables indicating the choice of the route.

Consideration of Weather Conditions and Constraints: We have demonstrated the importance of considering weather conditions and physical constraints, such as the speed and maneuverability of UAVs, in route planning. Mathematical models allow for the incorporation of these factors, ensuring the safety and efficiency of movement. By utilizing these models and methods, optimal traffic management for unmanned aerial vehicles can be achieved, reducing fuel costs, cutting flight time, and ensuring safe operations. Research in UAV traffic management holds significant potential for further improving automated air traffic systems and advancing unmanned aviation.

References

1. Kuchar, J.K., Yang, L.C., Boussemart, Y.: A review of conflict detection and resolution modeling methods. IEEE Trans. Intell. Transp. Syst. **3**(1), 28–38 (2002). https://doi.org/10.1109/6979.994791
2. Khatib, W., Lesire, C.: A survey on motion planning and control techniques for robotic unmanned aerial vehicles. Annu. Rev. Control. **38**(1), 113–132 (2014). https://doi.org/10.1016/j.arcontrol.2014.04.005
3. Rathinam, S., Koenig, S., Tovey, C.A.: Planning and replanning in domains with cost functions. In: Proceedings of the 19th National Conference on Artificial Intelligence, pp. 930–935. AAAI Press (2004). https://www.aaai.org/Papers/AAAI/2004/AAAI04-148.pdf
4. Ryan, J., How, J.P., Vian, J.: Motion planning in winds for UAVs. In: AIAA Guidance, Navigation, and Control Conference, p. 4435. American Institute of Aeronautics and Astronautics (2013). https://doi.org/10.2514/6.2013-4435
5. Frazzoli, E., Bullo, F.: Decentralized algorithms for fault-tolerant UAV formations. In: Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), vol. 3, pp. 2124–2130 (2000). https://doi.org/10.1109/IROS.2000.893292
6. Rios-Torres, J., Horowitz, R.: Reach set approximation and control synthesis for autonomous pursuit-evasion. J. Guid. Control. Dyn. **31**(2), 437–446 (2008). https://doi.org/10.2514/1.31233
7. Shishika, D., Kishida, M.: Unmanned aerial vehicle collision avoidance using receding horizon control. J. Guid. Control. Dyn. **39**(1), 65–79 (2016). https://doi.org/10.2514/1.G001390

8. Bresina, J., Khatib, W.: A framework for online aircraft conflict detection and resolution. In: AIAA Guidance, Navigation, and Control Conference and Exhibit, p. 8580. American Institute of Aeronautics and Astronautics (2007). https://doi.org/10.2514/6.2007-8580
9. Hoffmann, G.M., Waslander, S.L., Tomlin, C.J.: Quadrotor helicopter trajectory tracking control. In: Proceedings of the 2007 American Control Conference, pp. 2246–2251. IEEE (2007). https://doi.org/10.1109/ACC.2007.4282405
10. Zeghal, K., Charfi, T.: A survey on collision avoidance in UAVs using optimization techniques. Aerosp. Sci. Technol. **78**, 400–409 (2018). https://doi.org/10.1016/j.ast.2018.05.038
11. Ochieng, W.Y., See, L.M., Higgins, M., Tomlin, C.: Air traffic conflict resolution via local replanning. AIAA Guid. Navigat. Control Conf. Exhibit. (2002). https://doi.org/10.2514/6.2002-4593
12. Barros, A., Maza, I., Ollero, A.: Decentralized path planning for multiple UAVs: a potential fields based approach. In: Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), pp. 552–557 (2006). https://doi.org/10.1109/ROBOT.2006.1641859
13. Chen, Y., How, J.P.: Decentralized path planning for multi-agent teams in complex environments. Auton. Robot. **40**(1), 19–33 (2016). https://doi.org/10.1007/s10514-015-9425-1
14. Leung, J., Frazzoli, E.: Conflict resolution with continuous maneuvers using velocity obstacles. In: Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), pp. 4292–4297 (2009). https://doi.org/10.1109/ROBOT.2009.5152644
15. Pertijs, M., Chu, Q., Keviczky, T., How, J.P.: Path planning for UAVs in wind with input constraints using mixed-integer linear programming. In: AIAA Guidance, Navigation, and Control Conference, p. 4908. American Institute of Aeronautics and Astronautics (2013). https://doi.org/10.2514/6.2013-4908
16. Lin, T.Y., Frazzoli, E., Tomlin, C.: A mixed logical dynamical approach to modeling and analysis of manned and unmanned aircraft operations. In: Proceedings of the IEEE Conference on Decision and Control (CDC), vol. 4, pp. 3833–3839 (2004). https://doi.org/10.1109/CDC.2004.1430375
17. Yang, S.J., How, J.P.: Robust trajectory optimization with probabilistic state constraints. J. Guid. Control. Dyn. **33**(3), 896–903 (2010). https://doi.org/10.2514/1.45355
18. Rathinam, S., Tovey, C.A., Koenig, S.: Path planning for unmanned aerial vehicles to enable precision agriculture. In: Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), vol. 3, pp. 2383–2388 (2004). https://doi.org/10.1109/ROBOT.2004.1307671
19. D'Andrea, R., Rizzi, A.: Decentralized collision avoidance for two UAVs in wind. In: Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), pp. 361–366 (2005). https://doi.org/10.1109/ROBOT.2005.1570118
20. Sujit, P.B., Rathinam, S., How, J.P.: A mixed-integer linear programming approach for trajectory planning of multiple aircraft. J. Guid. Control. Dyn. **31**(5), 1165–1176 (2008). https://doi.org/10.2514/1.32546

