INFORMATION SYSTEMS IN PROJECT AND PROGRAM MANAGEMENT

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EIROPAS SAVIENĪBA

INFORMATION SYSTEMS
IN PROJECT AND PROGRAM MANAGEMENT

Collective monograph
edited by I. Linde

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The monograph presents the achievements of Ukrainian scientists in the field of business management, use of economic and mathematical modeling, information technologies, management technologies and technical means in the field of functioning, development, and project management at enterprises.

The publication is recommended for professionals in the fields of economics, information technology, project and program management - for undergraduate and graduate students, as well as academics and teachers of higher education.

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CONTENT

INTRODUCTION

The key to the successful operation of complex socio-economic and technical systems is their constant updating, adaptation to changing environmental conditions and appropriate self-regulation of the internal structure, processes and technologies.

The scientific and methodological developments proposed in the monograph relate to various areas of strategic development, the use of modeling and information technologies, project and program management technologies. They will help to improve existing processes and develop new ones in various sectors of the economy and production.

The issues of applying information technology in the management of dynamic objects in various industries are considered, each of which is characterized by the allocation of objects, management methods and their impact on the project as a way of organizing work to achieve a goal or solve a problem. Typical tasks that can be identified in project management are considered. Much attention is paid to the use of artificial intelligence methods.

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SYNTHESIS OF ADAPTIVE CRITICAL CONTROL METHODS, IDENTIFICATION AND MANAGEMENT

Anishchenko A., Timofeyev V. Yakushyk I.

The main problem of dynamic plant control is the variability of the parameters of the control object, and we are talking even about the nature of external disturbances, the lack of information about their statistical or stochastic characteristics. An approach to the development of an adaptive controller based on the recurrent least squares method is proposed.

Introduction

When solving control problems, it is assumed that the structure and parameters of the object are a priori known and unchanged on the accepted control interval. In real life, things are different. The object of control and management is subject to the influence of many controlled and uncontrolled disturbances, and it is simply unjustified to talk about their stochastic nature, and even more so about specific laws of interference distribution. Object parameters are generally unknown and may change in unpredictable ways over time. Thus, the problem of control in general and critical control in particular must be solved under conditions of significant and a priori current uncertainty.

In computer engineering and control problems, a situation often arises when a closed control system, which is under the influence of an external disturbing signal w (external, setting signal, interference, signals from other objects, variations in environmental parameters, etc.), must maintain the characteristics of the object control v (object output signal, control error, etc.) within some a priori specified boundaries so that

$$\left|v(t,w)\right| \le \varepsilon \,\forall\, t \in R, \tag{1}$$

where t is continuous or discrete time. In the event that the violation of inequality (1) is in principle unacceptable, for example, leads to catastrophic consequences, the control law that ensures strict maintenance of (1) is called critical, and the control system that implements it is called critical [1, 2].

Some features
of the synthesis of adaptive control systems

To date, the problem of managing technical objects under conditions of uncertainty is one of the central problems of modern control theory. An a dequate mathematical apparatus for solving this problem is the theory of adaptive control systems, and the widespread use of microprocessor technology has led to the development of discrete adaptive control systems [3, 4, 8].

The application of traditional methods of automatic control theory in practice is complicated by the fact that many essential properties of controlled objects and the conditions for their operation are not known in advance. At the same time, knowledge of these properties and conditions is necessary for the synthesis of the control law. Consequently, the control system in the process of work must accumulate the missing information and, on its basis, constantly improve the control law. This property is defining for adaptive systems.

At the same time, the application of the principles of adaptation in comparison with non-adaptive control will ensure high quality of control under conditions of unpredictable changes in the characteristics of an object subject to uncontrolled interference, increase the reliability of the control system, ensure its invariance to various types of objects, and reduce the time for development and adjustment of systems. All this will make it possible to make the transition from individual methods of designing control systems to mass ones, which is caused by the need for a sharp increase in the number of systems being developed and comes down to the widespread use of standard design tools.

Significant functionality that provides effective control of multidimensional non-stationary objects disturbed by noise of unknown nature, allows solving the problems of modeling and controlling complex objects, adapting the synthesized models to real data, finding optimal control laws and implementing them using simpler controllers. In principle, any task of automatic control turns into an adaptive control task if a number of characteristics of the object and the conditions for its operation are unknown, however, even those tasks that "fit" into the framework of traditional theory can be solved much easier using an adaptive approach due to the absence of a formalization stage a priori information.

The process of synthesizing an adaptive system consists of a number of stages, while as a priori information, as a rule, a structural description of the object model, specified up to parameters, is taken. In a more complex case, when the structure of the model is assumed to be unknown, one has to solve the problem of structural identification or operate with many possible different structures.

At the first stage of synthesis, the structure of the control device (regulator) is selected, which is largely determined by the adopted control objectives. The second stage is connected with the formation of a set of adjustable parameters. This is followed by the choice of the adaptation algorithm and, finally, at the fourth stage, the rationale for its choice is carried out. Since an adaptive system is generally non-linear and non-stationary, such a justification may present certain difficulties. Unfortunately, most of the practical work on adaptive systems does not have a rigorous theoretical basis. This direction still requires its further development, the creation of new adaptation algorithms, new design and research methods. It should be taken into account that most of the adaptation algorithms provide convergence to optimal modes with an infinite control interval. Therefore, there is an acute problem of synthesizing accelerated algorithms that provide high quality control over small intervals, and at the same time simple enough to ensure their implementation on microprocessor means.

Any adaptive control system contains at least two loops. The inner loop is the actual control loop, the outer loop is the adaptation loop. It is possible, of course, to introduce additional circuits, which expands the functionality of the system, but significantly complicates its study.

The key property of adaptive systems is the ability to track the drift of object parameters. It should be noted that the problems of control of non-stationary objects are the exclusive prerogative of the theory of adaptive systems. In the case of slow drift, outdated information is discounted using finite memory algorithms. Here, however, a rather complicated problem of establishing a compromise between the filtering and tracking properties of algorithms arises, which is far from being solved by now. In the case of a fast drift, one has to resort to special procedures associated with one form or another of the drift parameterization.

To date, a number of relatively independent trends in the theory of adaptive systems have been formed. Here, first of all, it is necessary to single out adaptive controllers with a minimum variance, adaptive controllers with a generalized minimum variance, adaptive systems with the required placement of zeros and poles (fundamental work, systems with adaptive predictors.

In all these approaches, it is assumed that the perturbations acting in the system are of a stochastic nature, and, as a rule, this is white noise with zero mathematical expectation and limited variance. In practical situations, the statistical assumptions are often far-fetched, and therefore it seems much more realistic to assume only that the noise or its differences in amplitude are limited. Under these conditions, the use of identification methods based on quadratic criteria and, above all, the recurrent least squares method is clearly inefficient. The difficulties that arise can be partially overcome within the framework of adaptive robust control systems, in which, nevertheless, certain statistical prerequisites are "hidden" anyway.

In this regard, it seems appropriate to develop adaptive critical methods for monitoring, identifying and managing dynamic objects operating under conditions of significant uncertainty about the characteristics of the object and the environment based on the combination of the principles of the theory of adaptive and critical control.

Modified Least Squares with Critical Properties

Consider a dynamic plant operating in a closed control system $S_D(P,C)$, described by the difference equation

$$A(q)y(k)=q^{-d}B(q)u(k)+w(k), \qquad (2)$$

where polynomials $A(q)\in R[q,n]$ with $a_0=1$, $B(q)\in R[q,m]$;

d – net delay time;

y, u and w – output, control and disturbing signals, respectively.

With respect to perturbations, it is assumed that $w\in D(0,\delta)$, i.e. the boundedness of their first differences.

If the object parameters are a priori known and unchanged, the critical control problem can be solved using the controller

$$\Delta F(q)B(q)u(k)=-E(q)y(k), \qquad (3)$$

where the polynomials $F(q)\in R[q,d-1]$ with $f_0=1$ and $E(q)\in R[q,n)$ are given by the equations

$$AF+q^{-d}E=C, \qquad (4)$$

$$AQ+q^{-d}BP=C. \qquad (5)$$

In the event that the object parameters are unknown, one can use one or another identification method, and then apply the control law (3), in which the true values of the object parameters are replaced by their estimates. This is the essence of the adaptive approach to the design of control systems for objects operating under conditions of uncertainty. As a rule, certain modifications of the recurrent least squares method or projection algorithms, one way or another related to quadratic criteria, are used as identification procedures. The use of criteria other than quadratic, for example, modular, although it leads to robust procedures, the statistical meaning of the identification problem is nevertheless preserved. Naturally, such identification algorithms cannot be used in critical control systems.

In this regard, there is a need to synthesize adaptive identification algorithms that are not associated with any statistical prerequisites, have a high convergence rate, computational simplicity, and are suitable for real-time operation in the circuit of a critical control system for a dynamic object.

Consider the polynomial

$$G(q) = 1 - \Delta A(q), \tag{6}$$

where $G(q) = g_1 q^{-1} + g_2 q^{-2} + \ldots + q^{-n-1}$

and rewrite the object equation (2) in the form

$$y(k) = \Theta^T \psi(k-1) + \Delta w(k), \tag{7}$$

where $\Theta = (g_1, g_2, \ldots, g_{n+1}, b_0, b_1, \ldots, b_m)^T$

$$\psi(k-1) =$$
$$= \left(y(k-1), y(k-2), \ldots, y(k-n-1), \Delta u(k\text{-}d), \Delta u(k-d-1), \ldots, \Delta u(k-d-m)\right)^T;$$

$$\Delta u(k) = u(k) - u(k-1);$$

$$\Delta w(k) = w(k) - w(k-1).$$

Note also that the symbol "lid" $\hat{x}$ in what follows will denote the estimate of the unknown parameter x.

RLSM and conditions for its convergence

RLSM is perhaps the most widely used in solving problems of identification, forecasting and adaptive control [9].

There are various approaches to obtaining RLSM, among which the most common is the construction of RLSM from the usual LSM based on the block representation of the observation matrix and the use of the matrix inversion lemma.

Modification of the minimized square functional (introduction of weight parameters, exponential smoothing mechanism, etc.) leads to the corresponding modification of the RLSM.

However, RLSM can be obtained directly by minimizing some quadratic functional. Since criteria (Lyapunov function) of the form $\tilde{\Theta}^T P^{-1}\tilde{\Theta}$, where $\tilde{\Theta}$ is the vector of identification errors, P^{-1} – is a positive definite matrix, fare widely used to analyze the convergence of recurrent algorithms, it is advisable to use such a criterion to obtain the RLSM algorithm itself.

This approach was applied in [5–7]. As shown in [5], the minimization of the functional

$$I(\Theta) = \left(\Theta - \hat{\Theta}(k-1)\right)^T P(k-1)\left(\Theta - \hat{\Theta}(k-1) + \gamma\left(y(k) - \Theta^T\psi(k-1)\right)^2\right) \quad (8)$$

leads to the following algorithm:

$$\hat{\Theta}(k) = \hat{\Theta}(k-1) + \gamma(k)P(k)\psi(k-1)\left(y(k) - \hat{\Theta}^T(k-1)\psi(k-1)\right); \quad (9)$$

$$P^{-1}(k) = P^{-1}(k-1) + \gamma(k)\psi(k-1)\psi^T(k-1). \quad (10)$$

Applying the matrix inversion lemma to the last relation gives

$$\begin{aligned} P(k) &= \left[P^{-1}(k-1) + \gamma(k)\psi(k-1)\psi^T(k-1)\right]^{-1} = \\ &= P(k-1) - \gamma(k)\frac{P(k-1)\psi(k-1)\psi^T(k-1)P(k-1)}{1 + \gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)}. \end{aligned} \quad (11)$$

Substituting (11) into (8), we obtain a formula for the recursive calculation of the estimate

$$\begin{aligned} \hat{\Theta}(k) &= \hat{\Theta}(k-1) + \\ &+ \gamma(k)\frac{P(k-1)\psi(k-1)}{1 + \gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)}\left(y(k) - \hat{\Theta}^T(k-1)\psi(k-1)\right). \end{aligned} \quad (12)$$

In this case, the modified RLSM algorithm is described by relations (10), (11), from which the usual RLSM follows at $\gamma(k) = 1$. By choosing different values of the parameter $\gamma(k)$, we obtain various modifications of the RLSM.

Let us determine the requirements that the parameter $\gamma(k)$ must satisfy in order to ensure the convergence of the algorithm.

Consider a Lyapunov function of the form

$$V(k) = \tilde{\Theta}^T(k)P^{-1}(k)\tilde{\Theta}(k). \quad (13)$$

Subtracting from both parts of (8) Θ and denoting $\tilde{\Theta}(i) = \hat{\Theta}(i) - \Theta$, we obtain a recursive expression for $\tilde{\Theta}(k)$, whose substitution into (13) gives

$$\begin{aligned} V(k) &= \left(\tilde{\Theta}(k-1) - \gamma(k)P(k)\psi(k-1)e(k)\right)^T \times \\ &\times P^{-1}(k)\left(\tilde{\Theta}(k-1) - \gamma(k)P(k)\psi(k-1)e(k)\right) = \\ &= \tilde{\Theta}^T(k-1)P^{-1}(k)\tilde{\Theta}(k-1) - \gamma(k)\tilde{\Theta}^T(k-1)\psi(k-1)e(k) + \\ &+ \gamma^2(k)\psi^T(k-1)P(k)\psi(k-1)e^2(k). \end{aligned} \quad (14)$$

Taking into account that $e(k) = \tilde{\Theta}^T(k-1)\psi(k-1) + w(k)$ and the matrix $P(k)$ is also related $P(k-1)$ to relation (11), $P^{-1}(k)$ with $P^{-1}(k-1)$is related to relation, we obtain

$$\begin{aligned} V(k) &= \tilde{\Theta}^T(k-1)P^{-1}(k)\tilde{\Theta}(k-1) + \gamma(k)\tilde{\Theta}^T(k-1)\psi(k-1))^2 - \\ &- 2\gamma(k)\left(\tilde{\Theta}^T(k-1)\psi(k-1)\right)e(k) + \gamma^2(k)\psi^T(k-1)\times \\ &\times\left(P(k-1) - \gamma(k)\frac{P(k-1)\psi(k-1)\psi^T(k-1)P(k-1)}{1-\gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)}\right)\psi(k-1)e^2(k) = \\ &= V(k-1) + \gamma(k)w^2(k) - \gamma(k)e^2(k) + \\ &+ \gamma^2(k)\frac{\psi^T(k-1)P(k-1)\psi(k-1)e^2(k)}{1+\gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)} = \\ &= V(k-1) + \gamma(k)w^2(k) - \gamma(k)\frac{e^2(k)}{1+\gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)}. \end{aligned}$$

If $|w(k)| \le \delta$, then

$$V(k) \le V(k-1) + \gamma(k)\delta^2 - \gamma(k)\frac{e^2(k)}{1+\gamma(k)\Psi^T(k-1)P(k-1)\Psi(k-1)}$$

and for the convergence of the algorithm, i.e. to fulfill the condition

$$\Delta V(k) = V(k) - V(k-1) \le 0 \quad (15)$$

inequality must hold

$$\gamma(k)\delta^2 - \gamma(k)\frac{e^2(k)}{1+\gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)} \le 0. \quad (16)$$

In this case, the Lyapunov function $V(k)$ is non-negative and bounded. It limits $V(0)=\tilde{\Theta}^T(0)P^{-1}(-1)\tilde{\Theta}(0)$ her. And since $V(k)\geq 0$, the sequence $V(k)$ converges.

Thus, from (15) and (16) it follows

$$\lim_{k\to\infty}\frac{\delta^2\left(1+\gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)\right)-e^2(k)}{1+\gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)}=0;$$
$$\delta^2\left(1+\gamma(k)\psi^T(k-1)P(k-1)\psi(k-1)\right)-e^2(k)\leq 0. \tag{17}$$

Thus, the establishment of the convergence of modifications of the RMLS with different choice of parameter $\gamma(k)$ is reduced to checking the fulfillment of inequality (16).

Conclusions

The article deals with the synthesis of an adaptive controller under the action of a limited interference. A procedure based on LMNC is proposed, which is characterized by sufficient computational simplicity. Conditions for the convergence of the proposed procedure are determined.

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SIMULATION MODELLING OF THE PROCESS OF DISTRIBUTION AND EXECUTION OF WORK PACKAGES

Bezkorovainyi V., Bezuhla H.

A new solution to the scientific and applied problem of increasing the efficiency of technological systems has been obtained. A model of the problem of distribution of work packages by indicators of material (financial) costs, system productivity and quality of work performance by elements with different functional and cost characteristics is proposed. Considering the probabilistic nature of the input flow of work packages and the time of their execution, it is proposed to determine the system performance using simulation statistical modelling of the system as a three-phase multi-channel queuing system. The software implementation of the model is carried out using a package of simulation statistical modelling software. Solutions to the problems of tactical planning of computer experiments are proposed, which allow obtaining results of the required accuracy and reliability. The developed models help to determine the characteristics of technological systems with an unequal number of elements and different laws of distribution of packet flow and time of execution of various works. The practical application of the proposed models will allow, in practice, taking into account the occupancy of channels and the cost of their reconfiguration, to obtain more efficient solutions to the problems of their distribution after the preliminary work has been completed.

Introduction

Rapid changes in the conditions of operation of production, technological, information, service, and other types of systems, in particular in a pandemic and martial law, necessitate their reengineering. Reengineering projects for such systems involve solving a set of multi-criteria problems of their structural, parametric, topological, and functional optimisation in conditions of incomplete certainty. The reengineering of modern facilities is carried out using a systematic approach that involves its decomposition into packages (complexes) of work and individual works. At the same time, in the management of reengineering projects and i n the management of such systems, there is a need to optimise the distribution of work between their elements (companies, departments, individual executors, equipment, etc.) under certain restrictions on quality, material, time, financial costs, or profit [1–4].

In many cases, work allocation problems can be reduced to a classic assignment problem or assignment problems with additional requirements.

Examples include the works of allocating construction work, developing software systems, manufacturing, and repair work, etc. [5].

The mathematical model of the classical assignment problem with the number of works equal to the number of executors in terms of costs can be presented as follows [2]:

$$\begin{cases} f(x) = \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} x_{ij} \rightarrow \min_{x}, \\ a_{ij} > 0, \ i, j = \overline{1, n}, \\ \sum_{i=1}^{n} x_{ij} = 1, \ j = \overline{1, n}; \ \sum_{j=1}^{n} x_{ij} = 1, \ i = \overline{1, n}; \ x_{ij} \in \{0, 1\}, \ i, j = \overline{1, n}, \end{cases} \quad (1)$$

where n - number of works and executors; a_{ij} – costs (time, material, financial) for the performance of the i-th work by the j-th executor; $x = \left[x_{ij} \right]$, $i, j = \overline{1, n}$ – assignment matrix (element $x_{ij} = 1$, if the work i is assigned to the executor j; $x_{ij} = 0$ – otherwise).

The features of some systems as objects of reengineering or management do not meet the requirements of the model of the classical problem (1) [5–10]: the goal may be to find the maximum of the objective function (profit, quality of work, etc.) $f(x) \rightarrow \max$; there may be several objective functions; the number of works n may not be equal to the number of executors r; there may be prohibitions on the assignment of certain works to certain executors; material (financial), time costs and other process parameters may be non-deterministic.

Taking into account the dynamics of the input flow of work packages, incomplete certainty of the parameters of the object functioning process, and the qualifications of executors, there is a need to jointly solve the problems of determining the workload of executors and work distribution. Therefore, the scientific and applied task of increasing the efficiency of technological systems by developing an analytical and simulation model of the cyclic distribution of work packages by a set of indicators, taking into account the workload of performers and incomplete certainty of process parameters, is relevant.

The object of the study is technological systems designed to perform design, construction, repair, and other types of work packages under conditions of incomplete certainty.

The subject of the study is the processes of cyclical distribution of work packages by a set of indicators and their implementation, taking into account the qualifications and workload of performers.

The purpose of the study is to develop an analytical and simulation model of cyclic distribution by a set of indicators and execution of work packages under conditions of incomplete certainty to improve the efficiency of technological systems.

Statement of the problem

A system where the technology for executing works packages consists of three phases is considered. Work packages are received at the system input at random moments of time. In the first phase, the supervisor distributes work packages $n = \text{var}$ of different specializations among $r \geq n$ performers of different qualifications according to the indicators of costs, efficiency and quality. The material (financial) costs, time and quality of each specialization depend on the qualifications of the performer and are random variables with specified distribution laws. The third phase involves the aggregation (compilation, quality assessment, documentation, etc.) of the completed package works. Its duration is a random variable with a given distribution law.

It is necessary to develop a mathematical model of the processes of cyclic distribution and execution of work packages, which will allow determining the indicators of costs, productivity, and quality of the completed work for a given structure and parameters of the system elements.

A mathematical model of a multi-criteria work package distribution task

The efficiency of a technological system is determined by the ratio of the effect obtained from its use to the costs of obtaining it, taking into account the quality of work execution. We formalize the task of assigning r system executors to execute the n work package according to the following indicators: material (financial) costs $k_1(x) \to \min$, time for work execution $k_2(x) \to \min$, which determines the system productivity, and quality of execution of the entire work package $k_3(x) \to \max$.

After performing the previous transformations, you can get a square matrix $a = \left[a_{ij} \right]$, $i, j = \overline{1,n}$ and go to the traditional task where the number of executors is equal to the number of works $r = n$ (1). Then, for example, the Hungarian method can be used to solve it.

Target function of material (financial) costs of the work package in the second phase is:

$$k_1(x) = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij} \to \min_x , \qquad (2)$$

where $c_{ij} = \left(c_{ij}^o + c'_{ij}\right)$, $i, j = \overline{1,n}$ – general material (financial) costs of execution of the i-th work by the j-th executor; c_{ij}^o – costs of moving to the execution of the current work after the execution of the work of the previous package; c'_{ij} – nominal costs of executing of the i-th work by the j-th executor.

Taking into account the parallel independent execution of works, it is proposed to choose the time of execution of the maximum duration of the work as the indicator of efficiency of the second phase:

$$k_2(x) = \max_i \left\{\tau_{ij} x_{ij}\right\} \to \min_x , \qquad (3)$$

where $\tau_{ij} = \left(\tau_{ij}^o + \tau'_{ij}\right)$, $i, j = \overline{1,n}$ – total expenditure of execution time of i-th work by the j-th executor; τ_{ij}^o – time to transition to the current work after completing the work of the previous package; τ'_{ij} – nominal execution time for the i-th workby the j-th executor.

To assess the quality of the works in the second phase, it is proposed to use its minimum value among all works of the package:

$$k_3(x) = \min_i \left\{q_{ij} x_{ij}\right\} \to \max_x , \qquad (4)$$

where q_{ij} – quality of the execution of the i-th work by the j-th executor.

To evaluate the options for the distribution and execution of works simultaneously in terms of material (financial), time costs and quality of their execution (2)–(4), we can use different convolutions of normalised values of local criteria. Due to the incomplete certainty of the situations of works distribution, we will use utility functions to normalise the local criteria $\xi_l(x)$, $l = \overline{1,3}$, which are considered as membership functions of the fuzzy set "best value". Let's use the classical utility function, which is a special case of the universal glue function [11]:

$$\xi_l(x) = \left[\frac{k_l(x) - k_l^-}{k_l^+ - k_l^-}\right]^{\alpha_l}, \ l = \overline{1,3}, \qquad (5)$$

where k_l^+, k_l^- – best and worst values of the local criterion $k_l(x)$; α_l – parameters that determine the type of function (convex, linear, or concave).

Regardless of the direction of improvement of local criteria values $k_l(x) \to \min$ (2)–(3) or $k_l(x) \to \max$ (4), their best values correspond to the maximum and worst values to the minimum values of the utility function $\xi_l(x)$, $l = \overline{1,3}$ (5) in the range from 0 to 1.

Taking into account that the total costs of the first and third phases of material (financial) resources c_Δ and time τ_Δ do not depend on the distribution of works for the second phase, the general objective functions for them can be presented as follows:

$$k_1(x) = c_\Delta + \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij} \to \min_x, \quad (6)$$

$$k_2(x) = \tau_\Delta + \max_i \left\{ \tau_{ij} x_{ij} \right\} \to \min_x . \quad (7)$$

Using the convolution of utility functions (5) of local criteria (6)–(7), the mathematical model of the multicriteria problem of distribution and execution of work packages is proposed to be presented in the following form:

$$\begin{cases} P(x) = \sum_{l=1}^{3} \lambda_l \xi_l(x) \to \max_x, \\ \sum_{i=1}^{n} x_{ij} = 1,\ j = \overline{1,n};\ \sum_{j=1}^{n} x_{ij} = 1,\ i = \overline{1,n};\ x_{ij} \in \{0,1\},\ i,j = \overline{1,n}, \end{cases} \quad (8)$$

where λ_l – weighting coefficients of local criteria, $\lambda_l \geq 0$, $l = \overline{1,3}$, $\sum_{l=1}^{3} \lambda_l = 1$.

If there is additional information about the decision maker's preferences, an additive-multiplicative convolution based on the Kolmogorov–Gabor polynomial can be used as an objective function [12–13]:

$$P(x) = \sum_{l=1}^{3} \lambda_j\, \xi_j(x) + \sum_{l=1}^{3} \sum_{i=l}^{3} \lambda_{li}\, \xi_l(x) \xi_i(x) + \sum_{l=1}^{3} \sum_{i=l}^{3} \sum_{j=i}^{3} \lambda_{lij}(x)\, \xi_l(x) \xi_i(x)\, \xi_j(x), \quad (9)$$

where λ_l, λ_{li}, λ_{lij} – weighting coefficients of local criteria and their products $\lambda_l \geq 0$, $\lambda_{li} \geq 0$, $\lambda_{lij} \geq 0$, $l,i,j = \overline{1,3}$.

The task of determining the parameters of the convolution functions (8)–(9) can be solved by the methods of ranking, hierarchy analysis, sequential preferences, or comparative identification [12–13].

Determination of the quality of performance and the cost of material (financial) resources for the objective function in (8) for a given distribution of works can be carried out directly using relations (4) and (6).

If the parameters c_Δ, τ_Δ, c_{ij}, q_{ij}, $i, j = \overline{1,n}$ in the proposed model will be given in the form of intervals, it is proposed to use the interval representation of the characteristics of the options for the distribution of works $x \in X$ (where X is the set of valid distribution options). In this case, each of the characteristics will be represented not by one value, but by two, which will define its boundaries $k_j(x) = \left\lfloor k_j^-(x); k_j^+(x) \right\rfloor$, $j = \overline{1,3}$.

For interval values $a \in \left\lfloor a^-; a^+ \right\rfloor$ and $b \in \left\lfloor b^-; b^+ \right\rfloor$ of local criteria $k_j(x)$, $j = \overline{1,3}$ the rules for performing classical arithmetic operations are determined by the relations [14]:

$$\left[c^-; c^+\right] = \left[a^-; a^+\right] \circ \left[b^-; b^+\right]; \tag{10}$$

$$[a] + [b] = \left\lfloor a^- + b^-; a^+ + b^+ \right\rfloor; \tag{11}$$

$$[a] - [b] = \left\lfloor a^- - b^+; a^+ - b^- \right\rfloor; \tag{12}$$

$$[a] \cdot [b] = \left\lfloor \min\left\{a^-b^-, a^-b^+, a^+b^-, a^+b^+\right\}; \max\left\{a^-b^-, a^-b^+, a^+b^-, a^+b^+\right\} \right\rfloor; \tag{13}$$

$$[a]/[b] = [a] \cdot \left\lfloor 1/b^+; 1/b^- \right\rfloor, \; b^- \neq 0, \; b^+ \neq 0 \; . \tag{14}$$

Comparison of estimates of distribution options represented by non-overlapping intervals will be carried out by comparing their centres (mean values). For interval values of local criteria that overlap, it is proposed to use the estimate of the generalised Hukuhara difference (interval difference, *gH*-difference) [15, 16].

In this case, we will represent the values of the j-th characteristic of the works distribution options $x_i, x_l \in X$ as intervals $A = \left\lfloor k_j^-(x_i); k_j^+(x_i) \right\rfloor$ and $B = \left\lfloor k_j^-(x_l); k_j^+(x_l) \right\rfloor$ in the form $A = [\hat{a};\ \bar{a}]$ and $B = \left[\hat{b};\ \bar{b}\right]$ where $\hat{a}$, $\hat{b}$, $\bar{a}$, $\bar{b}$ are the centres and radii of the intervals A and B, respectively:

$$\hat{a} = \left[a^- + a^+\right]/2, \; \bar{a} = \left[a^+ - a^-\right]/2, \tag{15}$$

$$\hat{b} = \left[b^- + b^+\right]/2, \; \bar{b} = \left[b^+ - b^-\right]/2. \tag{16}$$

Then the generalised Hukuhara difference $A \overset{-}{_{gH}} B$ and the comparison index $\gamma_{A,B}$ built on its basis for the entered intervals $A = [\hat{a};\ \bar{a}]$ and $B = [\hat{b};\ \bar{b}]$ will be determined by the following relations [15, 16]:

$$A \overset{-}{_{gH}} B = \left[\min\left\{a^{-} - b^{-}; a^{+} - b^{+}\right\};\ \max\left\{a^{-} - b^{-}; a^{+} - b^{+}\right\} \right] = \left(\hat{a} - \hat{b}; \left|\bar{a} - \bar{b}\right|\right), \quad (17)$$

$$\gamma_{A,B} = \left(\bar{a} - \bar{b}\right) / \left(\hat{a} - \hat{b}\right). \quad (18)$$

In this case, the comparison index $\gamma_{A,B}$ (18) will have the meaning of a measure of gain or risk, when the interval A is chosen instead of B just on the basis of fulfilling the inequality $\hat{a} > \hat{b}$.

Taking into account the probabilistic nature of the input flow of work packages and the time of their execution in the second phase, it is proposed to calculate the values of the objective function (7) using simulation modelling of the process as a queuing system. This involves the development of a modelling algorithm for the general process of distribution and execution of works.

Modelling algorithm of the system operation process

Based on the stochasticity of the flow of work packages and the duration of their execution, it is proposed to consider such systems as three-phase multichannel queuing systems (*Q*-schemes) (Fig. 1):

$$Q = < W, U, H, Z, R, A >, \quad (19)$$

where W – input flow of applications (work packages); U – service flow (distribution laws and parameters for the time of work execution by the channels of each phase); H – set of internal parameters (number of channels of the second phase, permissible length of queues in front of them); Z – set of permissible system states (occupancy of queues and channels); R – scheme of connections between system elements; A – system functioning algorithm (method of work distribution, service discipline)

The source (generator) G in the *Q*-scheme (Fig. 1) generates a stream of offers (work packages) that enter the system at random moments in time. The channel $C_{1,1}$ simulates the process of distributing orders (works packages), which are sent through the valve system to be executed by the channels of the second $C_{2,1}$, $C_{2,2}$, …, $C_{2,n}$ and third $C_{3,1}$ phases. Before the channels of each of the phases, there may be corresponding queues of orders $Q_{1,1}$, $Q_{2,1}$, $Q_{2,2}$, …, $Q_{2,n}$ and $Q_{3,1}$.

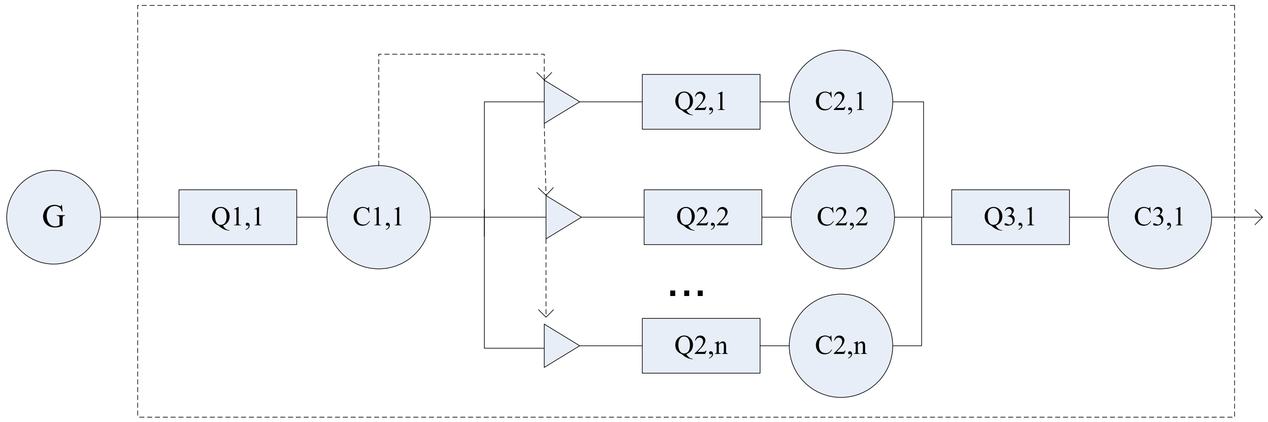

Fig. 1. Representation of the system in *Q*-chart notation

The purpose of modelling the system is to determine the total time of distribution and execution of orders $\tau(x) = \tau_\Delta + \max_i \{\tau_{ij} x_{ij}\}$ (7). To solve the problem, it is proposed to use the methodology of analytical and simulation statistical modelling [17]. Modelling algorithms based on the event principle are more accurate and economical for studying such objects. Taking into account the peculiarities of the system, a modelling algorithm based on the principle of sequential applications, which is a modification of the event principle for the study of queuing systems, is proposed to solve the problem of determining the indicators of costs, productivity and quality of work performed.

The proposed modelling algorithm involves the implementation of the following steps.

Start. Input of information (types and parameters of the laws of distribution of the flow of requests, time $\lfloor \tau_{ij} \rfloor$ and quality $[q_{ij}]$ of execution of requests, resource $[c_{ij}]$ consumption by channels of each phase, weighting coefficients and parameters of utility functions of local criteria $[\lambda_l]$, initial values $[p_{ij}(x)]$, $i, j = \overline{1, n}$ for the distribution of requests of the first batch, formation of initial conditions (values of the time counter, number of received requests (batches), variables for collecting statistics, state of queues and channels of each phase, etc.), determination of conditions for stopping the simulation.

Step 1. Based on the information about the type and parameters of the flow distribution law, generate the moment of receipt of the next order (work package).

Step 2. Modelling the process of an application's stay in the first phase (taking a place in the queue $Q_{1,1}$; occupying a channel $C_{1,1}$; releasing a place in the queue $Q_{1,1}$; if the order is not the first, calculating the value of the total utility of the distribution of works among the channels of the second phase $\left[p_{ij}(x) \right]$, $i, j = \overline{1, n}$ using the relations (8) or (9); allocating a family of orders for execution by the channels of the second phase using the Hungarian algorithm (8) $x = \left[x_{ij} \right]$, $i, j = \overline{1, n}$; releasing a channel $C_{1,1}$).

Step 3. Modelling the process of staying of a family of orders in the second phase (taking places in queues $Q_{2,1}$, $Q_{2,2}$, …, $Q_{2,n}$; occupation of channels $C_{2,1}$, $C_{2,2}$, … , $C_{2,n}$; release of places in queues $Q_{2,1}$, $Q_{2,2}$, …, $Q_{2,n}$; servicing of orders; release of channels $C_{2,1}$, $C_{2,2}$, …, $C_{2,n}$; combining a family of orders).

Step 4. Modelling the process of an order being in the third stage (taking a place in the queue $Q_{3,1}$; channel occupation $C_{3,1}$; release of space in the queue $Q_{3,1}$; servicing of the order; release of the channel $C_{3,1}$).

Step 5. Calculation of the values of local quality criteria for the processed order (work package) $k_3(x) = \min\limits_i \left\{ q_{ij} x_{ij} \right\}$ (4), costs $k_1(x) = c_\Delta + \sum\limits_{i=1}^{n} \sum\limits_{j=1}^{n} c_{ij} x_{ij}$ (6) and service time of the order $k_2(x) = \tau_\Delta + \max\limits_i \left\{ \tau_{ij} x_{ij} \right\}$ (7).

Step 6. Statistics collection on the time of servicing requests, queue status, channels, etc.

Step 7. If the conditions for stopping the algorithm are not met, then the algorithm proceeds to Step 1, otherwise – to Step 8.

Step 8. Statistical and analytical processing of modelling results (determination of the number of orders processed, assessment of cost, productivity and quality of work performed, characteristics of queues and channels of the system, etc.)

Completion. Output of modelling results.

The software implementation of the developed modelling algorithm and experiments make it possible to obtain the necessary results, the accuracy of which will increase with the number of experiments. To obtain the results of a given accuracy using the developed model under conditions of limited time and computing resources, it is necessary to solve the tasks of tactical planning of machine experiments: selection of initial conditions of modelling; assessment of the accuracy of modelling results and selection of the required number of experiments; reduction of the variance of the obtained estimates; determination of conditions for stopping modelling experiments.

In the process of selecting the initial conditions of modelling, taking into account the intensity of the flow of requests and the time of their service by channels, it is proposed to use analytical relations that allow an approximate assessment of the channel load and the length of the respective queues. The values obtained in this way are proposed to be selected as initial conditions.

In the process of evaluating the accuracy of the results, we will use its average value $\overline{\tau} = \frac{1}{N}\sum_{i=1}^{N}\tau_i$ based on the simulation results as an estimate of the time of work package $\tau(x)$ distribution and execution (where τ_i – is the time of work package distribution and execution in the i-th experiment; N – is the number of experiments). The accuracy (error) of the estimate will be determined by the ratio: $\varepsilon = \left|\tau(x) - \overline{\tau}\right|$. The probability α that the obtained error value ε does not exceed the specified value ε^*, will be considered as the reliability of the obtained estimate $p\left[\left|\tau(x) - \overline{\tau}\right| \le \varepsilon^*\right] = \alpha$.

Using the introduced notation, the formulas for estimating the error and the required number of experiments will be as follows:

$$\varepsilon = t_\alpha \sigma \big/ \sqrt{N}, \quad N^* = t_\alpha^2 \sigma^2 \big/ \varepsilon^2, \tag{20}$$

where t_α – table parameter (quantile of the normal probability distribution for a given confidence level α); σ – standard deviation of the time destribution and execution of the work package $\overline{\tau}$ estimation.

In order to reduce the variance of the obtained estimates, it is proposed to discard the initial statistics while maintaining the state of the channels and the occupancy of the respective queues.

It is proposed to determine the conditions for automatic stopping of the model experiment using a two-stage procedure. At the first stage, experiments are performed to estimate the required number of experiments N^* (20). If $N \ge N^*$, then the required accuracy of the results has been achieved (20), otherwise, $N \ge N^*$ experiments need to be performed at the second stage.

The software implementation of the proposed algorithm was carried out using a statistical simulation modelling software package. The results of the experiments made it possible to determine the characteristics of technological facilities as queuing systems with different numbers of channels and different laws of distribution of the flow of work packages and the time of execution of various works.

Conclusions

Based on the results of the review and analysis of the current state of the problem of management and reengineering of technological systems, it is established that the models of the classical problem of work package distribution in many cases do not meet the requirements of practice: the goal may be to find the maximum of the objective function (profit, quality of work, etc.); there may be several objective functions; the number of works in packages may not be equal to the number of executors; there may be prohibitions on the assignment of some works to certain executors; material (financial), time costs, and other parameters of the process of functioning of the facility.

Taking into account the dynamics of the incoming flow of work packages, incomplete certainty of the parameters of the facility's functioning process, and the qualifications of executors, it is necessary to jointly solve the problems of determining the workload of executors and the distribution of work. In view of this, a solution to the scientific and applied problem of increasing the efficiency of technological systems is proposed by developing an analytical and simulation model of the cyclic distribution of work packages by a set of indicators, taking into account the workload of executors and incomplete certainty of process parameters.

A model of the problem of distribution of work packages by indicators of material (financial) costs, system performance and quality of work performance by elements with different functional and cost characteristics is proposed. Taking into account the probabilistic nature of the input flow of work packages and the time of their execution, it is proposed to determine the system performance using simulation statistical modelling of the technological system as a three-phase multi-channel queuing system. The tasks of tactical planning of computer experiments have been solved, which allow obtaining results of the required accuracy and reliability.

The developed models help to determine the characteristics of technological systems with an unequal number of elements and different laws of distribution of packet flow and time of various works. Practical application of the proposed models will allow to obtain more efficient solutions to the problems of packet distribution, taking into account the occupancy of channels and the cost of their reconfiguration after the previous work.

Areas for further research include: developing a technology for implementing the proposed tools for modelling the processes of distribution and execution of work packages in control systems, design or reengineering of technological systems; creating mathematical models and decision support methods for optimising technological systems in conditions of incomplete certainty of costs and preferences of the decision maker.

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MODELING INTEGRATION STRATEGIES IN BRANCH PROJECTS

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The widespread use of project management methodologies shows a fundamental shift in the way organizations are trying to cope with the complexity and volatility of the external environment. In large-scale projects, integrating the work of many people often leads to conflicts in teams, but at the same time, it also contributes to the creation of innovative solutions. We explore promising strategies for managing integration in projects to describe different approaches to teamwork strategies. These types of strategies are illustrated by individual components and are relevant to large organizational projects. The implementation of the proposed scientific provisions will increase the efficiency of the implementation of projects to create new products and services of the enterprise.

Introduction

Nowadays, businesses and organizations operate in the era of the knowledge economy and are based on the use of modern information technologies. Given the current state of information technology, every enterprise needs to support its products at all stages of the life cycle. An important aspect of the company's activities is the adequacy of the level of knowledge, skills and abilities of managers to apply knowledge to implement specific tasks. Taking into account these features, it is advisable to carry out activities to create an integrated information environment of the enterprise on the basis of project management methodology [1].

Review of scientific literature on the topic

The search for methodological foundations for managing qualitative transformations in a company was marked by the emergence at the end of the last century of the ideology of continuous improvement management by E. Deming, the modern theory of innovation by P. Drucker, and the concept of business process reengineering by M. Hamer and J. Champy. Modern models Capability Maturity Model Integration (CMMI) and Process Assessment Model (PAM) are aimed at the technical maturity of the company in the field of IT, but do not fully take into account the managerial component of the internal environment of the enterprise. According to many researchers, integrating project management methodology into management processes provides companies with a real chance to provide organizational and resource support for the implementation of the company's strategy. Such problems have received considerable attention in the works of foreign and domestic scholars, in particular: Bushuyev S.D. [2], Koshkin K.V. [3], Molokanova V.M. [4], Chernov S.K. [5], Chumachenko I.V. [6]. However, the analyzed sources do not contain specific methods and models that allow to ensure the formation of an integrated information environment of an enterprise.

The purpose of this study is to solve the problem of managing the organization's integration process by the criteria of efficiency and timeliness of strategic decision-making.

Presentation of the main material

Only recently, it was a strange statement that the SPOD-world (steady predictable, ordinary, definite) had changed to the VUCA-world (volatile, unstable, complex and ambiguous). But such a world was not going to stabilize its course, and now people have to adjust to the BANI-world (brittle, anxious, nonlinear, incomprehensible). In the space of growing chaos, it is already clear to everyone that people's old ideas about economic models and management tools no longer work.

The previously dominant scientific management-oriented methods [7] and the shift to more general lean and agile development methods mean a shift in strategies for dealing with complexity and variability. Incomplete and constantly changing requirements, together with complex interdependencies between requirements and existing software, are just some of the attributes of the problem outlined. The first steps in describing this complex context were made by DeGrace and Stahl [8], who called software development "bad problems". More recently, the Cynefin Framework (see Fig. 1) [9] has emerged to define the relationship between working conditions and possible approaches to solving adaptive systems problems [10].

Integration is a way of organizing individual components into a single system that ensures their coordinated and purposeful interaction. Modern researchers rarely distinguish the integration of projects in a portfolio as a separate concept. As a rule, the concepts of "dependence", "coordination", and "communication management" are analyzed. In the domestic and foreign scientific literature, there are approaches to explaining the success of a portfolio in the context of deviations from the planned goals, results, and trajectory.

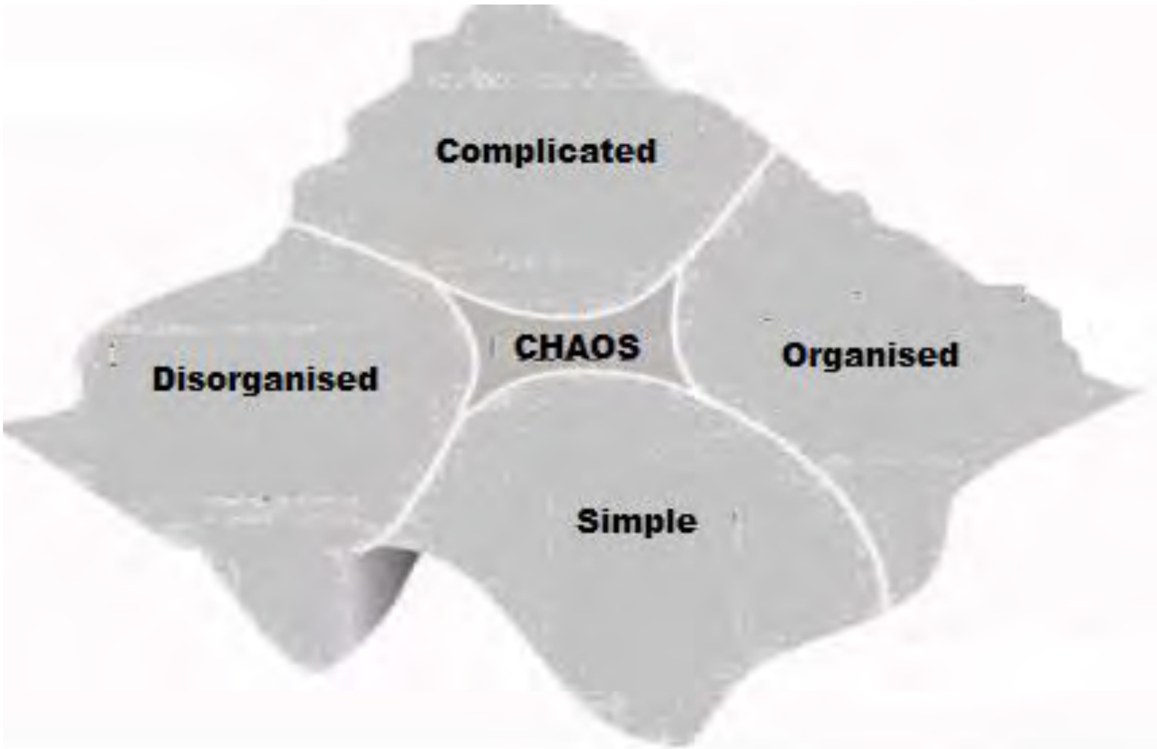

Fig. 1. Cynefin framework [9]

Coordination is a multifaceted field of study that includes, but is not limited to, various fields such as economics, organization theory, and computer science. Integration theory provides a framework for coordination analysis because it defines coordination as the management of dependencies. These dependencies must be managed by coordination mechanisms. However, no predictive power is derived from this theory, as neither hypotheses nor propositions are formulated [11]. Crowston et al [12] recognizes these limitations and calls for further research and the development of testable hypotheses.