Study of the Dimensions of Suburban Trains Movement on the Site by the Integer Programming Method

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Abstract. In this article, it is proposed to determine the size of the movement of suburban trains on the section for all periods of the day by the integer programming method. This calculation method makes it possible to increase the competitiveness of railway transport, reduce the loss of a part of passengers due to the transition to alternative modes of transport. Traffic dimensions, which can be obtained using the integer programming method, make it possible to simplify the development of prospective schedules of train traffic, taking into account the needs of the population in transportation. The research results can also be used in the technical and economic justifications for the reconstruction of track development of stations and passenger devices, as well as serve as a basis for technical re-equipment of lines with the aim of increasing their throughput (replacement of signaling and communication means, construction of second main tracks, reconstruction of station entrances, etc.). The results of the calculation also make it possible to identify schedule "threads" for removing trains on days of the week when they are not in demand, but at the same time take into account non-daily trains when developing a normative train schedule. The results of the calculations take into account the spatial unevenness of the passenger flow and make it possible to distinguish zone trains.

Keywords: Suburban Passenger Transportation · Passenger Flow · Travel Comfort · Field Studies · Mathematical Methods · Rolling Stock Passenger Capacity · Train Schedule · Vehicle Movement Interval

1 Introduction

Today, due to its wide development, distribution, universality and regularity of train traffic, as well as due to attractive fares for many years, suburban rail transportation has advantages over other modes of transport [1–3]. But over time, stricter requirements are being put forward for the organization of suburban transportation, especially for in-depth study of suburban passenger flows [4, 5], determining the size of suburban train traffic [6–8], passenger service at stations and in trains [9–11].

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The regularity of the movement of suburban trains on the routes is one of the main quality indicators that characterizes the accessibility of passenger travel and at the same time evaluates the level of the company's work (the state of technical readiness of the rolling stock, the availability of a reserve of rolling stock, the organization of control over the traffic schedule) [12]. The size of suburban trains is one of the defining parameters of the suburban passenger flow development system. They are also related to other important parameters of the subsystem – the amount of passenger flows and the capacity of the rolling stock, the carrying capacity of the section and the necessary frequency of train traffic [13–15]. In connection with the significant fluctuations of suburban passenger traffic during the seasons, on weekends and holidays, the traffic volumes of suburban trains are set for summer and winter periods, for working days and weekends. In addition, the distribution of passenger flows on the suburban section (by zones) is taken into account, and, accordingly, the volume of traffic changes as it moves away from the main station [16]. When determining the volume of suburban train traffic, the mass of suburban transportation, the uneven distribution of suburban passenger traffic within the suburban area by seasons, months, days of the week, and hours of the day must be taken into account [17–19].

The aim of this article is to determine the size of suburban train traffic in different periods of the day by the integer programming method.

2 Literature Review

The main task of the suburban transportation sector is to interest passengers in rail transport services, due to the need to increase the competitiveness of passenger transportation [18, 20–22]. And due to a lack of funds, the railways are forced to reduce the intensity of suburban train traffic, which does not satisfy the demand for these transportations. This state of affairs requires a review of the attitude to suburban transportation and the adoption of measures for the development of railway transportation in the long term [23–25].

Since passenger flow is a determining factor in the selection of rolling stock, train intervals and other parameters, it is necessary to analyze the population of suburban trains and develop theoretical provisions for determining the required number of cars in suburban trains [1, 3, 26]. Therefore, the development of theoretical provisions regarding the determination of the required number of vehicles in suburban trains, taking into account unevenness, is an urgent need [2, 27].