The study of integration in organizational theory has revealed several mechanisms for integrating employees. For example, March and Simon in their study [13] identify three main approaches to integration: standardization or rules, plans, schedules, and mutual adjustment. Van De Ven et al [14] added a fourth new perspective on team influence, which extends mutual adaptation through joint simultaneous interaction with neighboring teams. Similarly, Mintzberg [15] suggests mutual adjustment, direct control, and standardization of work processes, i.e., the introduction of standard procedures into employees' skills as the main mechanism of integration.

In an attempt to classify integration mechanisms, Espinosa et al. distinguish between three types of integration: mechanistic, organic, and cognitive coordination.

Mechanistic integration involves coordination according to plans and rules with a small share of personal communication. Organic coordination refers to mutual adjustment or feedback through joint interaction. That is, team communication can be both formal and informal, spontaneous. Cognitive coordination is based on the knowledge and judgments that managers have about each other and is achieved implicitly. Cognitive coordination is viewed as a key enabler of mechanistic and organic integration.

A similar position is also supported by Rentch and Stanievich [17], who propose to consider cognitive similarity as the main driving component of integration in project teams. All of these types of integration differ in the structure of similarity and forms of cognition and can be used to formulate a general strategy for the development of a manufacturing enterprise (see Fig. 2).

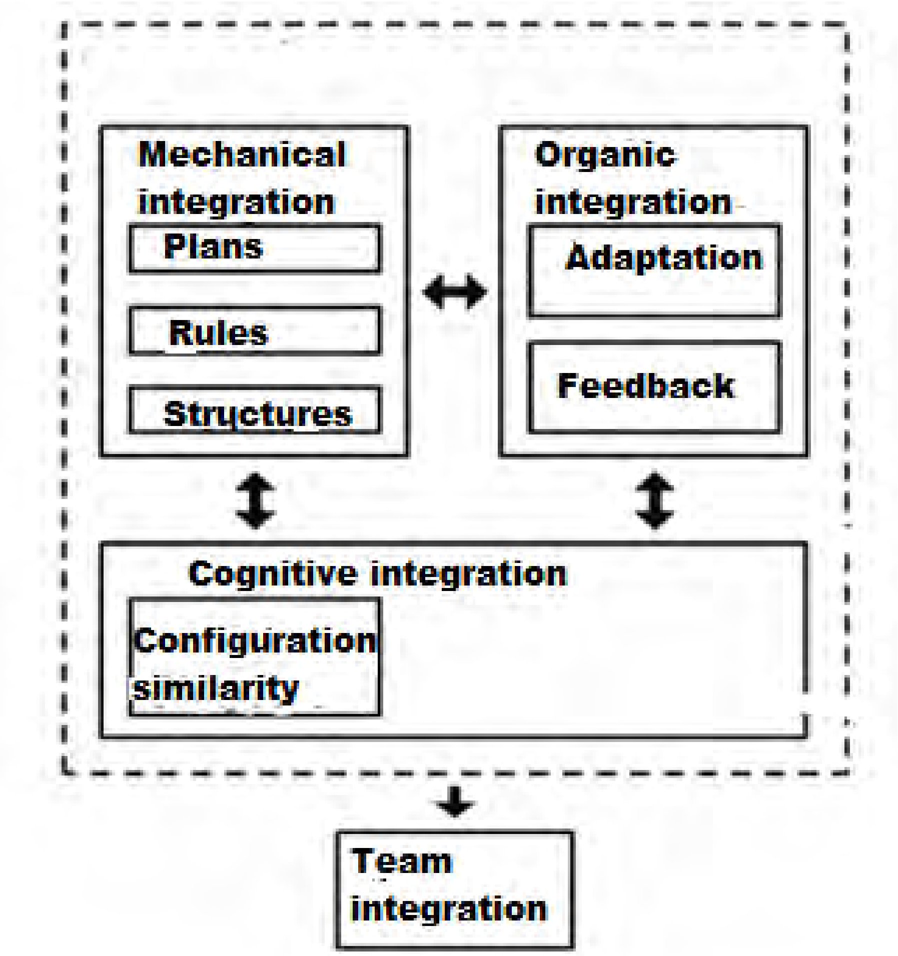

Fig. 2. Conceptual framework of strategies (adapted from [16])

This conceptual framework demonstrates a theoretical understanding of the process of effective team integration and the peculiarities of the interaction of mechanistic, organic, and cognitive integration mechanisms within the organizational strategy. Next, we consider certain types of projects inherent in the food industry, highlighting individual components of strategies. In accordance with the previously presented concepts of mechanistic, organic, and cognitive integration, we consider the conceptual archetypes of integration mechanisms within innovation projects. Table 1 shows the possible types of enterprise development strategies, taking into account the low and high degree of individual components within these strategies.

The findings allow us to create a matrix of combining mechanistic, organic, and cognitive integration (Fig. 3), based on the criteria in Table 1.

Type 1 strategy is characterized by high mechanistic, low organic, and low cognitive coordination. This archetype describes the ideal approach to planning the development of a production retooling. While coordination within teams may well be achieved through organic or cognitive mechanisms, the focus of team integration in this strategy is exclusively on mechanistic coordination with little communication between individual members.

This type of strategy assumes that the project development can be planned through full pre-planning, where all contingencies can be identified and accounted for in advance. Since such an integration is planned based on formal communication by a very small group of people, it is necessary to have a deep understanding of all the technical details of the system, the individual work packages, and the proper integration. While this type of strategy is quite plausible from a theoretical point of view, it has serious drawbacks for large projects, especially in the field of innovative technologies where requirements are constantly changing. This type of strategy can be illustrated by the previously presented complex framework, such as the Cynefin Framework (Fig. 1).

Table 1

Types and degree of influence of strategy components

Strategy types	Mechanistic	Organic	Cognitive
1	High	Low	Low
2	Low	High	High
3	Low	Low	High
4	High	High	High
5	Low	High	Low
6	Low	Low	Low

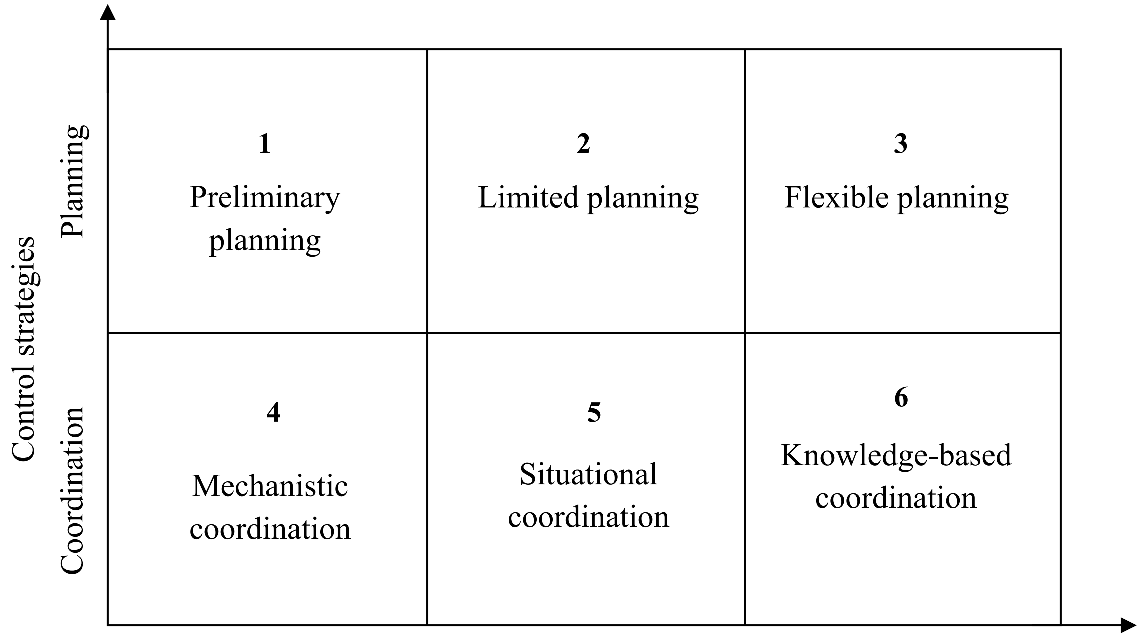

Fig. 3. Matrix for combining mechanistic, organic and cognitive integration

The leadership paradigm of "sense, analyze, and respond" is the basis of the Type 1 strategy. First, the problem space of the project is understood (sensed). Usually, a small group of people (including, for example, the chief engineer) analyzes the problem and develops a conceptual plan and a calendar plan (schedule). Accordingly, in this case, the main goal of the project is the implementation of these two plans (project implementation phase).

Type 2 strategy can be seen as the antithesis of type 1. As the mechanistic coordination is based on a high level of planning, strategy 2 relies on organic and cognitive mechanisms to achieve integration efficiency. This strategy may differ in the number of organic and cognitive management measures, but it always maintains a high level of organic integration. Strategy 2 recognizes that there are limitations to the planning capacity of individuals and small groups. However, pre-planning is seen as a necessary step to achieve overall coherence among individual team members and reduce unnecessary rework. To achieve effective integration, teams need to communicate comprehensively and mutually adjust their actions, which relies heavily on feedback and a common understanding or shared knowledge base. This calls into question the initial division of the team into individual performers. Less reliance on pre-planning and rigid rules allows for a more collaborative leadership paradigm, more exploration, feeling, and response. In line with the principle of project agility, you can experiment with requirements and present prototypes of solutions to the client to test and respond to the idea.

Type 3 strategy requires high cognitive coordination. This is difficult to achieve in reality, as it would be necessary to hire individuals who already have a high affinity, for example, by developing projects with the same people. Since cognitive coordination needs to be established in some way between team members, the use of mechanistic and organic integration in this strategy may hinder the establishment of the cognitive component.

In a Type 4 strategy, coordination is not an end in itself. Its right to exist depends on the actual tasks and work to be done. Intentionally implementing this strategy will mean accepting the high overhead of coordination with unclear benefits over other strategies.

Type 5 strategy is low in mechanistic, high in organic, and low in cognitive coordination. If the organic coordination activities are carried out without any shared understanding or knowledge exchange on which to communicate, this strategy promotes aimless communication and feedback. While Type 5 is not typical for achieving effective integration, it can be an intermediate state between Type 2 and Type 3. This strategy relies heavily on plans and rules with little or no communication, whereas organic coordination is communication-based. Type 5 strategy is rather implausible from a theoretical point of view, so it is considered to be rare.

Type 6 strategy shows poorly coordinated activities in any of the three types of integration. Although theoretically, the absence of integration in the discussion of coordination strategies seems to be a bad approach, sometimes this strategy can contribute to effective cooperation.

Conclusions

The provided analysis makes it possible to visually evaluate integration management strategies in organizations engaged in project activities. The proposed model for solving the problem of integrating project teams is considered as the basis for a methodology for assessing the viability of a project-oriented organization based on the laws of system development.

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SOCIAL PROJECTS OF THE CITY: EVALUATION OF THE INCLUSIVE EDUCATIONAL NETWORK

Danshyna S.

The subject of the study is the process of evaluating the city's inclusive educational network. The aim is to increase the objectivity of decisions made in the process of forming a city network of inclusive educational institutions. An information technology (IT) for evaluating an inclusive educational network has been developed, which is based on the author's own methodology for studying information processes. The structure of IT is presented in the form of a data flow diagram to explain the sequence of processing and generalization of a set of factors in the formation of decisions on the state of an inclusive educational network and the search for ways to improve it. An experiment to study the capabilities of IT has confirmed the effectiveness of its use in assessing the existing network of the city and its districts. It was determined that the level of inclusion of the educational network in Kharkiv is more than 30%, with the largest inclusive network created in the Kholodnohirskyi district and the smallest in the Industrialnyi district. The obtained estimates make it possible to substantiate decisions on the development of the network and the creation of inclusive educational institutions of certain types in the city districts.

Introduction

UN experts (https://news.un.org/) estimate that the number of people with disabilities accounts for about 10% of the world's population, including 240 million children as of the end of 2021. According to the Center for Medical Statistics of the Ministry of Health of Ukraine in 2011, the proportion of children with disabilities aged 0–17 years was 2.1% of the total child population, which increased by 16.9% since 2005 (from 177.6 to 207.6 per 10,000 children aged 0–17 years) [1, 2]. Perhaps that is why, within the framework of the concept of sustainable development, in order to eliminate inequality and ensure attention to each child, the number of studies that examine various aspects of medical and social problems of such children and develop solutions for their adaptation to social life is increasing [1–3]. The experience of economically developed countries shows that the funds spent on the rehabilitation of children with disabilities pay off tenfold. Therefore, the global trend to educate all students in inclusive education systems is recognized as one of the most significant reforms. Creating an inclusive education network is the most pressing issue in the world. Numerous international documents, such as the Salamanca Declaration (supported by UNESCO, 1994), the Convention on the Rights of Persons with Disabilities (supported by the UN, 2006), emphasize the importance of inclusive education as a way of teaching, raising and developing children, taking into account their needs and capabilities [3 – 5].

The reform of local self-government in Ukraine has given authorities significant powers and functions to make independent decisions on the provision of quality education. Therefore, inclusion issues can be successfully addressed at the local level, but in most cases, officials do not have the appropriate skills and knowledge to exercise the powers granted by law and need clear and understandable tools to help form a network of educational institutions capable of providing equal access to quality education in accordance with state standards. Given the annual increase in the number of children with special educational needs (SEN), the number of educational institutions that meet them is considered insufficient. Therefore, when formulating social projects and steps to improve the social sphere, it is necessary to understand the real picture and thoroughly identify possible areas of change [1, 2, 6].

Formalizing the process of evaluating an inclusive education network

As we enter the third decade of the twenty-first century, a significant number of countries face many sustainable development challenges related to environmental, economic, and social spheres. Their solution directly depends on the renewal and expansion of existing infrastructure systems, which, due to the financial crisis and budget deficit, requires careful justification [7]. Under these conditions, the development of an inclusive educational network is no exception, but given that inclusion can have different meanings in different contexts, it is important to understand that such a network is formed as a result of a complex interaction of historical, socio-cultural, economic and political factors. Taken together, they make it difficult to analyze and evaluate this network and to identify possible areas for its improvement [2, 4].

The process of evaluating the inclusive educational network of a city is an information process associated with data analysis and the formation of certain conclusions. According to the author's research methodology [8], we systematize the information flows of this process and conceptually present it in the form of a theoretical set model:

$$I\_\Pr = \left(V, O, A, \psi, Z, \varphi\right), \quad (1)$$

where $V=\{v_1,v_2,v_3\}$ – the set of input data required for the assessment of an inclusive educational network;

$O=\{o_1,o_2,o_3\}$ – the set of output data of the process;

$A=\{a_1,a_2,a_3\}$ – the set of operations performed during the assessment of an inclusive educational network;

$Z=\{z_1,z_2,z_3\}$ – the set of documents that regulate the process;

ψ,φ – the functions of outputs and updates, respectively.

The set $V=\{v_1,v_2,v_3\}$ of the model (1) combines the following data: on school and preschool children living in the city (input v_1), on educational institutions located in the city (input v_2), and on geospatial data about the city (input v_3). These data are necessary for convenient presentation of the final results of the study.

The set $O=\{o_1,o_2,o_3\}$, as a result of the process, combines o_1 – a database of children with SEN; o_2 – a database of educational institutions suitable for inclusive education; o_3 – assessments of the inclusive education network obtained during the implementation of the process.

The set $V=\{v_1,v_2,v_3\}$ is transformed into a set $O=\{o_1,o_2,o_3\}$ by sequentially implementing the operations of the set $A=\{a_1,a_2,a_3\}$, the elements of which form the evaluation sequence. That is, a_1 – the operation of assessing the demographic situation of the city; a_2 – the operation of assessing the existing inclusive educational network of the city; a_3 – the operation of forming estimates of the inclusive educational network of the city. The rules of this transformation are set by the output function [8, 9]:

$$\psi : A \times V \to O, \qquad (2)$$

which clearly defines the output of the process depending on the input elements of the set V and the defined operations of the set A.

The internal content of function (2), in accordance with the rules proposed in [9], is given in Table 1, where each row corresponds to an operation a_i $(i=1,...,3)$ of the set A, and each column corresponds to an input element v_j $(j=1,...,3)$ of the set V. The cell at the intersection of the row and column indicates the operation a_i to be performed when an element v_j enters the process input, as well as the output element o_l $(l=1,...,3)$ obtained as a result of the operation a_i.

Table 1

Table view of the output function (2)

Operations of the set A	Input elements of the set V		
	v_1	v_2	v_3
a_1	$a_1 \mid o_1$	$a_2 \mid o_1$	$a_1 \mid o_1$
a_2	–	$a_2 \mid o_2$	$a_2 \mid o_2$
a_3	–	–	$a_3 \mid o_3$

For example, Table 1 shows that when an element v_3 is received at the input of a process for an operation a_3, the output o_3 is formed as a generalization of the output o_1 obtained as a result of the operation a_1 and the output o_2 as a result of the operation a_2.

Infrastructure policy, urban growth, or sustainable development are areas that are significantly influenced by many interrelated economic, political, and social parameters, and decisions on their implementation require careful planning to set optimization priorities [10]. Therefore, a set of regulatory documents is needed to regulate the internal content of the information flows of model (1) during the transformation of input data into output. Within their powers, local governments form orders for the evaluation of the educational network, determine the parameters of the analysis, establishing a set of requirements taking into account the provisions of current legislation (for example, the Laws of Ukraine "On Education", "On Complete General Secondary Education", building codes DBN B.2.2-3:2018 "Buildings and structures. Educational Institutions", DBN B.2.2.-40-2018 "Inclusiveness of Buildings and Structures. Main Provisions", etc.) [2, 6]. Under the assumptions made, the set $Z=\{z_1,z_2,z_3\}$ combines z_1 – terms of reference for analyzing the existing inclusive educational network of the city, z_2 – requirements for an inclusive educational network, and z_3 – criteria for evaluating an inclusive educational network.

Normalization rules are set by the update function φ [8, 9]:

$$\varphi : V \times Z \to V, \quad (3)$$

which for each element of the set V determines the realization $v_j=\varphi(v_j,z_k)$ $\forall v_j \in V$, $\forall z_k \in Z$ provided that $j,k=1,...,3$.

For example, the implementation of function (3) in the operation a_2 allows to form, supplement and expand the template of the database of educational institutions suitable for inclusive education. The implementation of $\varphi(v_2, z_2)$ fulfills the requirement to take into account information about the qualifications of teachers, the material base of the educational institution, the possibility of providing certain psychological and pedagogical and correctional and developmental services, etc. For a_3 realization, implementation of $\varphi(v_3, z_3)$ in the formation of assessments allows to consider possible forms of inclusive education provision in the planning area, to investigate the possibility of observing the principle of territorial accessibility of the educational institution, etc.

Thus, summarizing the identified information flows, operations, and functions of the I_Pr model, while maintaining the formality of presentation and facilitating perception, we present the model in the form of a data flow diagram (Fig. 1).

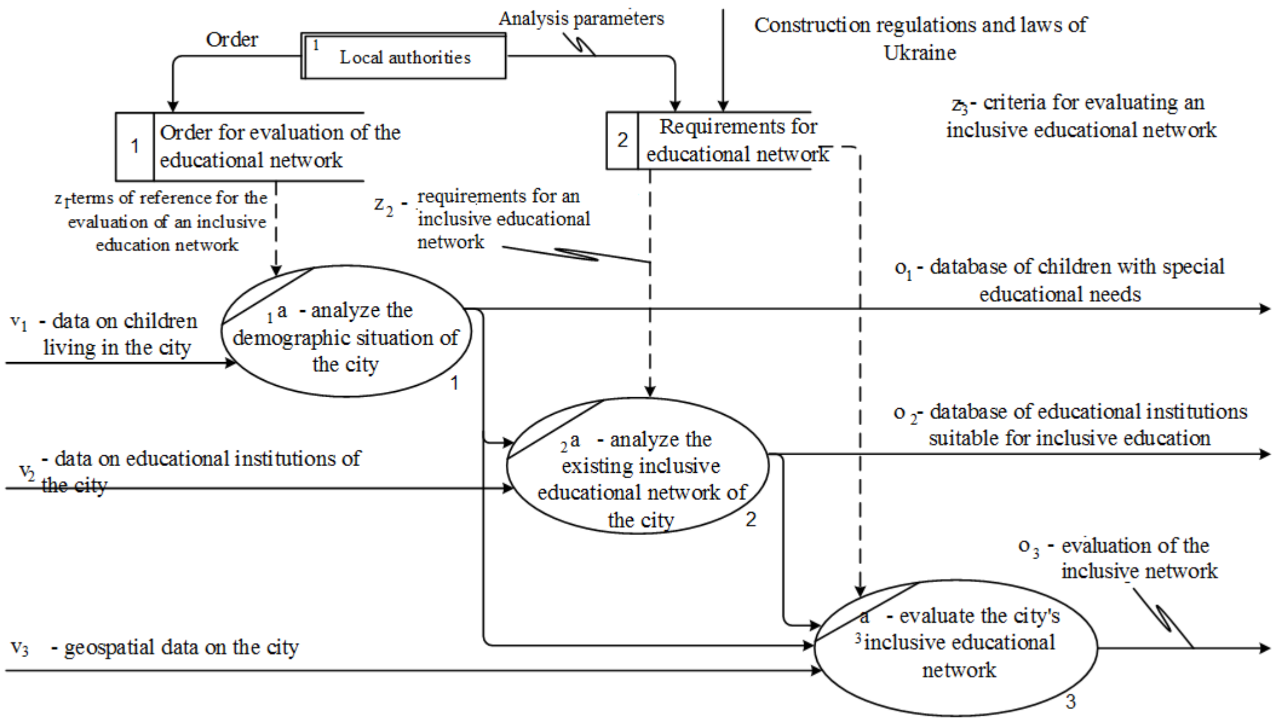

Fig. 1. Data flow diagram for I_Pr in Yourdon notation as a structure of information technology for evaluating an inclusive educational network

The proposed diagram contains all the data of the I_Pr model, their sources, the sequence of processing and transformation in accordance with the functions φ and ψ and defines the structure of information technology (IT) for assessing an inclusive education network. This IT, based on a consistent analysis of demographic and infrastructural factors, can become an effective tool for analyzing the inclusive education network to understand the real picture and find possible areas for its change, focusing on the actual amount of funding for educational institutions.

Evaluation of the inclusive educational network in Kharkiv

As an example, let's consider the use of the developed IT to evaluate the inclusive educational network of the city of Kharkiv.

It should be noted that some of the input data required for the IT system is subject to the Law of Ukraine "On Personal Data Protection". Therefore, to illustrate the IT, we used open VGI (Volunteered Geographic Information), which is considered an alternative, effective mechanism for obtaining and compiling information, especially in spatial research [11]. In this case, the following sources of information were used:

– statistical data of the Main Department of Statistics of Kharkiv region (http://kh.ukrstat.gov.ua/);

– data on educational institutions from the Kharkiv Oblast Education Management Information System (https://kh.isuo.org/) and educational portals http://vneshkoly.com.ua/ and https://www.education.ua/ ;

– VGI about the study area from GoogleMaps (https://www.google.com/maps/).

ArcGIS Desktop and Excel were used as data processing tools.