The dimensions of the movement of suburban trains largely determine the efficiency and quality of the transportation process, since, on the one hand, they are related to the conditions of passenger travel, and on the other hand, the need for rolling stock, the necessary capacity, the costs of railway transport for the performance of a given volume of suburban trains transportation [28–30]. Taking into account the high cost of suburban passenger transportation, and in modern conditions their unprofitability, the number of trains should correspond to the size and structure of suburban passenger traffic, the technical capabilities of depots, owners of rolling stock, routes and stations [31–33].

The dimensions of the movement of suburban trains on the site must ensure:

mastering the given passenger flow both during the hours of intensive and non-intensive traffic;

stationarity of movement, that is, the same number of threads of arrival and departure of trains at turnover stations, which is a necessary condition for building a turnover schedule;

minimal costs associated with transportation.

When the volume of suburban train traffic increases, the carrying capacity of the section decreases, a larger fleet of rolling stock is needed, and the costs of repairing and maintaining cars increase [3, 34, 35]. An excessive reduction in traffic volumes may lead to a deterioration in passenger service. Because at the same time, the waiting time for train passengers increases, and the trains will continue to be overcrowded. Therefore, the number of suburban trains must strictly correspond to the size and structure of suburban passenger flows in order to avoid undesirable consequences [2, 35–37].

3 Results and Discussion

Suburban passenger traffic is characterized by significant irregularity in time, and it is possible to distinguish characteristic periods of the day during which the intensity of passenger traffic can be considered constant. This is the morning "peak" period and the non-intensive period of arrival of trains to the main station of the section, as well as the evening "peak" period and the non-intensive period of departure of trains from the main station.

The number of suburban trains also depends on the type of schedule according to which suburban transportation is organized. Depending on the nature of suburban passenger traffic distribution along the length of the section, it is possible to use different types of schedule. During the intensive "peak" hours of suburban transportation, the available capacity and estimated capacity of the rolling stock should be used to the maximum. Therefore, in these periods, it would be advisable to use a zonal parallel schedule for the movement of suburban trains, in which trains have stops at all stopping points and zonal stations of the section.

In periods of decline in passenger traffic, it is possible to use a classic zonal non-parallel schedule, which ensures the highest speed of train progress on the section, in which each train has stops only at intermediate points of its zone and at the corresponding zone station. In non-intensive periods, it is also possible to use a zonal non-parallel schedule with train stops at zone stations that are included in the route of the train following and at the stopping points of the corresponding zone, as well as a zonal non-parallel schedule with train stops at zonal stations of the train following route, night stops of its zone and stopping points of other zones with a significant boarding and disembarking of passengers. In this regard, calculations of the size of the movement of suburban trains, based on the specified accuracy, can be carried out for one or another type of traffic schedule.

Therefore, it is necessary to distinguish the number of trains that follow the section during the hours of intensive and non-intensive arrival at the main station, as well as the number of trains that depart from the main station in intensive and non-intensive periods. This will make it possible to calculate the number of trains between the main and zone stations, as well as the fact that on the suburban section it is advisable to use trains with the maximum capacity during peak hours (for example, ten-car train

sets ER-9), and at other times of the day to reduce the number of cars in the train (for example, introducing eight-car and six-car ER-9 trains into circulation). For this, it is necessary to enter additional variables. Therefore, when determining the dimensions of train movement between the main and zone station, it is necessary to enter three variables for one direction of movement. In the general case, the number of variables will

$$k = 2(p + q)n, \tag{1}$$

where p– the number of train composition categories that operate in the intensive period;

q – The number of train composition categories, which rotate in the non-intensive period;

n – The number of zone stations in the suburban area.

For a suburban area with n = 6 zone stations, during peak hours of 10-car trains and 8- and 6-car trains at other times of the day, k = 2(1 + 2)6 = 36 variables must be entered to determine traffic volumes.

Let x_{i1}– be the number of trains of the i-th zone with the largest passenger capacity, which arrive at the main station in the morning intensive period;

x_{i2}– the number of trains of the i-th zone with the largest passenger capacity, which arrive at the main station in a non-intensive period;

x_{i3}– the number of trains of the i-th zone of reduced passenger capacity that arrive at the main station in a non-intensive period;

x_{i4}– the number of trains of the i-th zone with the largest passenger capacity that arrive at the main station in the evening "peak" period;

y_{i1}– the number of trains of the i-th zone with the largest passenger capacity, which depart from the main station in the evening "peak" period;

y_{i2}– the number of trains of the i-th zone with the largest passenger capacity, which depart from the main station in a non-intensive period;

y_{i3}– the number of trains of the i-th zone of reduced passenger capacity, which depart from the main station in the non-intensive period;

y_{i4}– the number of trains departing from the i-th zone station after the evening "peak" period and arriving at the depot station for a night stand.

Then, for a suburban area consisting of n zones, the restrictions on mastering the density of passenger flows will be as follows:

upon arrival at the main station of the site in the morning "peak" period

$$\Gamma_i^{mp} \le a_{\max} \sum\nolimits_{i=j}^{n} x_{i1}; \quad i = 1, 2, ..., n; \tag{2}$$

upon arrival at the main station in a non-intensive period of the day

$$D_i^{\text{op}} \le a_{\max} \sum\nolimits_{i=j}^{n} (x_{i2} + x_{i4}) + a \sum\nolimits_{i=j}^{n} x_{i3_{min}}; i = 1, 2, ..., n; \tag{3}$$

upon departure from the main station in the evening "peak" period

$$D_i^{\text{ep}} \le a_{\max} \sum\nolimits_{i=j}^{n} y_{i1}; \quad i = 1, 2, ..., n; \tag{4}$$

upon departure from the main station in a non-intensive period of the day

$$D_i^{\text{od}} \le a_{\max} \sum_{i=j}^{n\sum;} (y_{i2} + y_{i4}) + a \sum_{i=j}^{n} y_{i3_{min}};\ \ i = 1, 2, ..., n; \tag{5}$$

where $a_{\max}$, a_{min} – the maximum and, accordingly, the minimum capacity of the suburban train;

D_i^{mp}, D_i^{op}–estimated densities of passenger flows within the i-th zone in the direction of the main station, respectively, in the morning "peak" period and in other periods of the day;

D_i^{ep}, D_i^{od}– estimated densities of passenger flows within the i-th zone in the direction from the main station, respectively, in the evening "peak" period and in other periods of the day.

Conditions of parity of the number of threads of arrival and departure of trains for trains of each category (train capacity) at zone stations

$$x_{i1} + x_{i2} + x_{i4} = y_{i1} + y_{i2} + y_{i4};\ i = 1, 2, ..., n,$$

$$x_{i3} = y_{i3};\ i = 1, 2, ..., n. \tag{6}$$

Limitation on the number of tracks for standing trains at zone stations:

$$y_{i4} + r_i \ge x_{i1},\ \ i = 1, 2, ..., n \tag{7}$$

where r_i– the number of tracks for standing trains at the i-th zone station.

Limitation on the number of tracks for standing trains at the main station:

$$\sum_{i=1}^{n} y_{i4} + r_{в} \ge \sum_{\text{i=1}}^{\text{n}} y_{i1} \tag{8}$$
;

where $r_{в}$– the number of tracks for standing trains at the main station.

Minimum transportation costs can be achieved by introducing a corresponding estimate for each train. Since the speeds of the trains do not differ significantly, the time of following a train in one direction, taking into account the average idle time at the points of turnover, can be taken as a comparative estimate.

Since there may be trains with different numbers of wagons in circulation, this fact can be taken into account by increasing the estimate by m times, where m is the number of wagons in the train of the corresponding destination.

Then the conditional costs will look like this

$$z = \sum_{j=1}^{n\sum} \sum_{i=1}^{n\sum} \left(C_i^{\text{aj}} x_i^j + C_i^{\text{dj}} y_i^j \right) \to min, \tag{9}$$

where C_i^{aj}, C_i^{dj} – conditional estimates of trains arriving at the main station and departing from the main station, respectively.

In addition, the conditions of non-negativity and integer number of variables must be fulfilled

$$x_i \ge 0;\ \ y_i \ge 0,\ \ integers\, i = 1, 2, ..., n. \tag{10}$$

The problem of minimizing the function (9) under constraints (2) – (8), (10) is an integer problem of linear programming with a large number of variables, which can be solved by one of the known numerical methods.

For the convenience of calculating the volume of traffic in suburban sections, passenger traffic should be presented in the form of a diagram (Fig. 1), which is built on the basis of the specified (formed at the node) passenger traffic and the percentage of its distribution at intermediate stations of the suburban section. The correct distribution of passenger traffic in a specific node can be carried out only when conducting special observations.