Inclusive education as an international practice of education that promotes equal access is based on the existing educational network [2, 4, 12]. With this in mind, Article 7 of the Law of Ukraine "On Complete General Secondary Education" guarantees the right to education regardless of health status, disability, special educational needs, difficult life circumstances, etc. According to this, children with SEN have the full right to receive education in all educational institutions in distance and individual forms, and inclusion involves the education of such children not only in specialized boarding schools, but also in inclusive and special groups (classes) of general education schools (inclusive resource centers). This contributes to their adaptation and socialization regardless of their learning abilities [3, 12, 13]. Therefore, information about general education schools in Kharkiv was added to the database (output o_2) if, according to the conclusions of specialists, a child can receive inclusive education, and this education can be organized at school.

Fig. 2 shows an example of the formation of possible estimates of the inclusive educational network of Kharkiv for operations a_3 by generalizing the outputs o_1 and o_2, as the results of operations and, respectively, and the input v_3.

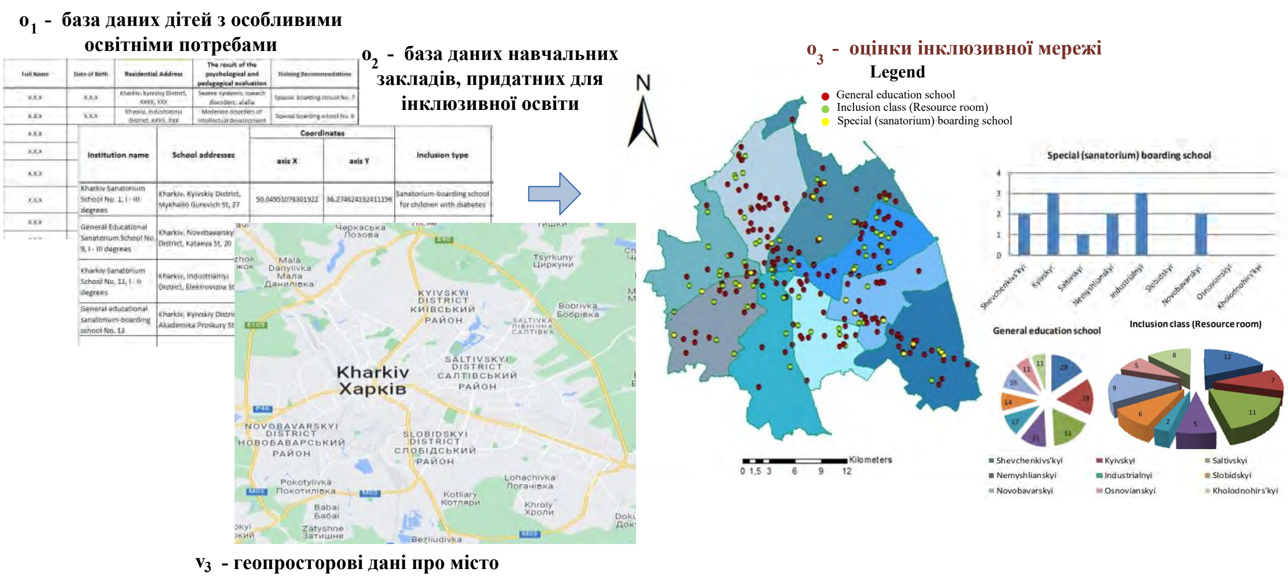

Fig. 2. Formation of o_3 output in the process of using IT-assessment of the inclusive educational network of Kharkiv

The structure of inclusive education in general secondary education institutions of Kharkiv is formed by 65 inclusive classes (resource rooms) and 13 specialized (sanatorium) boarding schools. With this in mind, the level of inclusion of the city's educational network can be calculated using the formula [2]:

$$K_{incl} = \frac{n_{incl}}{N} \times 100\% , \quad (4)$$

where n_{incl} – number of schools with inclusive education of different types;

N – total number of general secondary education institutions.

According to the formula (4) $K_{incl} = 30{,}59\%$. This indicates that local governments promote the implementation of inclusive education in the city [2, 6], but a more detailed analysis of the distribution of schools by district (Fig. 3) shows the following.

The highest level of inclusion is in Kholodnohirskyi district (42.1%), which, in our opinion, was made possible by the introduction of inclusive classes (resource rooms), positive attitudes of teachers towards inclusive education and wide involvement of teachers in the education of children with SEN. The lowest level is in the Industriyalnyi district (22.72%), despite the fact that there are 3 specialized (sanatorium) boarding schools in the district. However, the creation of inclusive and special classes on the basis of secondary schools is very slow. It should be noted that in Kharkiv's largest district, Kyivskyi, the inclusion rate is 26.31%. This requires educational activities among teachers to form their positive attitude towards inclusive education, and the wide involvement of psychologists and correctional and developmental specialists in the education of children with SEN. Attention should also be paid to the development of inclusive classes (resource rooms) at secondary schools, the number of which in the Kyiv district is one of the largest in the city.

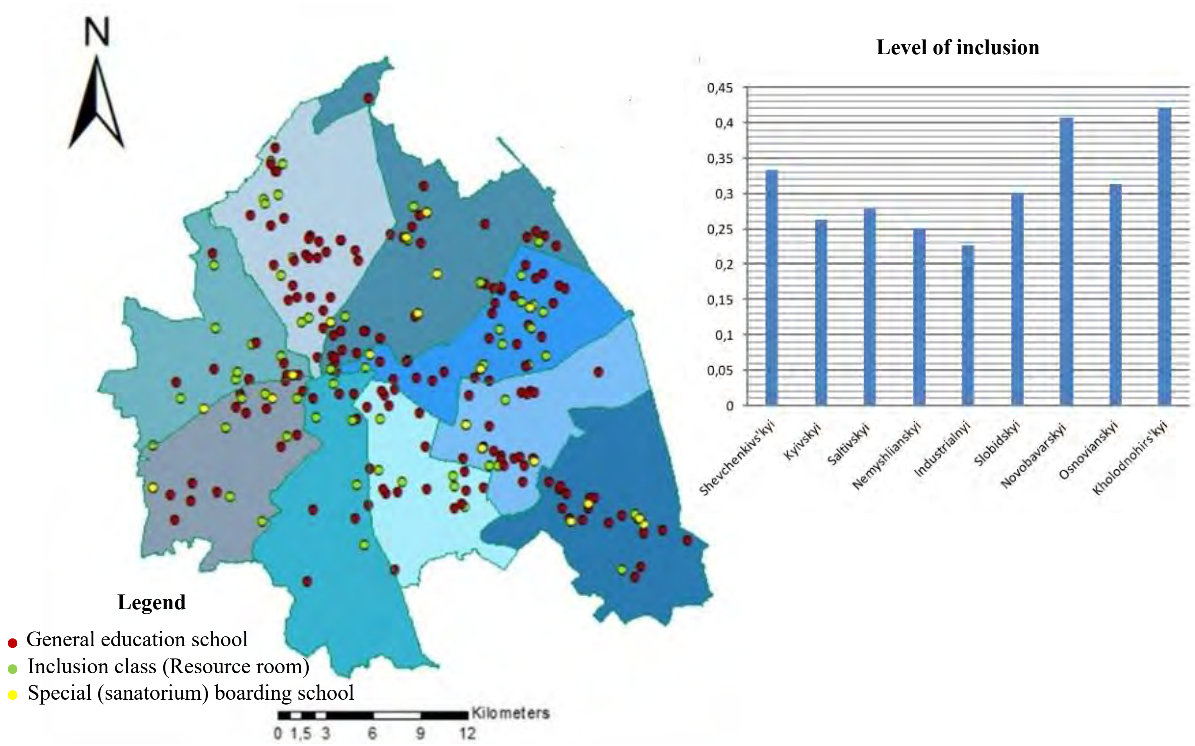

Fig. 3. Evaluation of the level of inclusion in the educational network of Kharkiv districts

It should be noted that teachers' good attitude to inclusive education, their retraining for inclusion, and support from the administration [2, 13, 14] contribute to the fact that the number of inclusive classes in Kharkiv is increasing. A study of their distribution across the city (Fig. 4) shows that the largest number of classes is concentrated in Shevchenkivskyi (12) and Saltivskyi (11) districts, the smallest – in Industrialnyi (2), Nemyshlianskyi (5) and Osnovianskyi (5) districts.

After analyzing the educational network of the most populated Saltivsky district, where more than 250 thousand people live, it is significant (Fig. 5):

– the level of inclusion in the district is 27.9%: inclusive education is provided by a special boarding school No. 3 and 11 inclusive classes based on secondary schools;

– the number of general education schools in Saltivsky district is the largest in Kharkiv, so the number of inclusive classes (resource rooms) can be increased if necessary.

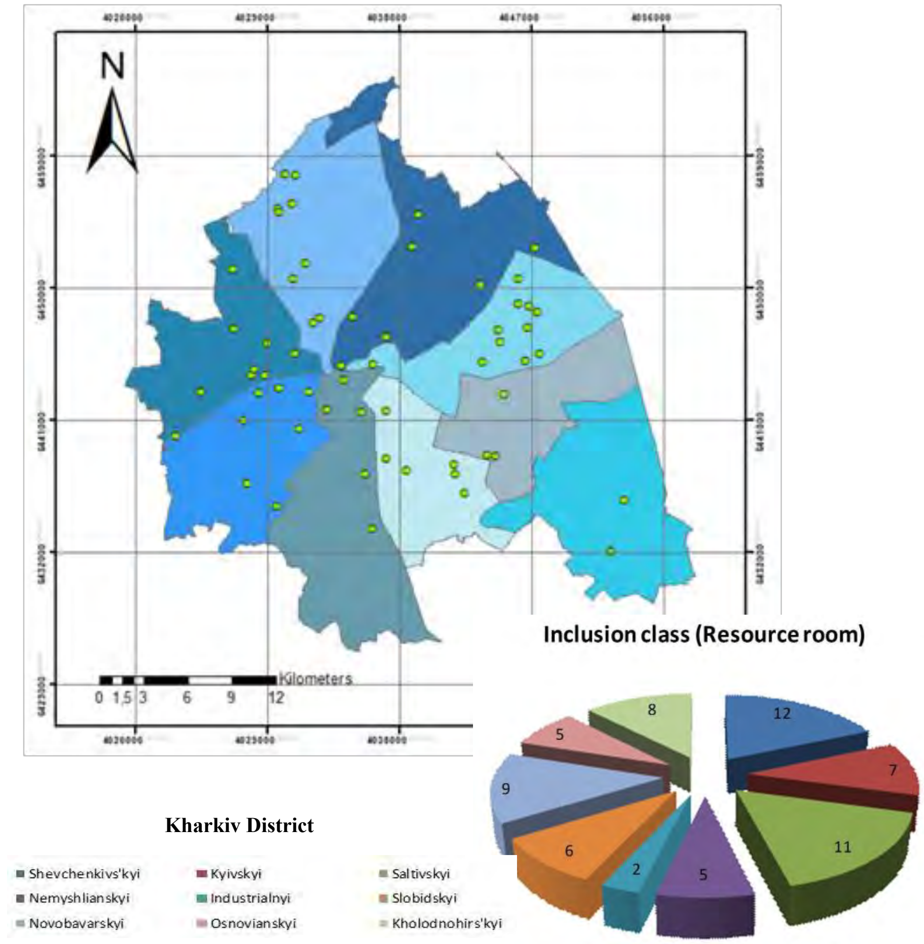

Fig. 4. Distribution of inclusive classes (resource rooms) in Kharkiv districts

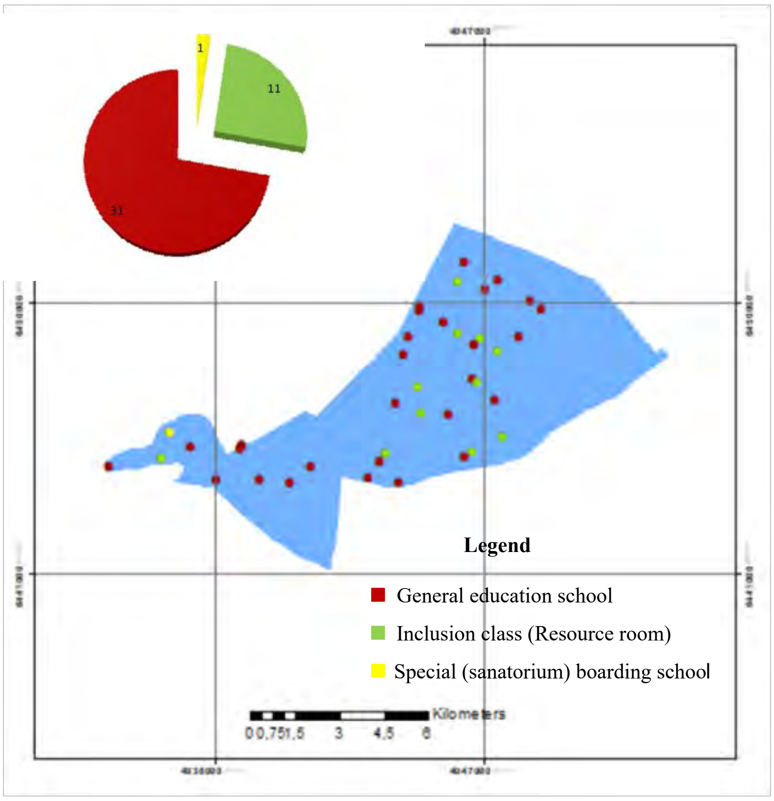

Fig. 5. The structure of the educational network of the Saltivsky district of Kharkiv

The Kharkiv Inclusive Resource Center contributes to the goal of increasing the level of inclusion and ensuring the rights of children with SEN to education. It is also located in Saltivsky district. The center cooperates with educational institutions, provides methodological assistance to teachers on supporting children with SEN, and promotes the organization of inclusive education in groups and classes of educational institutions in Kharkiv [6].

Conclusions

Current research confirms that inclusive education for children with SEN is a global trend [5, 14]. Therefore, social projects that promote equal rights and opportunities in the education of such children are and will be relevant [2, 3, 12].

As part of the local government reform, there is a need to create tools that help increase the objectivity of decisions and thoroughly determine the directions of development of an inclusive educational network [2, 6]. An IT assessment of the city's inclusive educational network has been developed. As a tool for its implementation, the methodology for studying information processes has been further developed by refining the theoretical and multiple model of information flows [8, 9]. Based on regulatory documents, the proposed IT combines demographic and infrastructure data from various sources. It takes into account the logic and dynamics of their interaction, explains the sequence of their processing and presentation to support decision-making in the formation of an inclusive educational network of the city and the search for ways to improve it, taking into account possible options for improvement. The estimates obtained in the study show that IT can be used to process large amounts of data, obtain objective results, and adapt them to real requests for inclusive education in the city.

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APPLICATION OF COORDINATION APPROACH TO CHANGE MANAGEMENT IN MEDICAL INDUSTRY AGILE TRANSFORMATION PROJECTS

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The significance of this research lies in the imperative to facilitate Agile transformations in the renovation processes of Ukrainian medical institutions, particularly in addressing public health challenges during wartime and its aftermath. Undertaking such transformative projects necessitates the advancement of contemporary methodological and instrumental tools. This study aims to formulate guidelines for employing a coordinated approach to change management within Agile transformation endeavors in the healthcare sector. It delves into the adaptation of coordination profiles for the nuanced management of alterations and requirements. The study also explores Mintzberg's coordination mechanisms and examines the interplay among the components of change management processes within healthcare transformation initiatives. Furthermore, the research modeled the change management procedure and stakeholder engagement processes. The proposal advocates adopting Bi-Directional Requirement Traceability to ensure synchronized management of changes in transformational projects. The methodologies employed encompass system analysis, project and program management techniques, and foundational management theory.

Introduction

Currently, Ukraine is experiencing a pronounced demand for medical professionals. This demand can be attributed to regional resource allocation disparities, ongoing mobilization, and migration dynamics. To adeptly address the evolving operational contexts of medical establishments and their institutional resource requirements, it is imperative to devise and implement contemporary strategies for transforming human resource management processes.

Analysis of literature and the problem under study

In today's context, several pressing issues pertaining to the resource provisioning of medical institutions, including:

– Regional imbalances in healthcare resource allocation are exacerbated by migration patterns [1].

– Overlooking the diverse operational conditions of medical facilities across various Ukrainian regions.

– A pronounced personnel deficit in the eastern and southern regions hinders the delivery of high-quality medical services.

– The inability to utilize medical infrastructures is due to damages, repurposing, or outright destruction.

The National Fund for Strategic Research suggests that one avenue for resource provisioning involves recruiting foreign specialists. However, this approach remains limited in scale and often overlooks the unique challenges of delivering medical services within the Ukrainian context. Future endeavors in healthcare provisioning should prioritize infrastructural reconstruction and resource reallocation [1].

The World Health Organization (WHO) underscores that the absence of a centralized, real-time database of medical professionals complicates resource allocation. This necessitates the establishment of a digital registry for healthcare workers [2].

While a hierarchical management structure facilitates national-level oversight of the healthcare system, it often neglects the specific needs of regions demanding swift interventions and support. Decentralizing the management of medical institutions enhances adaptability, yet local communities struggle to meet the demands of healthcare facilities in conflict or potential conflict zones.

A decline in patient numbers often precipitates a more significant reduction in healthcare professionals in specific regions. The migration trends of 2022–2023 resulted in a severe dearth of specialized experts, undermining the efficacy of medical care delivery in active conflict zones and potential hotspots.

The Helsi information system's limitations, such as outdated information and booking challenges, further complicate patient access to specialists. The system's incompatibility with the Windows XP operating system restricts patient access, emphasizing the importance of centralized healthcare facilities offering comprehensive services without necessitating multiple referrals.

H. Mintzberg posits that the future trajectory of healthcare transformation hinges on differentiation, demarcation, and integration [3]. These elements bolster the healthcare system's adaptability and resilience, aligning with contemporary demands.

The current landscape necessitates adapting resource management strategies in healthcare, particularly during wartime and its aftermath. Given the urgency of most emerging challenges, reevaluating change management processes is imperative. A detailed comparison of change management models and their applicability can be found in references [4, 5].

According to Deloitte's 2022 research in Ukraine [6, 7], the most pressing human resource management challenges encompass:

- Effective workload distribution.
- Real-time employee support and assistance.
- Reassessment of organizational structures.
- Ensuring process continuity.

Reengineering HR processes in the healthcare sector, especially in volatile contexts, demands robust coordination and integration. This cannot be achieved without a comprehensive change management framework. Consequently, a pivotal objective is to formulate a coordinated approach to change management for healthcare transformation projects.

This research aims to devise guidelines for implementing a coordinated strategy for change management in Agile transformation initiatives within the healthcare domain.

Methodical research materials

Transformation initiatives designed to effectuate change possess a distinct life cycle influenced by the unique characteristics of the organization in question. Employing a hybrid life cycle ensures the manageability of the transformation project and integrates the advantages of agile management methodologies. It is imperative to refine change management processes to enhance efficiency, amalgamating Agile methodologies with elements of standardization [8, 9].

Change management and requirements management are intricately linked, with management being inherently iterative and necessitating coordination.

To maintain oversight of alterations within a complex multi-project healthcare setting, it is recommended to utilize coordination mechanisms as delineated by H. Mintzberg [10]:

- Mutual adjustment (M1);
- Direct supervision (M2);
- Work process standardization (M3);
- Service/output standardization (M4);
- Standardization of skills and competencies (M5).

Leveraging mutual adjustment mechanisms facilitates considering stakeholder needs and aligning requirements with overarching healthcare development strategies (M1). Direct supervision (M2) enhances the efficacy of project requirement oversight. Incorporating standardization elements (M3–M5) alleviates decision-making burdens and fosters a more agile response to evolving requirements.

Executing an Agile transformation initiative necessitates a shift in the coordination profile, achievable through harmonizing change management systems, project prerequisites, and associated risks. At the onset of a transformation project within a multi-project healthcare context, a thorough evaluation of the existing change management framework and its interplay with requirements and risk management systems is essential. Based on the transformation trajectory, guidelines for tailoring the coordination profile to project demands are formulated. The triad of change management, requirements, and resource management constitutes the cornerstone of project transformation.

To adeptly navigate changes within the coordinated approach of an Agile transformation project, introducing a risk management framework in line with the ACMP Standard Change Management is proposed [11].

Strategies to mitigate the adverse impacts of change processes, especially those stemming from employee resistance, include:

- Dissemination of information and communication (I1);
- Training stakeholders for proficiency in novel systems (I2);
- Facilitating skill development (I3);
- Reassessment and modification of roles, responsibilities, incentives, organizational structure, service design, and more (I4).
- Employing User Stories to define functional requirements engages stakeholders in requirements and change management (I5).

The interrelationships among the components of change management processes within the healthcare transformation project are elucidated in Table 1.

Consolidating change management processes in line with the ACMP Standard Change Management necessitates the establishment of distinct process clusters:

- Evaluating the ramifications of changes and gauging organizational preparedness (F1);
- Crafting a strategic approach to change management (F2);
- Designing a comprehensive change management blueprint (F3);
- Executing the outlined change management strategy (F4);
- Concluding change management initiatives (F5).

Illustrations of change management models within Agile transformation projects can be found in Figures 1–2.