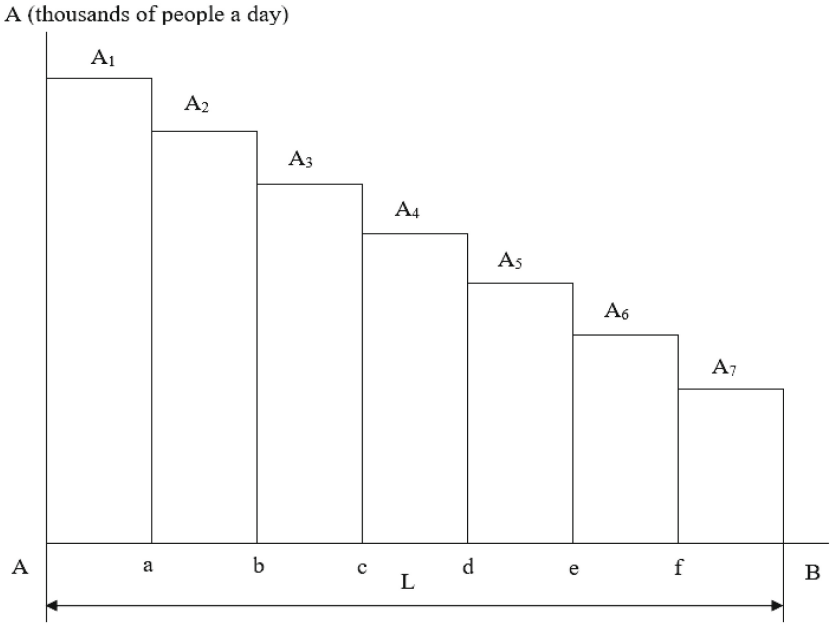

Fig. 1. Diagram of suburban passenger flow by departure from the main passenger station at the suburban section A – B

Suburban passenger flows, the type of rolling stock and the type of schedule affect the size of suburban traffic. In the absence of sharp changes in passenger flow along the length of the section, it is not divided into zones. Then the dimensions of the movement are determined:

$$N_{sub} = \frac{A}{a \cdot \alpha_{ut}}, \tag{11}$$

where A – the daily passenger flow, persons;

a– the capacity of the suburban train, persons;

α_{ut}– the coefficient of train capacity utilization (0.95).

Zone traffic of suburban trains is organized on the sections with sharp changes in suburban passenger traffic along the tracking route. Then the dimensions of the movement are determined separately by zone. Thus, if there are three zones, the number of suburban trains by zone is determined according to formulas

$$\text{to the first zone} \qquad N_{sub}{}' = \frac{A_1 - A_2}{a \cdot \alpha_{ut}}; \tag{12}$$

$$\text{to the second zone} \qquad N_{nsub}^{''} = \frac{A_2 - A_3}{a \cdot \alpha_{ut}} \tag{13}$$

$$\text{to the third zone} \qquad N_{nsub}^{'''} = \frac{A_3}{a \cdot \alpha_{ut}} \tag{14}$$

where A_1, A_2, A_3 – the total passenger flow that follows the 1st, 2nd and 3rd zones respectively, persons.

It should be borne in mind that in the near zone (1st and possibly 2nd) the estimated population can increase by 50% due to the use of standing places, so the population for these zones increases by 1.5 times.

Traffic volumes can be determined based on the conditions of full development of suburban passenger traffic, taking into account fluctuations in the density of passenger traffic by time of day, as well as ensuring train departure intervals in the estimated periods of the day and limitations on the size of the rolling stock fleet.

When calculating the traffic volume, it is necessary to observe the conditions for mastering the passenger flow

$$D_i \le \sum \delta_{i,j} \cdot a_t x_j \big(2 + s_j\big), pas., \tag{15}$$

where D_i– the possible value of the density of passenger flows in the i-th zone of the suburban section, pas.;

a_t– the average estimated population of one section of the suburban structure in a certain period of time t, pass/section (in "peak" hours for nearby zones, the population is taken into account taking into account parking spaces, in "off-peak" periods and when calculating for distant zones – only parking spaces seat);

x_j– the number of suburban trains on the j-th route of the turnover scheme, train;

2 – the number of main sections in the suburban train of the j-th route, section/train;

s_j– the number of trailer sections in the suburban train of the j-th route, section/train;

$\delta_{i,j}$– a sampling coefficient equal to 1 if trains of the j-th route follow section i, equal to 0 in other cases.

The number of suburban trains on the section should not be less than the set following frequency in the calculation periods:

$$C_i \le \sum \delta_{i,j} \cdot x_j, \; trains/period, \tag{16}$$

where C_i– the minimum number of suburban trains in the calculation period on section i, trains/period.