Table 1

Interrelationship of elements of change management processes in the transformation project in the medical environment

Processes	Coordination mechanisms					Tools				
	M_1	M_2	M_3	M_4	M_5	I_1	I_2	I_3	I_4	I_5
Definition of content and impact	+	+	+			+	+	+		+
Communications	+	+			+	+	+		+	
Training and development	+	+			+	+	+	+		
Stakeholder management	+	+			+	+	+	+	+	+
Resource management	+	+	+	+	+	+	+	+	+	
Interaction with leaders and sponsors	+	+			+	+	+	+	+	
Evaluation and achievement of benefits	+	+	+	+	+	+			+	+
Risk management	+	+	+	+	+	+	+	+	+	+
Sustainable development/ stabilization	+	+	+	+	+	+	+	+	+	+

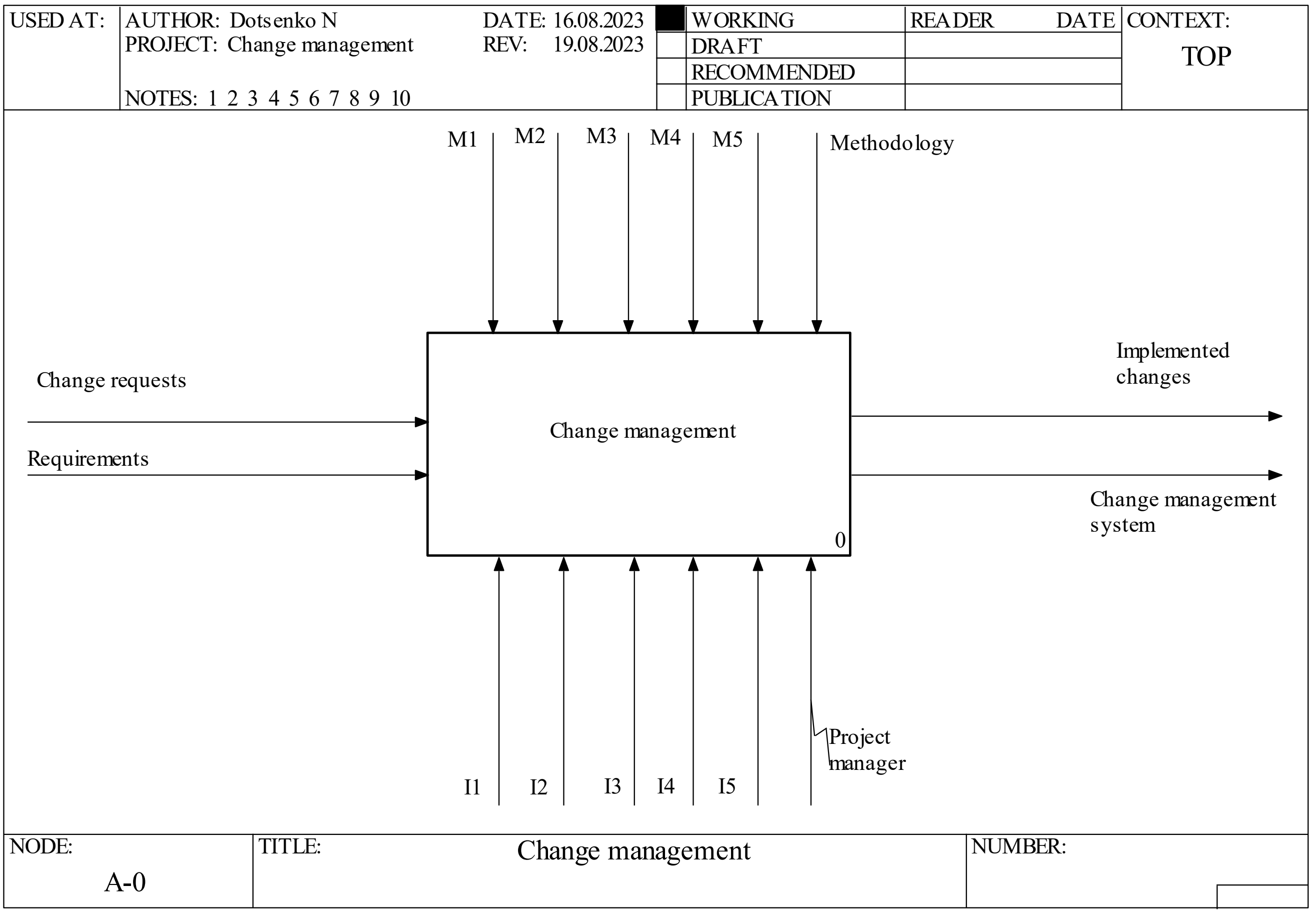

Fig. 1. Contextual model of the change management process

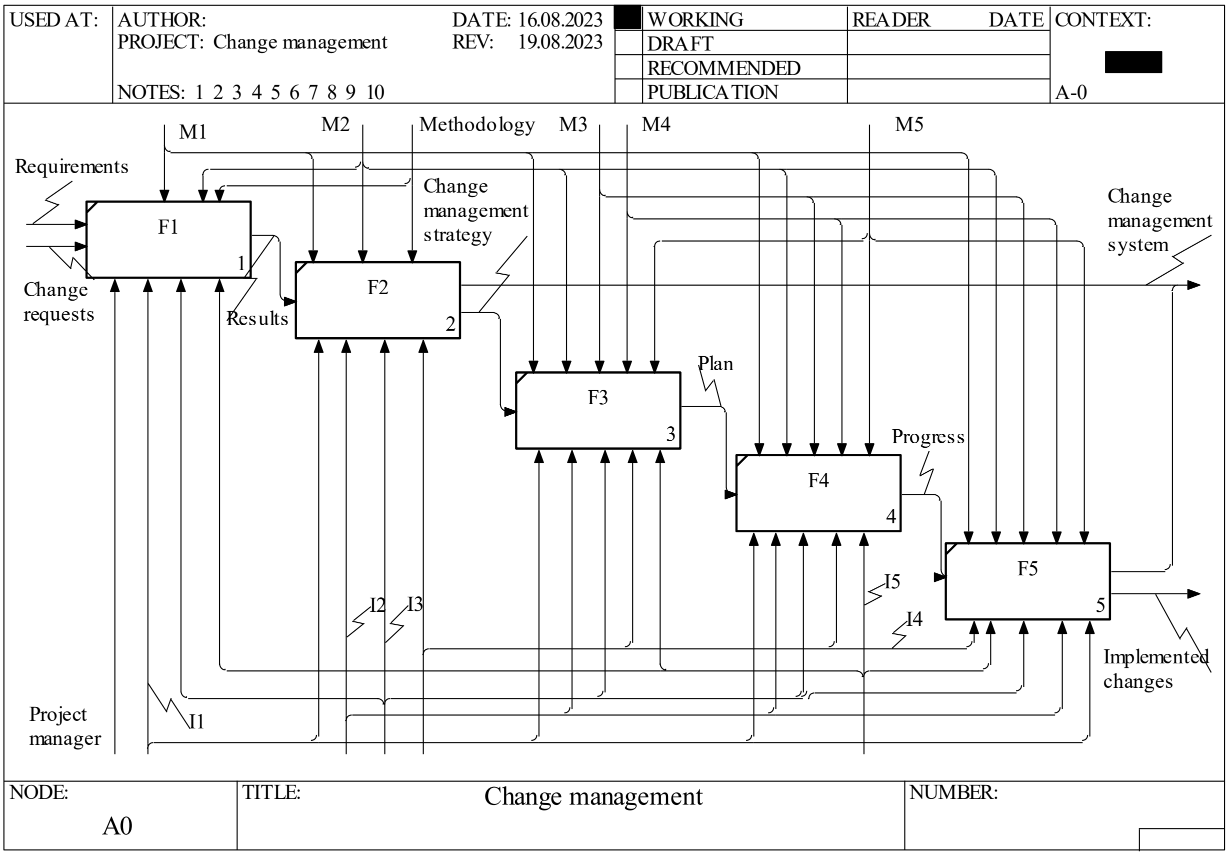

Fig. 2. Decomposition model of the change management process

Evaluating an organization's readiness to embrace transformative changes is integral to a coordinated approach to change implementation. In gauging preparedness for such shifts, several factors warrant consideration:

– The unique characteristics of the medical institution;
– Its hierarchical alignment or affiliation;
– The maturity of its processes;
– The adequacy of its resources;
– Prevailing operational conditions.

Furthermore, discerning the boundaries of feasible changes is crucial. A breach of these boundaries arises when the magnitude of changes within the organization surpasses its capacity to manage the impacted areas effectively [11]. Overstepping these change limits can compromise the organization's operational reliability and diminish managerial efficacy.

Given that Agile transformation unfolds in a challenging milieu pinpointing and engaging stakeholders in the project becomes pertinent as a facet of information management [12].

The schematic representation of stakeholder engagement in change and requirement management can be observed in Figures 3–4.

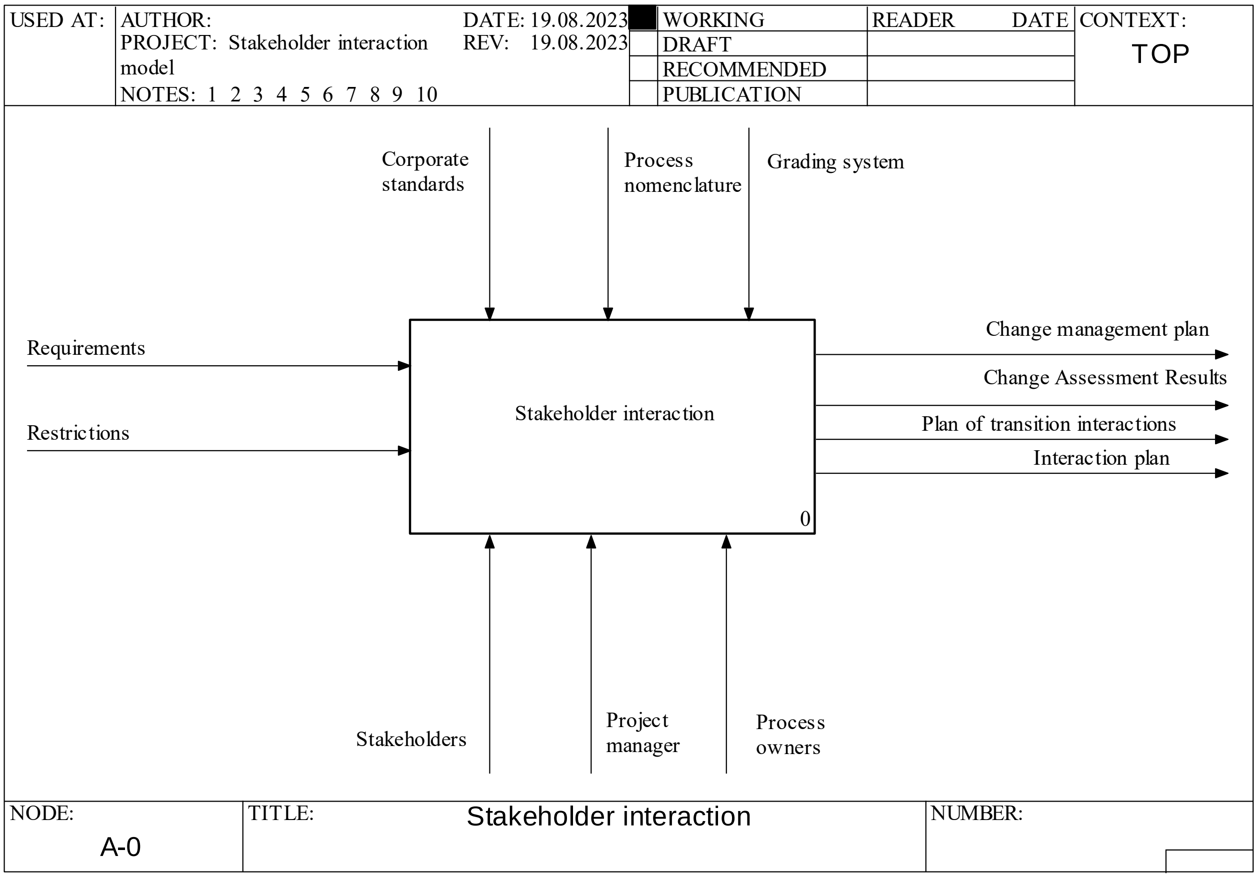

Fig. 3. Contextual model of the process of interaction of stakeholders in the management of changes and requirements

These proposed models systematize the process of stakeholder collaboration.

Involvement of process owners in change management allows you to determine the criticality of processes, the priority of changes being implemented, the availability of resources and organizational readiness.

For assessing the efficacy of Agile transformation, it is recommended to employ the Prosci Project Change Triangle model, which elucidates the interplay among project management, organizational leadership, and change management.

To facilitate effective change management, an enhanced Requirement Traceability Matrix is advocated. This matrix documents and delineates the connections between changes and requirements, offering a visual representation of their causal relationships.

Given the intricate nexus between changes and requirements in transformational endeavors, implementing Bi-Directional Requirement Traceability is prudent. This approach enables comprehensive oversight of both project requirements and ensuing changes.

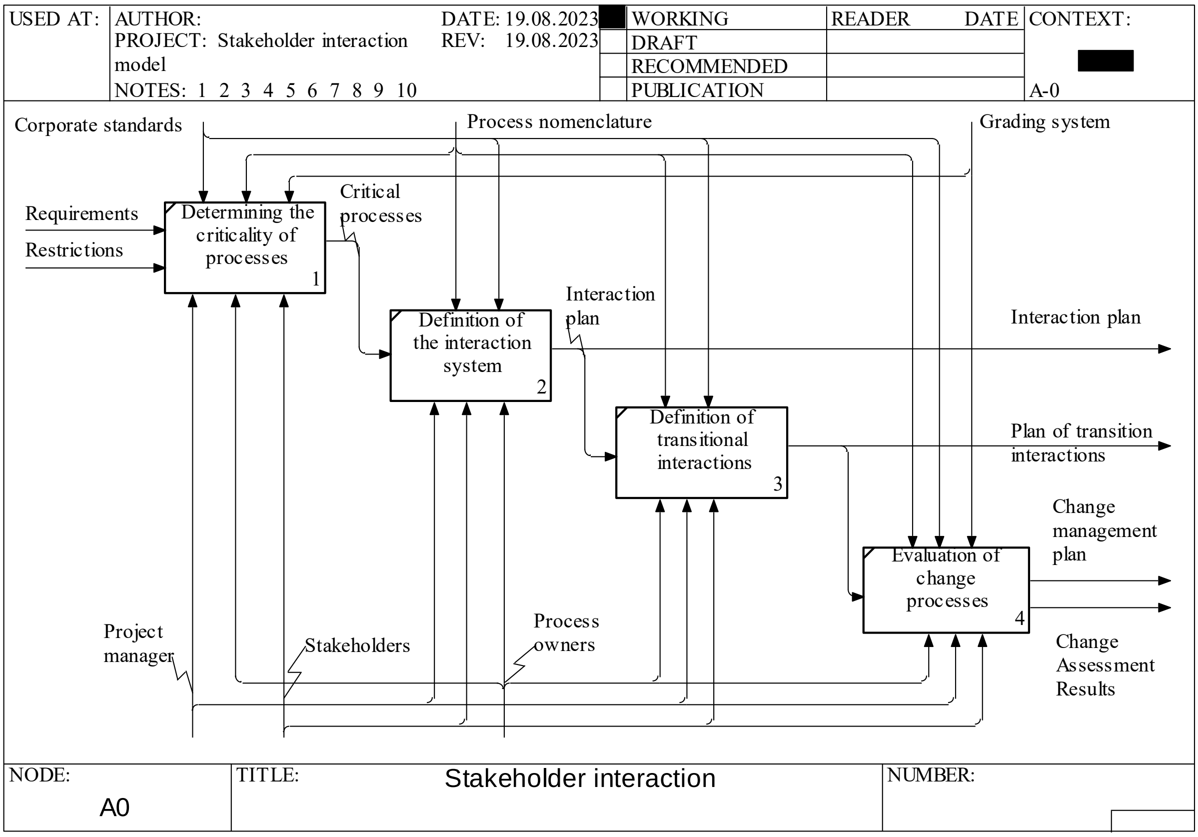

Fig. 4. Decomposition model of the process of stakeholder interaction in the management of changes and requirements

Consequently, leveraging a coordinated strategy in managing alterations within healthcare transformation projects ensures prompt responsiveness to evolving requirements, courtesy of coordination mechanisms and robust stakeholder engagement.

Conclusions

The adaptation of the coordination profile is explored with a focus on facilitating the adaptive management of alterations and requirements.

Mintzberg's coordination mechanisms are examined, leading to the identification of key components within change management processes.

The intricate interplay among change management process components, especially within healthcare transformation projects, is scrutinized. The project transformation triangle is introduced as a potential framework.

Systematic modeling of the change management procedure and stakeholder engagement processes has been undertaken.

The advocacy for Bi-Directional Requirement Traceability emerges as a strategic approach to synchronize managing changes within transformation initiatives.

The furnished guidelines offer a blueprint for structuring the change management system in transformational endeavors. These guidelines are versatile, allowing for scalability based on project magnitude and the desired level of aggregation.

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RISK-ORIENTED APPROACH TO OPTIMISING MANAGEMENT IN THE CONTEXT OF USING BIM TECHNOLOGY

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The article considers new approaches to the management of construction projects over the life cycle: design, construction, and operation of a building in the context of the introduction of information technology in Ukraine. In these circumstances, the scientific problems of assessing the impact of organisational and economic risks in a crisis situation and possible innovations in the future on the quality, timing and cost of construction for the survival of construction organisations have become particularly relevant. Based on the results of the SWOT analysis, the priority problems of managing organisational and economic risks in the construction industry have been identified. A methodology for assessing the risks of an investment project based on a risk-based approach is proposed. This will provide methodological support for obtaining real indicators for the leading project participants based on the current regulatory and reference framework using methods and models.

Introduction

The structural transformation process that has engulfed the modern global economy is characterised by new qualitative features and has become an organic component of global civilisational progress. The experience of developed countries shows that high levels of consumption come at a prohibitively high price: waste of land resources; irrational use of human potential; and disruption of the balance between human activity and the natural environment. Under these conditions, structural adjustment should contribute to the creation of the main (fourth) post-industrial civilisation, whose essential features should be:

1) transition to a new technological means of production and a new type of economic growth;

2) humanisation and socialisation of the economy;

3) the presence of different forms of ownership and economic systems, the evolution of economic relations and institutions;

4) strengthening of integration processes.

In Ukraine, the search for its own model of structuring the national economy is at an early stage and aims to implement a model of an open competitive economy of the European model. The structural imperfection of the national economy, the main features of which are the costly nature of production, raw material exports, monopoly energy imports, high external debt, territorial economic imbalances, irrational use of resource, production, scientific and technical potential, have had a negative impact on the dynamics of Ukraine's socio-economic development.

The objective basis for structural changes in the construction industry of Ukraine and optimisation of the industry structure is the mismatch of its capabilities with the general needs, violation of important proportions at all levels, the elimination of which is a prerequisite for its efficiency in the context of the industry's transition to the introduction of new BIM technologies. The use of BIM technologies is one of the key steps in the digital transformation of construction [9].

"BIM technologies are a tool for further reform, modernisation and digital transformation of the construction industry in Ukraine. Their systematic implementation at the state level will optimise the costs of construction and operation of facilities, increase the reliability and safety of buildings and structures, and make domestic construction products competitive", said Oleksiy Chernyshov, Minister of Communities and Territories Development.

Building information modelling (BIM) is a technology for optimising the design, construction and operation of a building, based on the use of a single model and the exchange of information on any object between all participants throughout the entire life cycle – from the owner's idea and the architect's first drafts to the maintenance of the finished building.

BIM technologies are a new approach to digital information management used in construction and urban planning that involves the collection and comprehensive processing of all architectural, design, technological, economic and other information about an object [11, 14]. Thanks to their use, it is possible to virtually recreate an object even before its construction begins, to track the processes of the life cycle of a construction project – from design to its construction, operation and dismantling. This approach makes it possible to increase the safety and reliability of buildings and structures, promptly manage construction and control the quality of construction work, significantly reduce the likelihood of errors in projects, reduce construction costs and optimise costs during the operation phase [2–4].

The use of BIM technology significantly increases the objectivity and reliability of design solutions, the likelihood of achieving the designed efficiency, and the ability to obtain real design indicators during the construction and operation of the facility. At the same time, a construction company within the framework of a contractor agreement gets a real opportunity to reduce the duration and cost of construction, increase profits and profitability, which is especially important for increasing the residual life of buildings and structures through innovative solutions [5, 6, 8].

Risk-based approach to construction project management

In the general methodology for assessing the statics and dynamics of the strategic innovative development of a building or structure for the future life cycle using BIM technology, in addition to digital software, it is necessary to take into account three main characteristics inherent in the economic system [1]:

– system capabilities – determination of real production capacities and provision of resources;

– accounting for and establishing the peculiarities of the relationship between the elements of the system – substantiation of real cause and effect relationships, search for implicit relationships in factor analysis;

– identification of explicit threats – risks of strategy implementation and its objective limitations.

An investment project risk is a set of possible circumstances that may lead to a decrease in the efficiency (profitability) of the project or the impossibility of its implementation. Risk is a certain probabilistic event that may occur and is associated with uncertainty. Risk management is a sequence of actions that allows for a reasonable balance of project risks and benefits. The purpose of risk management is to reduce project risks [1].

A risk-based approach to project management involves the gradual consideration of risks in the implementation of BIM technology for the development, implementation, and operation of a project according to a known algorithm:

- risk identification;
- identification and documentation of risks and their impact on the project;
- risk assessment – the probability of occurrence and quantification of the impact on project performance;
- response – justification of the necessary measures and resources to prevent and respond to threats;
- planning and organisation of actions in space and time to limit the impact of risks on the efficiency of design, construction and operation of the facility;
- implementation of measures to eliminate risks and assess their impact on technical and economic indicators that determine the economic efficiency of the project at all stages of its life cycle.

The task of the proposed algorithm in the market conditions of Ukraine can be solved by firms based on the modern regulatory and reference base with the use of methods of dynamic statistical modelling of the life cycle scenario with access to COSTS and SYNERGY EFFECT – joint evaluation of research results.

In this case, the risks for the investor-customer are as follows:

- delay in entering the market with products (goods, services) if the contractual terms of the project are delayed;
- Increase in construction costs due to changes in quality, timing, prices and tariffs, as well as "freezing" of invested funds;
- increase in operating costs of future production or housing by cost elements: depreciation, material costs, labour and social contributions.

For a construction company, project implementation risks are associated with the following factors:

- disruption of construction financing by the customer;
- changes in the contractual price of works;
- losses due to underutilisation of production capacity and material and technical facilities;
- poor quality of work and delays in its completion;
- increase in inventories and freezing of working capital;
- additional general production and administrative losses in case of failure to meet contractual construction deadlines.

A risk-oriented approach remains common to all participants in a construction project, but there are different requirements for project reliability, feasibility, and sustainability [1] (see Table 1).

Table 1

A risk-oriented approach to evaluating a construction project

Project participants	Reliability	Realisability	Sustainability
investor-operator	technical	financial	market
designer	technical	resource	market
general contractor	economic	production	resource

The risk-oriented approach adopted in the scientific study in the process of implementing BIM technology requires a modern regulatory and reference framework, as well as the use of methods and models that will create methodological support and real indicators at levels 4D-8D in accordance with the scheme (Fig. 1), which shows the leading project participants [1, 7].

The analysis of short- and long-term dynamics indicates that the recovery in construction will be long and unstable, and it creates new requirements for scientific research into the economic problems of the industry. In overcoming the crisis, the leading role is assigned to state regulation, and at the level of a construction organisation – to crisis management, in order to diagnose in time and find innovations for survival and development in the phases of recovery and growth.

Fig. 1. Leading participants in the implementation of the project using BIM technology

In these conditions, the scientific problems of assessing the impact of organisational and economic risks in a crisis situation and possible future innovations on the quality, timing and cost of construction, for the survival of construction organisations, have become particularly relevant [10].

These problems are studied by SWOT analysis methods.

SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) is a method of strategic analysis and forecasting that provides a structured scenario of a situation for which a management decision needs to be made. SWOT analysis allows you to identify and structure the strengths and weaknesses of a situation, as well as threats and potential opportunities for improvement in a matrix form. The components of the SWOT analysis can be ranked, and to reduce subjectivity, factor analysis is used with the selection of factors-causes, indicators, criteria [7, 12, 13].

In our case, based on the results of the SWOT analysis, the following issues have been identified as the top priorities for managing organisational and economic risks in the construction sector of Ukraine:

- optimisation of the construction schedule, taking into account the interest of the investor-developer and the production capabilities of contractors;

- improvement of the pricing system in construction based on a risk-based approach to resource management and assessment of the economic efficiency of construction projects;
- resource saving and labour productivity growth as a basis for assessing the economic efficiency of the formation and implementation of the strategic potential of the construction complex of Ukraine.

Assessment of the impact of organisational and economic risks on the quality, timing and cost of construction in the context of bim-technologies implementation

Two groups of methods are used to assess the risks of an investment project.

1. Qualitative assessment methods:
   - expert – general assessment of individual risks by experts (high, medium, low) and integral assessment;
   - cost-benefit analysis – identifying potential risk areas and expected cost changes;
   - analogies – for projects that are repeated by analogy with already completed projects.
2. Quantitative assessment methods based on the mathematical apparatus of probability theory, mathematical statistics, simulation modelling, and processing of expert opinions:
   - adjustment of the discount rate – changes in the interest rate on the securities market;
   - reliable cash equivalents – expected changes in cash flows due to project profitability;
   - sensitivity of performance indicators – changes in project performance indicators in the event of a change in the complex of factors that determine it within certain limits with the allocation of risk zones in the case of a multivariate calculation (for example: long-term interest rate $I = 0.05 - 0.3$; investment return rate $E = 0.05 - 0.4$);
   - the level of project sustainability – determining the level of assimilation of the projected volume of production when the profit is equal to 0 – the break-even point, which is determined by the formula with the construction of a graph.

Evaluation of the project's effectiveness is completed by analysing its sustainability by determining the break-even point (*BEP*) and building a schedule:

$$BEP = (Cn - an)/(P - an), \qquad (1)$$

where P is the price without VAT, UAH/unit;

Cn is the operating cost;

an is the variable cost.