The working park of the motor-car depot in terms of the number of sections with main and trailer cars should be sufficient for the traffic organization option under consideration

$$NS^{main} \cdot T_{per} \geq \sum 2t_j^{turn} \cdot x_j, \ section - h, \tag{17}$$

$$NS^{\text{trail}} \cdot T_{per} \geq \sum t_j^{turn} \cdot s_j x_j, \ \ section - h, \tag{18}$$

where NS^{main} – the number of main sections of the motor-wagon depot, section;

T_{per}– estimated time period, hours;

t_j^{turn}– ч train turnover time along the j- th turnover route, h.

The modern organization of suburban passenger transportation on the railways of Ukraine needs such a system that would be able to adapt the existing technology to transformations in the transport market, taking into account the peculiarities of suburban transportation [2, 4], in particular, their unevenness. The obtained data on the unevenness of the departure and arrival of passengers can be used when drawing up the schedule of suburban trains and organizing the work of suburban ticket offices, since they depend on the amount of passenger traffic for the current season, day of the week, time (period) of the day [7]. If the number of departed trains is more than needed at the moment, then there will be many free seats in the train, and therefore unproductive costs. Therefore, in order to prevent overcrowding of electric trains, as well as their operation with unfilled seats, it is necessary to carefully monitor the fluctuations of passenger flows and, in accordance with statistical and calculation data, with corrections for the current situation, ensure the specified dimensions of train movement [5, 6].

4 Conclusions

So, based on the above, it can be said that the size of the movement of suburban trains on the section is the main parameter for the development of suburban passenger flows.

The volume of traffic depends not only on the amount of passenger traffic, but also on the nature of the distribution by hours of the day and the length of the suburban section, on the capacity of suburban trains, their speed along the section, as well as the way traffic is organized (type of schedule), the capacity of the suburban section.

Analytical methods for calculating the size of the movement of suburban trains, which are determined only by the amount of passenger flows for intensive and non-intensive periods of transportation, do not fully reflect the specific features of suburban transportation, do not take into account the requirements of stationarity, track development of zone stations, as well as the loss of passengers in connection waiting for trains.

It is advisable to carry out the calculation of the volume of traffic comprehensively for all periods of the day, determining the economically advantageous option, which takes into account the total costs of railway transport for the carried-out transportation. This calculation method makes it possible to increase the competitiveness of railway transport, to reduce the loss of a part of passengers in connection with the transition to alternative modes of transport. In order to reduce the costs of railway transport for the organization of passenger transportation, it is advisable to put into operation trains with a smaller capacity (eight- and six-car trains) in non-intensive periods of the day.

References

1. L Tang A D'Ariano X Xu Y Li X Ding M Samà 2021 Scheduling local and express trains in suburban rail transit lines: mixed–integer nonlinear programming and adaptive genetic algorithm Comput. Oper. Res. 135 105436 https://doi.org/10.1016/j.cor.2021.105436
2. Neshcheret, V., Ivanov, K., Overianova, L., Goolak, S., Riabov, I.: Method of defining parameters of traction characteristics for suburban multi-unit trains. Proceedings of the 27th International Scientific Conference on Transport Means 2023, Part II, pp. 487–492. Kaunas University of Technology, Kaunas (2023). https://ebooks.ktu.edu/pdfreader/transport-means-2023.-part-i.-proceedings-27th-international-scientific-conference
3. PK Alimo S Agyeman SM Zankawah C Yu L Cheng W Ma 2022 Factors causing low demand for a suburban passenger train in Sekondi-Takoradi J. Transp. Geogr. 98 103268 https://doi.org/10.1016/j.jtrangeo.2021.103268
4. Krystopchuk, M., Pashkevych, S., Khitrov, I., Tkhoruk, Y.: Formation and distribution flows of external transport in the city. In: International Conference on Reliability and Statistics in Transportation and Communication, pp. 141–150. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-44610-9_15
5. Strelko, O., Hrushevska, T., Toropov, B., Berdnychenko, Y., Soloviova, O. (2023). Study of the formation of passenger flows in transport hubs. In: Integrated Computer Technologies in Mechanical Engineering - 2022. ICTM 2022, pp. 733–744. Springer, Cham. https://doi.org/10.1007/978-3-031-36201-9_60
6. Vdovychenko, V., Driuk, O., Samchuk, G.: Method of traffic optimization of urban passenger transport at transfer nodes. Eastern-Eur. J. Enterprise Technol. **3**(3), 47–53. https://doi.org/10.15587/1729-4061.2017.103333
7. Bakalinsky, O., Ilchenko, V., Khmylievska, V., Petrovska, S.: Total management of customer service value-a tool for sustainable changes in service behavior: Ukrainian experience in suburban passenger traffic. In: International Conference on Business and Technology, pp. 803–817. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-08084-5_58
8. Strelko, O., Hrushevska, T., Gaba, V., Berdnychenko, Y., Kyrychenko, H. (2023). Improvement of the system of arranging commuter passenger transportation based on the Kyiv transport hub. In: Smart Technologies in Urban Engineering. STUE 2022, pp. 752–763. Springer, Cham. https://doi.org/10.1007/978-3-031-20141-7_67
9. Lai, X., Teng, J., Ling, L. Evaluating public transportation service in a transit hub based on passengers energy cost. In: 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), pp. 1–7. IEEE, Rhodes (2020). https://doi.org/10.1109/ITSC45102.2020.9294662
10. E Codina F Rosell L Cadarso Á Marín 2017 Setting services in public transit lines in short time periods under time-varying demand Transp. Res. Procedia 22 615 624 https://doi.org/10.1016/j.trpro.2017.03.054
11. O Pietrzak K Pietrzak 2019 The role of railway in handling transport services of cities and agglomerations Transp. Res. Procedia 39 405 416 https://doi.org/10.1016/j.trpro.2019.06.043
12. T-W Lu EJ Yao Y Yang N Huan L Chen 2021 Multimodal timetable optimization between urban transport hubs considering elastic demand J. Transp. Syst. Eng. Inf. Technol. 21 1 16
13. A Rossolov V Naumov N Popova E Vakulenko O Levchenko 2021 Estimation of transport accessibility in case of rational transport hub location Transport 36 1 1 12 https://doi.org/10.3846/transport.2021.14299
14. Strelko, O., Pylypchuk, O.Y., Berdnychenko, Y., Hurinchuk, S., Korobchenko, A., Martyian, Y.: Historical milestones of creation of computers technology automated system for passenger transportations management "Express" on the railway transport in the USSR. In: 2019 IEEE 2nd Ukraine Conference on Electrical and Computer Engineering (UKRCON), pp. 1214–1219. IEEE, Lviv (2019). https://doi.org/10.1109/UKRCON.2019.8879892