The *BEP* level of 0.5–0.8 indicates high project sustainability and, together with other indicators, its economic efficiency:

- scenario method – development of several scenarios of project development with simultaneous changes in its parameters – from optimistic to pessimistic with the aim of reaching economic efficiency;
- simulation modelling – the Monte Carlo method simulates the laws of probability distribution of changes in project parameters with computer development and evaluation of many scenarios.

The leading role in risk forecasting belongs to economic and mathematical methods of extrapolation and modelling in combination with expert methods at a certain phase of the life cycle, especially in the context of the economic crisis, when we are now moving from the depression to the recovery phase.

The implementation of these transitions in the face of incomplete or inaccurate information about external and internal factors significantly increases the risk of creating and implementing a project in a market environment.

The level of risk is statistically determined by the following indicators:

- mathematical expectations $\left(\vec{X}\right)$ – the average value for *n* observations;
- fluctuations of the possible result:

a) absolutely, like

dispersion (D):
$$D = \frac{\sum\left(X_i - \vec{X}\right)^2}{n} \qquad (2)$$

standard – deviation (SO):
$$SO = \sqrt{D}, \qquad (3)$$

b) relative – coefficient of variation $(V,\ \%)$:

$$V = \frac{SO}{\vec{X}} \times 100. \qquad (4)$$

- the value of a particular indicator (Xn) with a certain probability (P) by the law of normal distribution:

$$Xn = \vec{X} + k \times SO, \qquad (5)$$

if $k = 1 - P = 0{,}683$; $k = 2 - P = 0{,}954$; $k = 3 - P = 0{,}997$.

We used this method to model the organisational and technological scheme of project implementation based on a network model with a 95.4% probability of duration risk.

We propose specific measures to reduce investment risk in the face of uncertainty of the economic result.

- Setting aside funds to cover expected costs. In Ukraine, in the process of determining capital investments, the risk by design stage can be as follows: concept $\pm 25\%$, feasibility study and preliminary design $\pm 15\%$, project $\pm 5-7\%$, tender – contract price. The consolidated estimate takes into account construction risks (up to 6%) and inflation risks, based on the inflation rate in the state budget.
- Redistribution of risk between project participants.
- Risk insurance - transfer to an insurance company.
- Collateral for invested funds.
- A system of guarantees from the state, banks, and investment funds.

Measures to reduce construction time are proposed for construction projects.

- Combining design and construction, starting with 10% of the project documentation.
- Reducing the period of project capacity utilisation to 1–2 months.
- Use of standard designs and unified structures.
- Commissioning of the final production process with the supply of raw materials from another enterprise - tail-end construction.
- Economic incentives from the customer: bonuses or sanctions, preferential lending, etc.

Particular attention should be paid to the risks that arise in project quality management. The quality of design decisions made in BIM at the 3D level is a leading factor in determining the effectiveness of architectural space-planning, structural, technological and other solutions that, taking into account market factors, will determine the organisational and economic conditions and risks during the design, construction and implementation of the facility.

BIM technology at the 3D level should help to eliminate the risks associated with quality management in a construction project, namely:

- errors in the design of architectural, planning and structural solutions that require redesign and additional work during construction;
- use of low-quality construction materials;
- violations of technology, hidden works and defects;
- low level of staff qualification;
- significant interruptions in the execution of works due to lack of funding, which leads to a decrease in quality and delay;
- imperfect or non-existent quality control system.

To eliminate the risks, we propose a quality control system for construction works using the International Organisation for Standardisation (ISO) standards, which should ensure quality in the development, implementation and operation of the project. The main provisions of ISO 9001-9004 provide for the coordination of the interests of the client, designer and contractor, a set of quality assurance measures, and quality control at all stages of the project life cycle.

The certification of design and construction organisations according to ISO 9001:9004 standards should ensure the level of risk of construction participants within the limits established by the National Standard of Ukraine DSTU B D1.1-1:2013, with additions and changes in subsequent years.

Conclusions

The practical value of the models and methods lies in the adoption of modern computer models and methods by designers, managers of construction companies, and building operators to optimise innovative development and predict the use of production reserves. This will increase profits, save energy and resources, and increase the life cycle of the facility.

Forecasting the production potential of a construction company and justifying performance criteria at all stages, starting with the tender for the selection of a contractor, the conclusion of a contract and other supporting documents (a schedule of work, a plan for financing the construction of the facility in the current year, schedules for the transfer of project documentation and resources), is important.

Most developed countries are already actively using BIM technologies in the design of construction projects. In particular, their use is mandatory for public procurement projects. The Ukrainian construction industry currently has a very low level of digitalisation, and few organisations are using BIM technologies.

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METHODS AND MODELS OF MILITARY LOGISTICS RESEARCH FOR EFFECTIVE COMBAT OPERATIONS IN THE CONFLICT ZONE

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The monograph is devoted to the problem of studying the logistics processes of supplying weapons and military equipment to combat units in a military conflict zone. The relevance of the work is associated with complex logistics processes in a heterogeneous transport environment (road, rail, sea and other modes of transport) with transshipment of military cargo, their temporary warehousing and storage in conditions of military threats and reduction of delivery time. ***The aim*** *of the study is to create models and methods for researching the logistics processes of military equipment supply to provide combat units with the necessary modern weapons, which makes it possible to create military parity of forces in a military conflict zone. The logistics processes of transportation in a heterogeneous transport environment in the face of threats are studied, which complicates the supply of weapons and can cause delays and disruption of military equipment delivery schedules. The occurrence of possible losses due to delays is modulated, which can lead to the loss of personnel, damage and destruction of military equipment, disruption of defensive structures, etc. The article solves the multivariate task of creating military parity of forces in the combat zone through the use of modern weapons with enhanced combat capability characteristics (range, accuracy, area of impact, etc.), which contributes to the establishment of asymmetry and the superiority of the quality of weapons over quantity. The article examines the impact of the variety of weapons supplied to the zone of military conflict on the effectiveness of combat operations. The logistics of training military personnel to acquire special competencies in the use of modern diverse weapons (HIMARS, PATRIOT, NASAMS, etc.) and the risks that arise from the possible incomplete knowledge and skills acquired after training are modeled. Low-quality knowledge can arise due to the short period of training and training risks. A logistics model is created for the formation of the necessary stocks of weapons and military equipment required for effective combat operations using multi-criteria optimization. A set of arms suppliers is selected that can provide the maximum level of military equipment stocks in the combat zone in an accelerated time frame. The logistics process of relocation of high-tech enterprises to the rear is modeled to establish the production of weapons and military equipment in the face of military threats and risks of relocation.* ***Scientific novelty and originality of the study*** *are related to the formation of a set of methods and models that study the complex logistics processes of supplying weapons and military equipment to the conflict zone in the context of modern hybrid warfare.* ***Mathematical methods used in the study*** *are: system analysis, multivariate choice, lexicographic ordering of options, multicriteria optimization, integer (Boolean) programming, theory of experiment, quantitative and qualitative evaluation of options, simulation modeling, agent-based modeling.*

Introduction

The globalization of the economy has led to the emergence of distributed production, the planned nature of which requires timely delivery and formation of the necessary stocks of components, materials and raw materials. Due to the changing environment, challenges and threats, there are risks to the implementation of plans to develop modern high-tech products, including weapons and military equipment. The nature and level of threats in the world has changed, as terrorist and military threats have emerged in addition to political, economic, and climate threats. This can disrupt the logistics process of building up stocks of weapons and military equipment. This is especially true during martial law, when supply logistics and production are affected by military threats. Therefore, there were problems with both supply and stockpiling of military equipment. The use of various weapons in the conflict zone requires timely planning and stockpiling, as well as the creation of relatively safe transportation and storage routes for further use during hostilities. The nature of modern military logistics requires a study of the formation of weapons stockpiles, and an assessment of the impact of the number of stockpiles on the effectiveness of combat operations. Therefore, the topic of this study is relevant, as it creates a set of models and methods for analyzing the logistics processes of stockpiling, assessing the losses that arise in the event of a delay in the supply of military equipment, and the process of developing special competencies in the military to use modern weapons.

New problems in military logistics in the context of hybrid warfare have emerged that need to be addressed to ensure the country's defense capability:

1. The problem of the diversity of military equipment entering the combat zone, for which it is necessary to ensure the timely production of ammunition, spare parts and components.

2. The problem of a heterogeneous transport environment used to deliver military cargo to the military conflict zone. There are transshipment of weapons, temporary storage, which is dangerous in the face of military threats.

3. The problem of long, sometiWME intricate supply chains that complicate the logistics of military cargo transportation, increase the time for delivery and the risks of stockpiling.

4. The problem of late delivery of weapons and military equipment. This can lead to military losses and changes in the nature of hostilities (e.g., a shift from offensive to defensive actions).

5. The problem of training personnel to use a variety of military equipment in a short time, ensuring the necessary special competencies, and conducting quality training. Insufficient knowledge in combat conditions can lead to damage to military equipment and military losses.

6. The problem of relocating high-tech enterprises that produce modern weapons and military equipment to the rear in the context of martial law.

These problems and methods of their solution are the basis of the study, the results of which are presented in this section of the collective monograph.

Modeling the logistics of military cargo and the occurrence of losses due to delays in delivery

The unit solves a multi-criteria task related to modeling the transport logistics of military cargo delivery to the combat zone. The relevance of the study is related to the analysis of losses that occur in the combat zone (loss of personnel of the Armed Forces of Ukraine, damage and destruction of military equipment, change in the nature of combat operations from offensive to defensive, etc.) due to possible delays in the supply of weapons and military equipment. The purpose of the study is to model transportation logistics in a heterogeneous transportation network to ensure timely delivery of military cargo in the face of wartime risks that affect the amount of damage in the combat zone.

Logistics is one of the most important components in wartime [1]. The untimely delivery of weapons, military equipment, ammunition and spare parts to the combat zone significantly affects the nature and course of the war. Delayed delivery of military cargoes leads to possible losses during combat clashes (loss of personnel of the armed forces, damage and destruction of military equipment, change in the nature of hostilities from offensive to defensive, etc. Therefore, it is important to solve the problem of organizing rational logistics interactions in the process of transportation of military cargoes, which are carried out in a heterogeneous transport network with transitions (transshipment) from one type of transport highway to another. For example, the delivery of military cargo can be carried out along a long logistics transport chain: air – automobile – rail – automobile modes of transport.

To organize such complex interactions, distribution logistics centers, transshipment sites, temporary storage, etc. are being formed. Such a variety of logistics components, as well as long logistics chains, lead to great risks that must be taken into account when forming wartime military cargo supply routes.

The analysis of publications on this topic has shown that the main focus of scientific papers is on the formation of cargo routes in a homogeneous (mono-) transport environment without taking into account transitions from one transport artery to another, cargo transshipment and temporary storage [3]. In addition, there are currently no studies related to the occurrence of losses (especially in wartime) as a result of logistical delays and the analysis of risks arising in supply logistics due to wartime conditions [4].

Thus, a contradiction arises between the requirements of timely delivery of military cargo, which significantly affects the amount of damage and the course of hostilities, and the capabilities of transport logistics associated with a heterogeneous transport network and long logistics chains with transshipment, which leads to increased risks of transportation in wartime.

A complex scientific and applied task of a multicriteria nature arises related to the timely delivery of military cargo, the delay of which affects the amount of damage and the course of hostilities. At the same time, it is necessary to take into account the heterogeneity of the transportation network, the availability of transshipment, and the risks of supply arising from military threats [5].

The main criteria for assessing the achievement of the research objective are the time of cargo transportation in a heterogeneous transport network, the amount of damage associated with the late delivery of military cargo, and the amount of accumulated risk in wartime supply logistics.

To realize the research goal, the following tasks need to be solved:

1) to build an agent-based simulation model to study the transportation of military cargo;

2) to develop an algorithm for minimizing the time of delivery of military cargo in a heterogeneous transportation network;

3) to create a routing algorithm to minimize the risks of military cargo delivery;

4) to develop a method for analyzing possible damage associated with the delay in the delivery of weapons and military equipment to the combat zone;

5) to formulate a method for finding compromise solutions for developing routes for the supply of weapons and military equipment to the combat zone;

6) to provide an example of modeling the supply of military cargo to a combat zone.

Agent-based simulation model for studying military cargo transportation

Due to the long logistics chains associated with the delivery of military cargo, the main aspect of the study is aimed at modeling dynamic supply processes in a complex heterogeneous transportation network. Therefore, the main research tool used is the developed agent-based simulation model, which allows simulating time delays in complex structures of transportation networks with possible parallel supply processes interconnected by synchronization conditions.

The simulation model is implemented as an agent-based representation. It is based on the classical GPSS system for modeling complex processes, which is used to simulate dynamic processes in sociotechnical systems.

The simulation model identifies a control agent that, using a given time scale, manages the main events that occur during the movement of applications (military cargo) in the transportation network. The following main events related to the movement of military cargo were used:

– formation (generation) of a request in the transportation network;

– exit of the request from the vertex of the graph G of the transport network (transport node);

– receipt of a request at a transportation hub;

– occupation of the highway section by the request;

– release of the transportation section of the highway;

– arrival of a request (military cargo) in a combat zone;

– synchronization of several requests (for example, arrival of military equipment and ammunition).

The developed simulation model allows for the study of parallel processes of request movement, each of which is associated with its own route. The processes can be synchronized, which is related to the peculiarities of using military cargo in the combat zone.

The simulation model is implemented as a set of agents in relatively isolated program modules, with its own internal decision-making structure related to the implementation of events in the simulation system. Events are modeled in system time, taking into account a given scale, using a sequential list of events. Events are realized by viewing the header of the event list. Planning of future events is based on the cause-and-effect relationship. For example, due to the occupation of a section of a transportation highway, a consequence arises – the release of this section in the process of moving military cargo. The final event in the modeling is the event of the request (military cargo) entering the combat zone.

Let us list the main agents of the simulation model.

1. Agent for describing the transportation network.

2. Order generator agent (used to generate orders in the form of military cargo entering the transportation network).

3. Transport node agent (associated with the events of arrival and departure of military cargo from the transport node).

4. Agent of a transport section of a highway (associated with events of occupation and release of a section of a highway by military cargo).

5. Agent for synchronizing the receipt of multiple requests (triggered in the event of receipt of requests related to the condition of their synchronization).

6. Agent for getting requests (military cargo) into the combat zone (CZ).

7. Agent of risk accumulation during the movement of the order (military cargo) in a heterogeneous transportation network. Risks are set in advance by experts for both transportation hubs and sections of transportation highways.

8. Agent for generating losses associated with late delivery of military cargo. The amount of damage is set by experts and depends on the specified delivery time of military cargo.

9. Agent for managing the simulation process. It generates system time in accordance with a given scale, plans and implements a list of future events, taking into account causal events.

10. Agent of modeling results. The results include: the time of arrival of military cargo to the combat zone, the time of delay in the delivery of military cargo, the amount of damage due to the delay in the arrival of military cargo, the amount of the final risk of delivery of military cargo.

Fig. 1 shows a block diagram of the agent-based model.

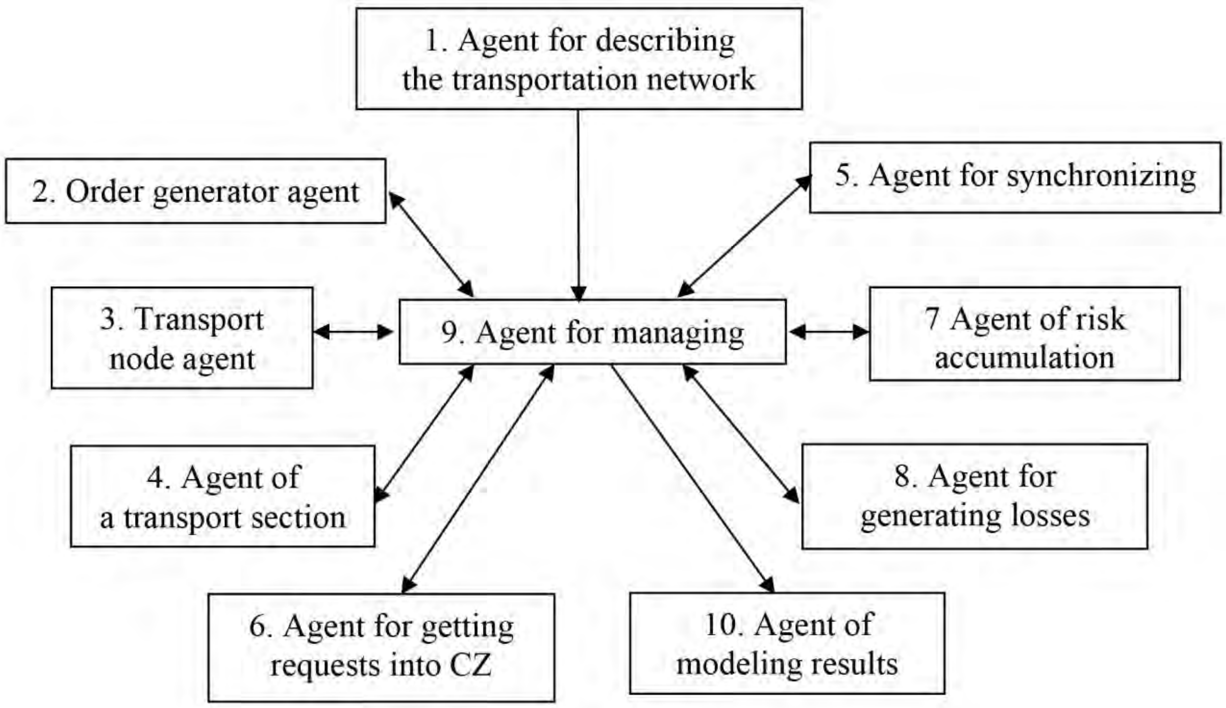

Fig. 1. Structural scheme of the agent model

Algorithm for minimizing the time of military cargo delivery in a heterogeneous transportation network

Publications discuss algorithms for minimizing cargo delivery time (for example, the well-known Dijkstra algorithm). Most of them are of an academic nature, so they cannot be used in real conditions related to the transportation of military cargo and combat operations. It is necessary to emphasize the following features of military cargo delivery in wartime:

– the use of a heterogeneous transportation network with a significant number of transitions (transshipment) from one transportation highway to another;

– use of parallel movements of military cargo from different sources of supply;

– meeting the requirements for synchronization and consolidation of military cargo;

– taking into account the military risks associated with the movement of goods both along transportation routes and at hubs;

– forced delays in the delivery of military cargo, which can lead to losses (loss of personnel of the armed forces, damage to engineering structures and destruction of military equipment, change in the nature of hostilities from offensive to defensive, etc.)

Therefore, we developed an original routing algorithm that takes into account the above features of military cargo delivery in wartime. The algorithm is implemented in the developed agent-based simulation model. Let us present the sequence of actions of the algorithm in the form of the main steps.

1. Generate requests (military cargo) related to a given batch of weapons and military equipment. Requests are generated using an agent – a request generator – based on a given schedule for the supply of weapons and military equipment.

2. Copies (clones) of applications of various types moving along all possible transportation sections of the highway associated with a particular transportation hub are sent from the transportation hub (including derivatives).

3. When a request arrives at a neighboring transport node, it is checked that no other requests are routed through that transport node. If a request (clone) occupies this transport node, it is blocked. Its movement is stopped due to the later arrival time at the already marked transport node, which was passed by another request earlier (the request is unpromising for further movement).

4. When a request (clone) arrives at a particular transport node, the synchronization (consolidation) condition is checked. If this condition exists, the request is waiting for other requests. The arrival of the last request ensures the formation of a complex request of a new type and its further movement in a heterogeneous transport network.

5. When the orders reach the combat zone (CZ), the time of their arrival is recorded.

6. From the finishing transport node of the CZ in the opposite direction, the route (routes) of movement of applications (military cargo) is formed by sequential passage through the designated transport nodes.

7. The resulting route is minimal in time and is used in the future to determine the possible delay in the arrival of military cargo to the combat zone, taking into account the specified delivery time.

8. During the movement of applications (clones) along the sections of the highway and transport nodes, risk values are accumulated, which is formed in the form of a final risk value after the arrival of all military cargo in the combat zone.

9. Depending on the time of delay of military cargoes in the CZ, military specialists form the amount of possible damage by means of expert assessment.

A routing algorithm to minimize the risks of military cargo delivery

Long supply chains become particularly vulnerable in wartime. The risks associated with the late delivery of military cargo to the war zone are growing. Therefore, it is necessary to model the accumulation of risks in long logistics chains, taking into account possible threats and vulnerabilities.

A routing algorithm has been developed to minimize the risks of supply in the face of threats and vulnerabilities. The basis for the development is an algorithm for minimizing the time of cargo delivery in a heterogeneous transport network. The peculiarity of the algorithm, unlike the developed one, is the change in the controlling action of events in the modeling. As event control, we use not time but the value of the accumulated risk in the process of movement of orders (clones) in column G, which is a heterogeneous transportation network. Therefore, the list of future events is formed not by the value of time, but by the value of the accumulated risk.

The event with the lowest value of the accumulated risk is always at the top of the event list. During the movement of orders (clones), transport nodes are marked with passed orders (clones). Unpromising orders (clones) with a higher value of accumulated risk are discarded.

The final transport node (combat zone) receives the application (clone) in the form of a military cargo consignment with the minimum value of the accumulated risk. In the reverse phase of the algorithm (movement from the CZ to the derivative transport hubs), a route for the movement of applications is formed and thus the task of routing is solved to minimize the risks of supplying military cargo in the face of threats and vulnerabilities.

A method for assessing the possible damage associated with the delayed delivery of military equipment to the combat zone

The success of combat operations in a particular area of military conflict depends primarily on the timeliness of the logistics supply of the necessary weapons and military equipment. Delay in the supply of certain components for weapons and military equipment leads to damage (loss of personnel of the armed forces, damage and destruction of military equipment and defensive structures, change in the nature of hostilities from offensive to defensive, etc.), the amount of which depends on the importance of certain types of weapons that are essential for the successful execution of military operations in the combat zone. An urgent task arises – to investigate the delay of certain types of weapons and military equipment that should be delivered to the combat zone. These delays affect the amount of damage during combat operations. To solve this problem, it is necessary to analyze possible (alternative) variants of delays for certain types of weapons and military equipment. Next, it is necessary to assess the impact of the delay on the amount of damage. The task is to search through the set of delay options associated with certain types of weapons and military equipment. For example, for three types $(n=3)$ of weapons, the total number of possible delay options is $N = 2^n = 2^3 = 8$.

You can generate all possible options using a binary counter, in the form:

1. 000
2. 001
3. 010
4. 011
5. 100
6. 101
7. 110
8. 111,

where the first option, for example, means no delays, i.e., timely arrival of all three types of weapons in the combat zone, which corresponds to no (or minimal) damage. The last, eighth, option means that there are delays for all types of weapons, which means the maximum value of damage in the combat zone. To assess the damage, the opinions of military experts are used, who can estimate the value of damage, for example, on a ten-point scale, where the minimum value of damage is associated with the first option, and the maximum – with the last, eighth option.

To estimate the impact of delays on damage, we will use a full factorial experiment (FFE), where the row of the plan is a combination of possible delays for individual weapons, and the final column (right) is the expert estimates of possible damage.

Consider an illustrated example of studying the impact of delays on the amount of damage in a combat zone. For the purpose of the example under consideration, let's assume that three types of weapons are used to successfully perform combat missions:

1) multiple launch rocket systems (MLRS) (variable X_1);

2) artillery systems (guns, howitzers, mortars) (variable X_2);

3) anti-tank systems (variable X_3).

The plan of the virtual experiment with assessments of military specialists (experts) is presented in the form of a FFE (Fig. 2).

№	X_1	X_2	X_3	Y
1	–1	–1	–1	0
2	–1	–1	+1	2
3	–1	+1	–1	3
4	–1	+1	+1	5
5	+1	–1	–1	5
6	+1	–1	+1	7
7	+1	+1	–1	8
8	+1	+1	+1	10

Fig. 2. Using FFE for loss assessment

Here, –1 means no delay (zero value of the binary counter), and +1 means a delay (one value of the binary counter). Column Y contains the estimated values of losses in points. Further, using the known calculation formulas for FFE, the values of the parameters are determined in the form of an incomplete quadratic dependence:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3 + b_{123} X_1 X_2 X_3,$$

where b_0 corresponds to the center of the experiment;

b_1 – coefficient associated with the influence of the factor X_1;

b_2 – coefficient associated with the influence of the factor X_2;

b_3 – coefficient associated with the influence of the factor X_3;

b_{12} – coefficient for assessing the relationship of factors X_1 and X_2;

b_{13} – coefficient for assessing the relationship of factors X_1 and X_3;

b_{23} – coefficient for assessing the relationship of factors X_2 and X_3;

b_{123} – coefficient for assessing the relationship of factors X_1, X_2 and X_3.

First of all, we are interested in the linear part of this relationship, which allows us to estimate the impact of certain types of weapons on the amount of loss (Y). After performing the calculations in the example, we have:

$$Y = 3,75 + 2,5X_1 + 1,5X_2 + X_3 \ .$$

The dependence shows that the most significant impact on the amount of damage in the combat zone is caused by the late delivery of MLRS. Delayed delivery of artillery systems has a lesser impact. Late delivery of anti-tank systems has the least impact on the amount of damage in the combat zone.

If a group of experts rather than a single military specialist is involved in assessing the damage (related to delays) when certain types of weapons and military equipment arrive in the combat zone, then the estimates are averaged to form the damage values.

If there is a significant difference in expert estimates, the ELEKTRA method can be used to generate compromise estimates. With its help, through multi-step iteration, we achieve compromise values for a group of experts.

A method of finding compromise solutions in the formation of routes for the supply of weapons and military equipment to the combat zone

The analysis of the tasks of supplying weapons and military equipment to the combat zone showed that there is a contradiction between the criteria related to the time of delivery of military cargo, risks and losses. Therefore, it is necessary to find a compromise solution related to the delay of military cargo and losses that occur in the combat zone by means of multivariate analysis.

Let's assume that a set of alternative routes for the delivery of weapons and military equipment to a combat zone has been formed using the opinions of military experts. For each k-th route option, a preliminary estimate of possible time delays t_{ik} for the i-th transport nodes of the logistics supply chain is known, t_{jk} is the delay on the highway sections during the movement of military cargo.

Then the total time associated with the supply of military cargo can be represented as:

$$T_k = \sum_{i=1}^{n_k} t_{ik} + \sum_{j=1}^{m_k} t_{jk},$$

where n_k – is the number of transport nodes in the k-th route of military cargo movement;

m_k – is the number of sections of the transportation highway in the k-th route option.

The amount of possible delay if military cargo arrives in the combat zone for the k-th route variant:

$$\Delta T_k = T_k - T_0,$$

where T_0 – the planned time of delivery of military cargo to the combat zone.

In this way, it is possible to assess the risks that accumulate during the movement of goods in the combat zone. For the k-th route:

$$R_k = \sum_{i=1}^{n_k} r_{ik} + \sum_{j=1}^{m_k} r_{jk}.$$

At the same time, it is necessary that $R_k \le R_0$, where R_0 is the acceptable risk value associated with the delivery of military cargo to the combat zone.

To find a compromise route for the delivery of military cargo to the combat zone, we will use the method of integer (Boolean) programming.

Let's introduce the variables x_k, in this case $X_k = 1$ corresponds to the use of the k-th route of delivery of military cargo to the combat zone, $X_k = 0$ corresponds to the non-use of the k-th route. In this case $\sum_{k=1}^{N} X_k = 1$, which corresponds to the selection of one alternative route to solve the routing problem, here N is the number of possible routes for the movement of military cargo specified by experts.

Then, taking into account the variables X_k, the criterion for the delay of military cargo when entering the combat zone will be as follows:

$$\Delta T = \sum_{k=1}^{N} \left(\sum_{i=1}^{n_k} t_{ik} + \sum_{j=1}^{m_k} t_{jk} \right) X_k - T_0.$$

In its turn, the amount of accumulated risk will be calculated as:

$$R = \sum_{k=1}^{N} \left(\sum_{i=1}^{n_k} r_{ik} + \sum_{j=1}^{m_k} r_{jk} \right) X_k.$$

To find a compromise solution, let's introduce a comprehensive criterion:

$$Q = \alpha_T \Delta\hat{T} + \alpha_R \hat{R} = \alpha_T \sum_{k=1}^{N} \Delta\hat{T}_k X_k + \alpha_R \sum_{k=1}^{N} \hat{R}_k X_k =$$

$$= \frac{\alpha_T}{\Delta T_{max} \left[\sum_{k=1}^{N} \left(\sum_{i=1}^{n_k} t_{ik} + \sum_{j=1}^{m_k} t_{jk} \right) X_k - T_0 \right]} + \frac{\alpha_R}{R_0} \left[\sum_{k=1}^{N} \left(\sum_{i=1}^{n_k} r_{ik} + \sum_{j=1}^{m_k} r_{jk} \right) X_k \right].$$

Here ΔT_{max} is the maximum value of the delay, which was taken after analyzing the set of possible routes for the supply of military goods to the combat zone, where $\alpha_T + \alpha_R = 1$, α_T is the significance (weight of the delay criterion), and α_R is the significance (weight of the supply risk criterion).

It is necessary to find min Q taking into account $R \le R_0$, $\sum_{k=1}^{N} X_k = 1$.

The resulting solution is a compromise and takes into account possible delays and risks in the delivery of military cargo to the combat zone

An example of modeling the supply of military cargo to a combat zone

Let's consider an illustrated example of the supply of military cargo to a combat zone for a transportation network depicted as graph G in Fig. 3.

The vertices of the graph represent transportation nodes, and the edges represent sections of the transportation network. The time delays at the nodes and sections of the transportation highway are given in hours. For the convenience of assessing risks and losses, qualitative assessments are used in the form of values of linguistic variables, which are then converted into terms of points.

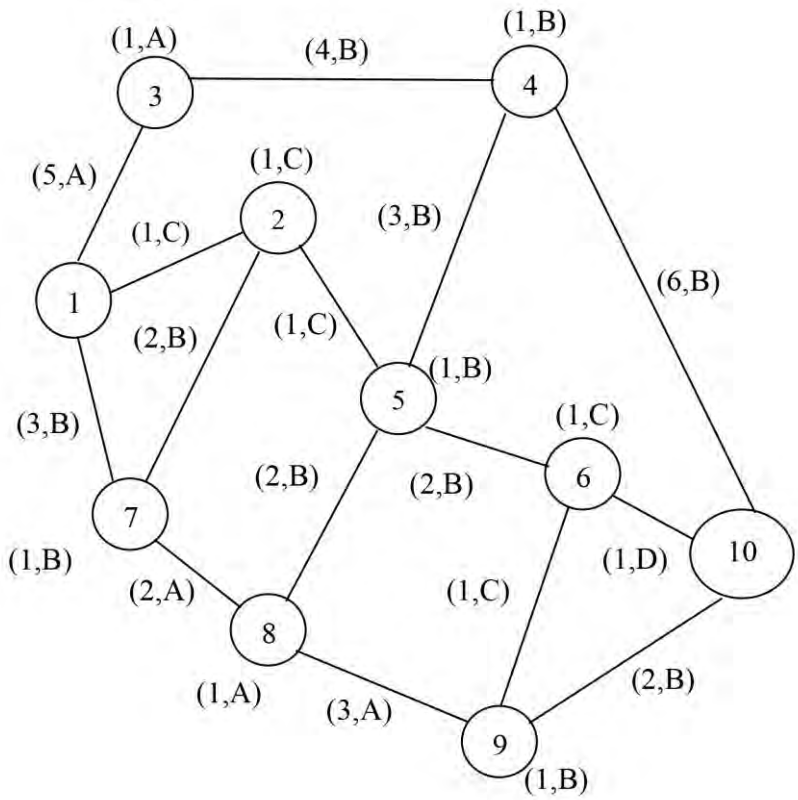

Fig. 3. Graph G of military cargo supply

We have the following qualitative assessments for risks:

A – minimum risk value;

B – satisfactory risk value;

C – acceptable risk value;

D – maximum risk.

In terms of points: $A = 3$, $B = 5$, $C = 7$, $D = 10$.

The following linguistic variables are used to estimate the loss caused by delays in the delivery of military supplies to the combat zone:

K – minimum loss;

L – satisfactory value of loss;

M – acceptable value of loss;

N – critical value of loss.

In brackets in Fig. 3 shows the values of time and risk on sections of the highway and transportation hubs. The first vertex of graph G corresponds to the transportation hub, the source of military supplies. The last, tenth vertex of graph G corresponds to the arrival of military equipment in the combat zone. Using the developed agent-based simulation model (p. 1), the algorithm for finding a route with the minimum time (p. 2) and the algorithm for finding a route with the minimum risk value (p. 3), as well as estimates from military specialists (experts), we constructed Table 1 with a set of possible routes for the supply of military equipment to the combat zone.

Table 1

An example of a study on the supply of military equipment in the CZ

№	Routes	Travel time	Time of delay		Risks		Loss
			hours	%	Linguistic variables	Points	
1	1-3-4-10	16	8	100	2A, 3B	21	N
2	1-2-5-4-10	14	6	75	4B, 3C	41	M
3	1-2-5-6-10	8	0	0	2B, 4C, D	48	K
4	1-2-5-8-9-10	13	5	63	2A, 3B, 3C	42	M
5	1-2-7-8-5-6-10	15	7	88	2A, 5B, 3C	52	M
6	1-2-5-6-9-10	11	3	38	4B, 5C	55	L
7	1-2-7-8-9-6-10	15	7	88	3A, 3B, 3C D	55	M
8	1-2-7-8-5-4-10	21	13	163	A, 7B, 2C	52	N
9	1-7-2-5-6-10	14	6	75	4B, 3C, D	51	M
10	1-7-2-5-4-10	20	12	150	A, 5B, 2C	42	N
11	1-7-2-5-6-10	14	6	75	5B, 3C, D	56	M
12	1-7-2-5-8-9-10	13	5	63	2A, 4Bb, 3C	47	M
13	1-7-2-5-8-9-10	20	12	150	3A, 5B, 3C, D	65	N
14	1-7-8-5-4-10	22	14	175	2A, 7B	41	N
15	1-7-8-5-6-10	12	6	75	2A, 6B, C, D	53	M
16	1-7-8-5-6-9-10	17	9	113	2A, 7B, 2C	55	N
17	1-7-8-9-10	13	5	63	3A, 4B	29	M
18	1-7-8-9-6-10	14	6	75	3A, 3B, 2C, D	48	M

A preliminary analysis of the modeling results showed:

1. The options for military equipment supply routes 1, 8, 10, 13, 14, 16 were eliminated in further research due to unacceptable (critical) values of damage that occurs in the combat zone.

2. Taking into account the total risk value (over 50 points) that arises and accumulates during the movement of military cargo on sections of the highway and nodes, route options 5, 6, 7, 9, 11, 15 were eliminated from further study.

3. The third route option for the supply of military equipment corresponds to the minimum time of delay, but at the same time there is a rather high risk value of R=48 points.

4. The first option of the route for the supply of military equipment to the combat zone corresponds to the minimum risk value of $R = 21$ points, but at the same time has an unacceptable value of damage – N, the time of delay corresponds to 100%, so it was also excluded from consideration.

5. It makes sense to consider the options of routes for the supply of military equipment to the combat zone with intermediate values of delay, risks and losses 2, 4, 12, 17, 18 to select a compromise solution.

The final route option for the supply of military equipment to the combat zone was chosen as route option 17 with a delay of 63%, a minimum risk of 29 points, and an acceptable value of damage of M.

The study described in this subsection is related to the modeling of logistics chains for the supply of military cargo (weapons, military equipment) to the combat zone.

The article reveals the shortcomings of existing routing methods, which are mainly related to peacetime and do not take into account delays and risks that arise in long logistics supply chains for military cargo, which leads to losses. An agent-based simulation model and an original routing algorithm have been developed that allows, by multiplying requests (request clones), to find the optimal route in a heterogeneous transportation network with minimal time and risk.

The article analyzes the losses due to late delivery using the method of theory of experiment. The method of integer (Boolean) programming is used to find compromise solutions in the problem of military cargo routing.

An example of modeling delays in the supply of military cargo to a combat zone is presented.

The proposed approach makes it possible to formulate rational routes for the transportation of military cargoes in the planning of the supply of weapons and military equipment to the combat zone, taking into account delays, losses and risks.

Modeling the logistics of establishing military parity of forces

The chapter solves a multivariate problem related to the modeling of the logistics process of creating military parity of forces in a military conflict zone, which contributes to the successful fulfillment of the objectives of a combat operation. The relevance of the study is related to the analysis of threat factors to the establishment of military parity of forces, logistical difficulties arising from the supply of weapons and military equipment, which causes damage in a military conflict zone (loss of personnel, breach of defensive structures, transition from offensive to defensive actions, etc.) The purpose of the study is to model the actions related to the logistics of forming parity of forces in the conflict zone under the threat of martial law.

Conducting a successful military operation in modern conditions depends on many factors, in particular, on the existence of military parity of forces with a possible enemy [6]. Creating parity in weapons and military equipment is one of the important tasks in preparing for a military operation [7]. The formation of military parity of forces is a complex logistical task, which should involve developers, suppliers of weapons and military equipment, logistics of transportation in a heterogeneous transport environment with possible transshipment from one transport highway to another and temporary storage of military cargo. Therefore, the task of ensuring military parity of forces in the combat zone for the successful execution of a military operation in the face of threats and vulnerabilities associated with the logistics of production and supply of weapons and military equipment is relevant. The analysis of publications on the research topic showed that the available works are mostly related to certain aspects of the task, in particular, consideration of the requirements for the formation of military parity of forces [8] for the successful execution of a military operation, the logistics of military cargo transportation, the presence of uncertainties related to the logistics of military transportation [9]. There are no publications with a comprehensive solution to the proposed task, analysis of threats caused by violation of military parity in the zone of military conflict, logistical threats related to the transportation of military cargo to the combat zone. In addition, the probability of vulnerabilities related to the problems of logistics of military cargo delivery to the combat zone, which leads to a violation of military parity of forces and, as a result, to the death of armed forces personnel, destruction of defense infrastructure, transition from offensive to defensive actions, etc. has not been studied. In order to successfully fulfill the purpose of the study, the main criteria are the levels of threats, logistical risks, time and expences required to establish military parity of forces in the zone of military conflict. To realize the research objective, it is necessary to solve the following tasks [10]:

1. To analyze the threat factors in the process of forming military parity of forces in the combat zone.

2. To model threats in the logistics of production and supply of weapons and military equipment to ensure military parity of forces in the combat zone.

3. To develop a method to increase the effectiveness of the use of zurich, which contributes to the creation of asymmetry in the military parity of forces in the combat zone.

4. To create an agent-based simulation model for studying the logistics of production and supply of weapons and military equipment to the combat zone to establish military parity of forces.

Analysis of threat factors in the process of forming military parity of forces in the combat zone

In order to form military parity of forces, it is necessary to analyze the main components of weapons and military equipment in a particular combat zone. For example, such components in the form of threat factors are the lack of specific types of weapons in the required quantity:

– aviation
– heavy weapons,
– ammunition,
– unmanned aerial systems.

Suppose that with the help of military experts for the combat zone under consideration, the necessary types of weapons and their quantity, as well as military equipment are determined in the form of a set M, $m_i \in M$, $i = \overline{1,N}$. Where m_i is the number of weapons of the i-th type required to create military parity of forces, N is the number of required types of weapons to establish military parity of forces in the CZ.

It is known, according to military experts, how many weapons of the i-th type are available in the CZ – $m_{0i} \in M_0$, where m_{0i} is the availability of weapons of the i-th type in the CZ at the moment.

Then $\Delta m_i = m_i - m_{0i}$ – is the number of weapons of the i-th type required to ensure military parity of forces in the CZ. The greater the value of , the higher the threat associated with the lack of the required number of weapons of the i-th type in the CZ. The emergence of threats associated with the lack of a certain number of certain types of weapons can lead to losses in the CZ (loss of personnel, disruption of defense infrastructure, transition from offensive to defensive actions, etc.) Therefore, it is necessary to assess the level of threats, taking into account possible factors related to the lack of weapons.

For the convenience and simplicity of analyzing the level of threats, we use the estimates of military experts for each i-th type of weapon. To do this, we will use qualitative assessments of the level of threats in the form of values of the linguistic variable:

$$x_i = \begin{cases} A - \textit{low threat level for i-th type of weapon;} \\ B - \textit{acceptable threat level;} \\ C - \textit{high threat level;} \end{cases}$$

For each i-th type of weapon and military equipment, there is a set of suppliers P_i that can supply m_{ij} number of weapons and military equipment $m_{ij} \le \Delta m_i$. The value of m_{ij} is a factor that affects the threat level x_i and is estimated with the help of military experts for each i-th type of weapon. In addition, it is necessary to take into account the time of production and delivery t_{ij} of the i-th type of weapon by the j-th supplier, w_{ij} – the expence of production and delivery of the i-th type of weapon by the j-th supplier, r_{ij} – the risks of production and delivery of the i-th type of weapon by the j-th supplier.

Where:

$$t_{ij} = \begin{cases} A - \textit{minimum delivery term;} \\ B - \textit{satisfactory delivery term;} \\ C - \textit{maximum delivery term;} \end{cases}$$

$$w_{ij} = \begin{cases} A - \textit{minimal expences;} \\ B - \textit{acceptable expenses;} \\ C - \textit{maximum expences;} \end{cases}$$

$$r_{ij} = \begin{cases} A - \textit{minimum risk;} \\ B - \textit{acceptable risk;} \\ C - \textit{maximum risk}. \end{cases}$$

To determine a possible supplier in the set P_i, we represent each j-th supplier for the i-th type of weapon as a sequence of qualitative values x_{ij}, t_{ij}, w_{ij}, r_{ij}, where x_{ij} is the level of threat determined by military experts depending on the value m_{ij} associated with the quantity of the i-th type of weapon that can be provided by the j-th supplier.

The list of qualitative values x_{ij}, t_{ij}, w_{ij}, r_{ij} will be represented conventionally as a word, for example, B A B C. Then for the set P_i of possible suppliers of the i-th type of weapons and military equipment, we will get a list of "words" that will be options for the suppliers to choose. For example, we have 10 variants:

1. A, C, B, B
2. B, A, B, B
3. B, B, A, B
4. C, A, A, B
5. B, B, C, B
6. B, A, C, C
7. C, A, A, A
8. B, B, A, C
9. C, A, A, C
10. A, B, B, C.

By organizing the options in a lexical and graphical form (as in a dictionary), you can select the option with the lowest threat level. We get:

10. A, B, B, C
1. A, C, B, B
2. B, A, B, B
6. B, A, C, C
3. B, B, A, B
8. B, B, A, C
5. B, B, C, B
7. C, A, A, A
4. C, A, A, B
9. C, A, A, C.

It is noticeable that the options with the lowest level of threat will be located in the upper half of the ordered list of possible suppliers of weapons and military equipment of the i-th type. In the above example, it is advisable to take the second option of the supplier with an acceptable level of threats, the minimum period of production and delivery of the i-th type of weapon, acceptable expence and risk.

Thus, for each i-th type of weapon and military equipment, suppliers will be selected that ensure the minimum level of threat for all weapons in the process of forming military parity of forces in the combat zone.

Given a significant number of possible suppliers of weapons and military equipment, we will use quantitative estimates to solve the optimization problem of choosing a supplier from a set of suppliers that minimizes the level of threats in the process of forming military parity of forces in the CZ.

Let z_{ij} be a Boolean variable that takes the values:

$$z_{ij} = \begin{cases} 1 - \textit{if the j-th supplier is selected for the i-th type of weapon;} \\ 0 - \textit{otherwise;} \end{cases}$$

at the same time $\sum_{j=1}^{n_i} z_{ij} = 1$.

Then the threat criterion can be presented as follows:

$$V = \sum_{i=1}^{N} \sum_{j=1}^{n_i} v_{ij} z_{ij},$$

where v_{ij} – is a quantitative assessment of the level of threat proposed by military experts (for example, on a 10-point scale) for selecting the j-th supplier of the i-th type of weapon, n_i is the number of possible suppliers of the i-th type of weapon. It should be noted that v_{ij} depends on the number of $m'_{ij} \le \Delta m_{ij}$, where m'_{ij} is the planned number of weapons of the i-th type that can be delivered by the j-th supplier.

Total time for production and delivery of weapons (pessimistic estimate of time due to the sequential nature of weapons delivery):

$$T = \sum_{i=1}^{N} \sum_{j=1}^{n_i} t_{ij} z_{ij}.$$

Expences associated with the production and supply of the necessary weapons and military equipment to establish parity of forces in the CZ:

$$W = \sum_{i=1}^{N} \sum_{j=1}^{n_i} w_{ij} z_{ij}.$$

Risks of production and supply of weapons in wartime to establish military parity of forces in CZ:

$$R = \sum_{i=1}^{N} \sum_{j=1}^{n_i} r_{ij} z_{ij}.$$

It is necessary to minimize the threat associated with lack of the required number of weapons of different types in the CZ:

$$\min V, \quad V = \sum_{i=1}^{N} \sum_{j=1}^{n_i} v_{ij} z_{ij},$$

subject to the following restrictions:

$$T \le T', \quad T = \sum_{i=1}^{N} \sum_{j=1}^{n_i} t_{ij} z_{ij},$$

$$W \le W', \quad W = \sum_{i=1}^{N} \sum_{j=1}^{n_i} w_{ij} z_{ij},$$

$$R \le R', \quad R = \sum_{i=1}^{N} \sum_{j=1}^{n_i} r_{ij} z_{ij},$$

where T', W', R' – acceptable values of the time of production and delivery of weapons, acceptable expences and risks of establishing military parity of forces in the CZ.

In the case of possible parallel deliveries of weapons and military equipment to the CZ (optimistic estimate of delivery time):

$$T = \max_{i=1}^{N} \left(\sum_{j=1}^{n_i} t_{ij} z_{ij} \right).$$

If military experts have difficulties in determining threat assessments, we will use the values $\Delta m'_{ij} = \Delta m_{ij} - m'_{ij}$ that need to be minimized in the process of planning the production and supply of weapons and military equipment in the CZ. In this case, it is necessary:

$$\min \Delta m', \quad \Delta m' = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \Delta m'_{ij} z_{ij},$$

taking into account the allowed values:

$$T \le T', \quad T = \sum_{i=1}^{N} \sum_{j=1}^{n_i} t_{ij} z_{ij},$$

$$W \le W', \quad W = \sum_{i=1}^{N} \sum_{j=1}^{n_i} w_{ij} z_{ij},$$

$$R \le R', \quad R = \sum_{i=1}^{N} \sum_{j=1}^{n_i} r_{ij} z_{ij}.$$

If for the i-th type of weapon it is possible to use not one supplier, but a group of suppliers, then it is necessary to evaluate each k-th group of possible suppliers for the j-th option of choosing suppliers of the i-th type of weapon:

$$v_{ij} = \sum_{k=1}^{l_j} v_{ijk},$$

$$t_{ij} = \sum_{k=1}^{l_j} t_{ijk},$$

$$w_{ij} = \sum_{k=1}^{l_j} w_{ijk},$$

$$r_{ij} = \sum_{k=1}^{l_j} r_{ijk},$$

where l_j – is the number of possible suppliers in the group for the j-th option of choosing possible suppliers.