15. Bobyl, V.V., Charkina, T.Y., Martseniuk, L.V., Matusevich, O.O., Keršys, A.: Rail passenger hubs. In: Proceedings of the 23 International Conference Transport Means 2019, Pt. II., pp. 999–1003. Kaunas University of Technology, Kaunas (2019). https://transportmeans.ktu.edu/wp-content/uploads/sites/307/2018/02/Transport-means-2019-Part-2.pdf
16. Hrushevska, T., Strelko, O., Horban, A., Soloviova, L., Soloviova, O.: Modeling the impact of technology and arranging commuter passenger transportation by competing modes of transport. In: Smart Technologies in Urban Engineering. STUE 2022, pp. 717–728. Springer, Cham. (2023). https://doi.org/10.1007/978-3-031-20141-7_64
17. Zheng, W., Nie, T., Zhao, X., Li, Q., Han, X.: The configuration of transfer facilities in integrated passenger transport hubs. In: CICTP 2021, pp. 2007–2014. Chang'an University,l Xi'an (2021)
18. A Shevchenko O Matviienko V Lyuty V Manuylenko M Pavliuchenkov 2018 Ways of introduction of the high-speed movement of passenger trains in Ukraine Matec Web Conf. 230 01014 https://doi.org/10.1051/matecconf/201823001014
19. A Torti M Galvani A Menafoglio P Secchi S Vantini 2022 A general bi-clustering algorithm for object data with an application to the analysis of a Lombardy railway line Int. J. Approximate Reason. 142 161 177 https://doi.org/10.1016/j.ijar.2021.12.003
20. Lovska, A., Fomin, O.: A new fastener to ensure the reliability of a passenger car body on a train ferry. Acta Polytechnica **60**(6), 478–485 (2020). https://doi.org/10.14311/AP.2020.60.0478
21. Ursarova, A., Mussaliyeva, R., Mussabayev, B., Kozachenko, D., Vernyhora, R.: Multi-criteria evaluation of professional qualities of railway dispatching personnel using computer simulations. Natsional'nyi Hirnychyi Universytet. Naukovyi Visnyk (2), 141–147 (2022). https://doi.org/10.33271/nvngu/2022-2/141
22. Bernatskyi, A., Siora, O., Sokolovskyi, M.; Lukashenko, V., Nabok, T., Shamsutdinova, N., Bondarieva, V.: Development of equipment and testing the technology of semi-automatic laser welding of railway carriage design elements using a handheld tool. Proceedings of the 26th International Scientific Conference on Transport Means 2022, Part I, pp. 89–94. Kaunas University of Technology, Kaunas (2022). https://transportmeans.ktu.edu/wp-content/uploads/sites/307/2023/02/Transport-Means-2022-Part-I.pdf
23. Naumov, V., Zhamanbayev, B., Agabekova, D., Zhanbirov, Z., Taran, I.: Fuzzy-logic approach to estimate the passengers' preference when choosing a bus line within the public transport system. Communications-Scientific letters of the University of Zilina 23(3), A150–A157 (2021). https://doi.org/10.26552/com.C.2021.3.A150-A157
24. L Zhou YJ Liu L Yu Y Liu 2016 Research on the spatial-system-based rail transit systems of the world cities Procedia Eng. 137 699 708 https://doi.org/10.1016/j.proeng.2016.01.307
25. V Kombarov Y Tsegelnyk S Plankovskyy Y Aksonov Y Kryzhyvets 2021 Investigation of the required discreteness of interpolation movement parameters in cyber-physical systems Periodica Polytechnica Mech. Eng. 66 1 1 9 https://doi.org/10.3311/PPme.17884
26. A Severino L Martseniuk S Curto L Neduzha 2021 Routes planning models for railway transport systems in relation to passengers' demand Sustainability 13 16 8686 https://doi.org/10.3390/su13168686
27. A Mohammadi L Amador-Jimenez F Nasiri 2020 Reliable, effective, and sustainable urban railways: a model for optimal planning and asset management J. Constr. Eng. Manag. 146 6 04020057 https://doi.org/10.1061/(ASCE)CO.1943-7862.0001839
28. I Ghalehkhondabi E Ardjmand WA Young GR Weckman 2019 A review of demand forecasting models and methodological developments within tourism and passenger transportation industry J. Tourism Futures 5 1 75 93 https://doi.org/10.1108/JTF-10-2018-006
29. S Ammirato AM Felicetti R Linzalone AP Volpentesta G Schiuma 2020 A systematic literature review of revenue management in passenger transportation Meas. Bus. Excell. 24 2 223 242 https://doi.org/10.1108/MBE-09-2019-0096

30. N Epicoco M Falagario 2022 Decision support tools for developing sustainable transportation systems in the EU: a review of research needs, barriers, and trends Res. Transp. Bus. Manage. 43 100819 https://doi.org/10.1016/j.rtbm.2022.100819
31. Aston, L., Currie, G., Kamruzzaman, M., Delbosc, A.: Methodologies for empirical research on the link between the built environment and transit use. In: Handbook of Public Transport Research, pp. 30–55. Edward Elgar Publishing, Cheltenham (2021). https://doi.org/10.4337/9781788978668.00008
32. J Hansson F Pettersson H Svensson A Wretstrand 2019 Preferences in regional public transport: a literature review Eur. Transp. Res. Rev. 11 1 1 16 https://doi.org/10.1186/s12544-019-0374-4
33. K Grzelec A Jagiełło 2020 The effects of the selective enlargement of fare-free public transport Sustainability 12 16 6390 https://doi.org/10.3390/su12166390
34. Cevallos-Torres, L., Botto-Tobar, M.: Case study: logistical behavior in the use of urban transport using the monte carlo simulation method. In: Problem-Based Learning: A Didactic Strategy in the Teaching of System Simulation, pp. 97–110. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-13393-1_6
35. P Bocz N Liegner Á Vinkó S Fischer 2023 Investigation of the causes of railway track gauge narrowing Vehicles 5 3 949 977 https://doi.org/10.3390/vehicles5030052
36. D Baratov E Astanaliev 2023 Improvement of the scientific bases of creating means of automation of documentation of devices of railway automation and telemechanics E3S Web Conf. 402 06005 https://doi.org/10.1051/e3sconf/202340206005
37. Holub, H, Kulbovskyi, I., Skok, P., Kharuta, V., Zaiats, O.: Analytical aspects of managing complex processes in modern intelligent information systems. In: Proceedings of the 27th International Scientific Conference on Transport Means 2023, Part II, pp. 820–825. Kaunas University of Technology, Kaunas (2023). https://ebooks.ktu.edu/product/transport-means-2023.-part-ii.-proceedings-27th-international-scientific-conference

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