Then, to assess the level of threats:

$$\min V, \quad V = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\sum_{k=1}^{l_j} v_{ijk} \right) z_{ij},$$

subject to the restrictions:

$$T \le T', \quad T = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\sum_{k=1}^{l_j} t_{ijk} \right) z_{ij},$$

$$W \le W', \quad W = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\sum_{k=1}^{l_j} w_{ijk} \right) z_{ij},$$

$$R \le R', \quad R = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\sum_{k=1}^{l_j} r_{ijk} \right) z_{ij}.$$

If difficulties arise in quantifying the military level of v_{ijk} threats, it is necessary:

$$\min \Delta m', \quad \Delta m' = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\sum_{k=1}^{l_j} \Delta m'_{ijk} \right) z_{ij},$$

subject to the restrictions:

$$T \le T', \quad T = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\sum_{k=1}^{l_j} t_{ijk} \right) z_{ij},$$

$$W \le W', \quad W = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\sum_{k=1}^{l_j} w_{ijk} \right) z_{ij},$$

$$R \le R', \quad R = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left(\sum_{k=1}^{l_j} r_{ijk} \right) z_{ij}.$$

Modeling threats in the logistics of production and supply of weapons and military equipment

In wartime, the logistics chains used for the production and supply of weapons and military equipment to the conflict zone may be disrupted by threats related to the aggressor's actions. In this case, the realization of threats leads to possible vulnerabilities in production and supply logistics, which can ultimately cause damage in the combat zone (loss of personnel, disruption of defense infrastructure, transition from offensive to defensive actions, etc.)

The chain that needs to be investigated is: threat – vulnerability – damage. Vulnerabilities, for example, may be related to the state and shortcomings of the heterogeneous transport network used to transport weapons and military equipment (moral and physical obsolescence of the transport system, a large number of bridges and interchanges, bottlenecks in the form of places of transshipment of military cargo from one transport highway to another, warehousing and temporary storage of military cargo in certain places of the transport network, transportation of ammunition that may explode due to the actions of the aggressor, violation of the requirements for dimensions and weights). In the event of a threat from the aggressor (air raids, missile attacks, long-range artillery, etc.), vulnerabilities are perturbed, which lead to damage in the combat zone.

Therefore, there is an urgent task of determining the impact of threats on the perturbation of vulnerabilities that cause damage. This affects the nature of hostilities in a military conflict zone (transition from offensive to defensive actions, retreat from previously occupied positions, etc.) To analyze the sequence: threat – vulnerabilities – losses, we will use the estimates of military experts, which are formed using a full factorial experiment (FFE).

As an example of such an analysis, consider the impact of an air raid on a section of railroad that is used to transport artillery weapons. Suppose military experts who know the specific route of the military cargo have identified three possible transportation vulnerabilities in the form of factors x_j FFE:

– cargo transshipment (x_1),

– temporary storage (x_2),

– violation of the special transportation regime (x_3).

Fig. 4 shows the FFE plan, where the rows correspond to possible vulnerabilities (no vulnerabilities – the first row (–1, –1, –1), the presence of all vulnerabilities – the last row of the plan (+1, +1, +1)).

	x_1	x_2	x_3	y
1	–1	–1	–1	0
2	–1	–1	+1	5
3	–1	+1	–1	3
4	–1	+1	+1	8
5	+1	–1	–1	2
6	+1	–1	+1	7
7	+1	+1	–1	5
8	+1	+1	+1	10

Fig. 4. FFE plan for loss assessment

The right column of the FFE plan contains military experts' estimates of the levels of damage that would result from the vulnerabilities due to an air attack (for example, on a 10-point scale). The FFE plan can be used to build a regression relationship that allows you to estimate the impact of individual factors (vulnerabilities) on damage, provided that the vulnerabilities are perturbed in the event of a threat (air raid):

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_2 + b_{23}x_2x_3 + b_{123}x_1x_2x_3,$$

where b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23}, b_{123} – coefficients associated with the impact of factors x_1, x_2, x_3 on the value of the loss (y). We are interested in the linear part of the regression relationship, which is related to the impact of individual factors (vulnerabilities) on the amount of loss. After simple calculations, we have:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 = 5 + x_1 + 1{,}5x_2 + 2{,}5x_3.$$

The dependence obtained in the illustrated example with a virtual experiment indicates the influence of three factors (vulnerabilities).

1. According to experts, the most important vulnerability that is triggered during an air raid is the violation of the special regime during the transportation of military cargo $(b_3 = 2,5)$.

2. Less important is the vulnerability associated with the temporary storage of military cargo $(b_2 = 1,5)$.

3. In terms of damage caused, the smallest vulnerability in an air raid is the one associated with the transshipment of military cargo $(b_1 = 1)$.

A method of increasing the effectiveness of the use of weapons by creating asymmetry in the military parity of forces in the combat zone

Military parity of forces is most often associated with the use of approximately the same types of weapons by adversaries in the combat zone. The emergence of new types of weapons and military equipment makes it possible to use more effective weapons in the conflict zone that far exceed the combat characteristics of their analogues (for example, the use of modern HIMARS MLRS for rocket and artillery weapons with increased range and accuracy of impact). Therefore, by creating an asymmetry in the quality and quantity of weapons for different types of weapons, it is possible to increase the overall effectiveness of the use of weapons in the CZ (quality over quantity). Therefore, it is important to develop a method to increase the effectiveness of the use of weapons in the combat zone, which contributes to the creation of asymmetry by type in the military parity of forces. Due to the multivariate nature of establishing asymmetry in military parity of forces, we will use the method of integer (Boolean) programming as a mathematical tool to solve the problem.

Let x_{ijk} be a Boolean variable with the following values:

$$x_{ijk} = \begin{cases} x_{ijk} = 1, \textit{ if the j-th type of weapon} \\ \qquad \textit{and its k-th supplier are selected for the i-th type of weapon;} \\ x_{ijk} = 0, \textit{ otherwise}. \end{cases}$$

Then, military specialists (experts) determine the effectiveness q_{ij} of its use in the combat zone for each type of weapon. Then, for each i-th type of weapon, the effectiveness of its use is as follows:

$$Q_i = \sum_{j=1}^{n_i} \sum_{k=1}^{p_j} q_{ij} m_{ijk} x_{ijk},$$

where m_{ijk} – is the number of weapons that can be developed by the k-th supplier of the j-th kind for the i-th type of weapon;

p_j – is the number of possible suppliers of the j-th type of weapon.

Then the total efficiency of the use of all types of weapons in the combat zone

$$Q = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{k=1}^{p_j} q_{ij} m_{ijk} x_{ijk},$$

where N – number of types of weapons.

To ensure the success of combat operations in the conflict zone, it is necessary

$$\max Q, \quad Q = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{k=1}^{p_j} q_{ij} m_{ijk} x_{ijk},$$

subject to restrictions:

$$T \leq T', \quad T = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{k=1}^{p_j} t_{ijk} m_{ijk} x_{ijk},$$

where T – time expences associated with the production and supply of weapons to the combat zone;

T' – the time allowed for the production and delivery of weapons to the conflict zone;

t_{ijk} – is the time spent on the production and delivery of one sample of weapons of the i-th kind, j-th type by the k-th supplier.

$$W \leq W', \quad W = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{k=1}^{p_j} w_{ijk} m_{ijk} x_{ijk},$$

where W – expenses for the production and supply of weapons to the combat zone;

W' – acceptable expenses;

w_{ijk} – are the expenses associated with the production and supply of one sample of weapons of the i-th kind, j-th type by the k-th arms supplier.

$$R \leq R', \quad R = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \sum_{k=1}^{p_j} r_{ijk} m_{ijk} x_{ijk},$$

where R – risks associated with the production and supply of weapons to the combat zone;

R' – acceptable risks,

r_{ijk} – is the risk associated with the production and supply of one sample of weapons of the i-th kind, j-th type by the k-th supplier.

In this case, the following conditions must be met:

$$\sum_{k=1}^{p_j} x_{ijk} = 1,$$

which means the mandatory selection of a supplier for the i -th kind, j -th type of weapon.

An agent-based simulation model for studying the logistics of weapons supply to establish military parity of forces

In order to calculate the time to create military parity of forces in the face of threats, a model has been created that allows simulating the logistics of military cargo transportation (applications in the simulation model), taking into account the emergence of threats and vulnerabilities, which leads to a possible stoppage of cargo movement to the combat zone. The agent-based model was created using the Any Logic simulation environment, taking into account the main events that occur during the transportation of military cargo. The transportation network for the supply of military cargo is represented as a graph G, in which the vertices are transport nodes and the edges are sections of the transportation highway. Possible transshipment and temporary storage of cargoes are considered in the form of corresponding modeling agents. The main agents in this simulation model for studying the logistics of military cargo supply to establish military parity of forces in the conflict zone are:

1) the agent describing the transportation network;
2) agent generating requests (military cargo);
3) agent of threats emergence;
4) agent of vulnerability perturbation;
5) agent for the route formation for the transportation of military cargo;
6) agent of transport hubs;
7) agent of the transportation highway sections;
8) agent of temporary storage (warehousing) of military cargo
9) transshipment agent
10) agent of time delays of military cargo (due to vulnerability perturbations);
11) risk agent
12) combat zone agent;
13) simulation control agent;
14) simulation results agent.

Fig. 5 shows a block diagram of the agent-based model.

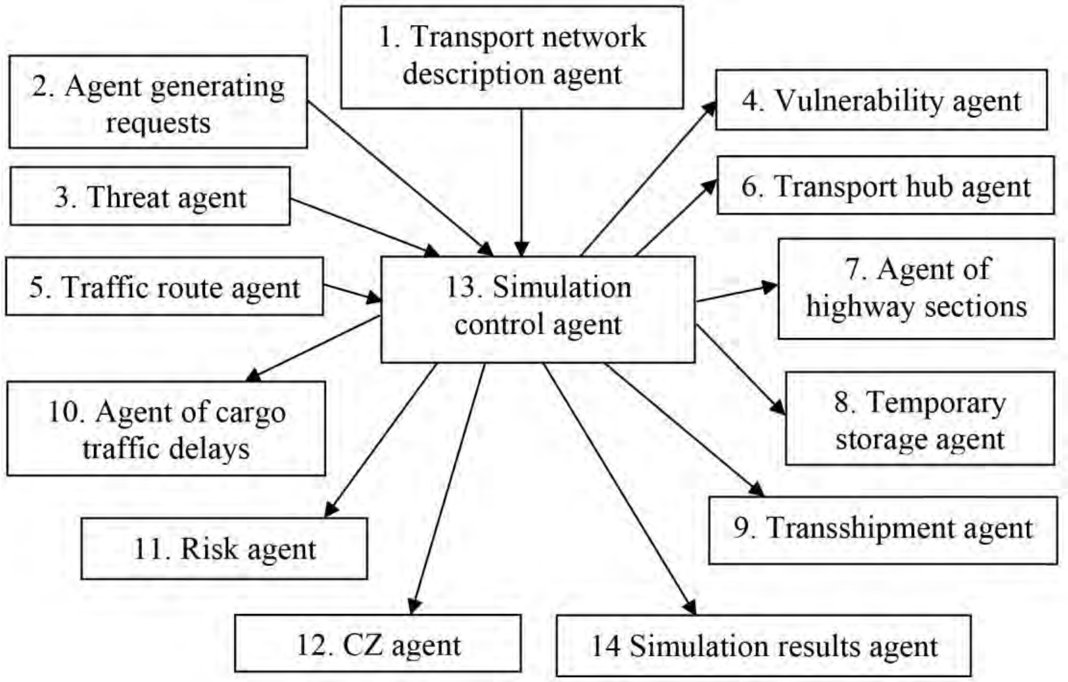

Fig. 5. Block diagram of the agent model

Let us briefly describe the simulation modeling algorithm. With the help of military experts, a transport network (or a fragment of it) is set to be used for the transportation of military cargo to the CZ in the form of sets of transport nodes and sections of a heterogeneous transport network (transport network description agent). Next, the time of the start of the military cargo movement along the transportation highway is set (agent – request generator). Then, with the help of the cargo route agent, the request (military cargo) is transported along the transport nodes and sections of the highway with the involvement of the transport node agent and the highway section agent. During the movement of the application (military cargo), vulnerabilities may be disturbed (vulnerability disturbance agent) due to the occurrence of threats (threat agent). This leads to a temporary delay in the application (military cargo) for a period related to the nature of the threat and the disturbed vulnerability. After the request (military cargo) arrives in the combat zone (CZ agent), the simulation is stopped and the results are displayed (simulation results agent) in the form of

– time of receipt of applications (military cargo) in the CZ;

– time spent on the transportation of military cargo along a given route (without perturbation / with perturbation of vulnerabilities);

– total time delays of military cargo;

– violation of the terms of delivery of military cargo to the CZ;

– time spent on transshipment;

– time spent on temporary storage (warehousing) of military cargo.

An algorithm for finding a route with the shortest possible time for the transportation of military cargo to the Czech Republic was developed. Subject to the availability of risk assessments proposed by military experts, an algorithm for the formation of accumulated risk in supply logistics in the CZ (risk agent) was developed.

The research conducted in the unit is related to the modeling of threats in the logistics process of forming military parity of forces in the combat zone. The identified shortcomings of existing methods that consider certain aspects of the process of establishing military parity do not allow a comprehensive solution to the problem. The author analyzes the threat factors associated with the lack of military parity of forces in the zone of military conflict. Military experts have evaluated various types of weapons to determine their impact on the balance of military forces in the CZ. Given the large number of possible options for choosing suppliers of weapons and military equipment, the method of integer (Boolean) programming is used. The following criteria are used to evaluate suppliers of weapons and military equipment: time, expencess and risks of production and supply. The article examines the sequence: threats – vulnerabilities – losses, which is associated with the emergence of threats in the logistics of production and supply of weapons and military equipment to establish military parity of forces in the conflict zone. It is found out how the emergence of the threat affects the perturbation of vulnerabilities in the logistics of production and supply of military equipment, which causes damage in the combat zone (deaths of personnel, disruption of defense infrastructure, transition from offensive to defensive actions, etc.) A method of increasing the efficiency of the use of weapons by means of modern types of weapons has been developed, which makes it possible to successfully achieve the goals of a combat operation in a conflict zone by creating an asymmetry in military parity of forces. An agent-based simulation model has been developed to study the logistics process of creating military parity of forces in a military conflict zone.

The proposed approach allows, when planning the objectives of a military operation, to formulate requirements for the production and supply of weapons and military equipment to establish military parity of forces in the combat zone, which contributes to the success of the military operation.

Modeling the logistics of high-tech weapons supply and military training

The subsection solves the problem of modeling logistics activities related to various military equipment and weapons entering the zone of military conflict. The relevance of the study is related to a comprehensive solution to the problem of logistics supply and the acquisition of skills in the use of modern weapons by the military to establish parity of forces in a military conflict zone. The purpose of the study is to create a method and models that allow analyzing the training of military personnel, the supply of weapons, ammunition and spare parts to the zone of military conflict for the successful achievement of the objectives of a military operation.

Establishing military parity of forces in a combat zone requires the use of various types of weapons supplied by manufacturers from different countries. This causes significant logistical difficulties and leads to problems related to the effective use of different types and types of weapons in a military conflict zone. The analysis conducted by military experts on the use of modern military equipment has revealed a number of problems that are not sufficiently covered in publications on this topic.

1. Small batches of various weapons coming from different suppliers to the area of military conflict. The available works do not consider the sources of supply of various types of military equipment [11].

2. Differences in ammunition coming from different suppliers that can be used only for specific types of weapons. Publications do not address this issue in detail [12].

3. Insufficient number of spare parts and repair kits that are supplied separately from the weapon. This problem is not addressed in published works [13].

4. Difficulties related to the repair of military equipment and routine maintenance in the area of military conflict. The removal of military equipment repair bases has not been given due attention in the current literature [14].

5. The need to conduct training of the military in a short time to acquire knowledge of the use of various types and types of new weapons. The problem of accelerated training of the military in a short time in the face of military threats is not considered in existing publications [15].

6. The problem associated with long logistics chains of supply of weapons and military equipment under martial law threats, through a heterogeneous transportation network with transshipment, temporary storage and warehousing of military cargo. Existing publications do not pay due attention to the supply of military equipment in the context of a heterogeneous transportation network and military threats [16].

An analysis of the literature on this topic has shown that there is no systematic study of the logistics problem of supplying military equipment to a military conflict zone. Insufficient attention is paid to the impact of military threats on logistics chains with critical vulnerabilities of transportation systems. The papers do not consider the modeling of military competencies necessary to acquire skills in the use of various modern weapons.

Hence the relevance of the topic of the proposed work, which models a set of logistics activities related to the supply, acquisition of skills and use of various types of modern weapons by the military in the combat zone.

There is a contradiction between the need to establish military parity of forces in the CZ through the use of modern weapons and the ineffectiveness of existing methods for studying the logistics processes of supplying, mastering, and using weapons in the combat zone. This problem is addressed in this paper [17].

In accordance with the aim of the study, the following tasks need to be solved:

1) to analyze the supply of various weapons from different manufacturers to the military conflict zone;

2) to create an optimization model for justifying and selecting suppliers of military equipment;

3) to develop a simulation model to study the logistics supply chains of military equipment;

4) to form a set of military competencies necessary for the use of new weapons systems;

5) to provide an example of choosing the composition of competencies for the use of a new combat system.

Analysis of the supply of various weapons to the military conflict zone

Let's form a systematic representation of the logistics processes associated with the supply of various types and types of weapons to a military conflict zone to establish military parity of forces.

Figure 6 shows a diagram of the logistics process of supply, which contains the main components of weapons:

– weapons

– ammunition

– spare parts.

Suppliers of different types and kinds of military equipment may be located in different countries and at a long distance from the conflict zone. An example is the geography of suppliers of various artillery weapons: M777 towed howitzers (USA, Austria, Canada), self-propelled howitzers (Caesar (France), Panzerhaubitze (Germany), M109 (USA), ANS Krab (Poland)).

Spare parts suppliers have limited capacity to produce and supply (small batches) for the needs of the frontline.

Ammunition is not always interchangeable, so it can only be used for specific types of weapons. For example, different calibers of 102, 122, 105, 152, 155.

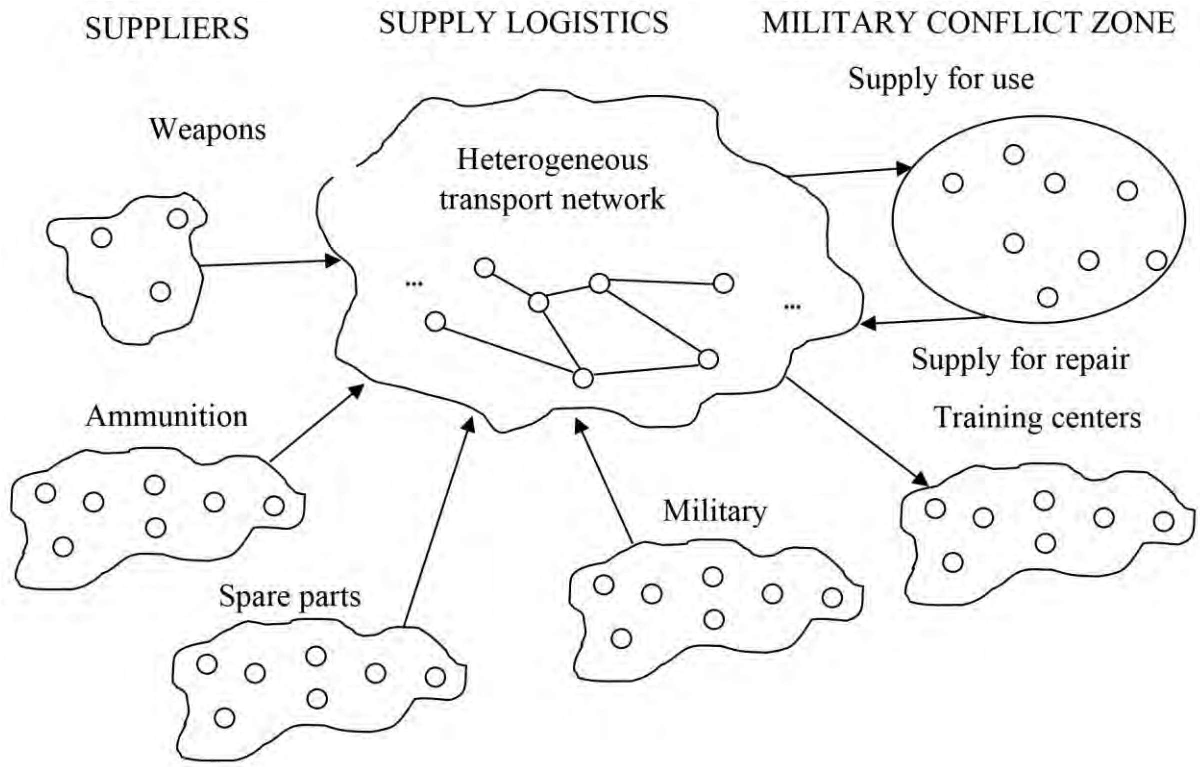

Fig. 6. Logistics scheme for the supply of weapons and military equipment

Spare parts and repair kits are not always supplied in the required quantity with weapons and military equipment. The lack of spare parts can lead to the failure of weapons in the conflict zone. To repair military equipment, it must be sent to the manufacturer.

Supply logistics is carried out in long logistics chains of a heterogeneous transportation network (air, rail, road, sea), which leads to transshipment from one transportation route to another, as well as temporary storage of military cargo.

This nature of the logistics of supplying weapons, spare parts, and ammunition to the combat zone results in

– long and complicated logistics supply chains;

– detentions during movement across state borders, as well as when changing from one mode of transportation to another;

– detentions related to the temporary storage of weapons and military equipment;

– threats to the transportation of military cargo related to the actions of the aggressor;

– the need to assess the risks that arise in elements of a long logistics supply chain in wartime. In the event of damage and failure of weapons, there are difficulties in repairing them, which requires specialists who are not available in the combat zone. Therefore, it is necessary to transport damaged military equipment to manufacturers located at a great distance from the military conflict zone.

In addition to the logistical problems of supplying weapons and military equipment, there is the task of acquiring skills in the use of new types and types of weapons in wartime. The solution to this problem is to accelerate the training of personnel in training centers. In the course of such activities, it is necessary to add new, special competencies related to modern types and types of weapons to the basic competencies of the military. At the same time, it is necessary to carry out logistical actions related to the transportation of military personnel to training centers in the face of wartime threats.

A systematic presentation of logistics activities related to the supply of weapons and preparation of the military for their use has been formed. This is the basis for solving the tasks of our study.

Optimization model for selecting military equipment suppliers

The formation of a plurality of suppliers of weapons, ammunition and spare parts to create military parity of forces in the conflict zone requires an analysis of the capacity of each supplier and consideration of logistics activities related to the transportation of military cargo in wartime.

To assess the capacity of producers, it is necessary to take into account the formation of groups of suppliers of a particular type and type of weapon, since one supplier cannot deliver the required quantity of weapons due to production limitations and financial conditions related to new defense orders. Formation of a set of possible composition of a group of suppliers for the i-th kind and j-th type of weapon is a combinatorial problem of searching for options, taking into account the limited capabilities of each manufacturer.

Suppose, for example, that military specialists (experts), after analyzing manufacturers for the i-th kind and j-th type of weapon, have identified three possible suppliers. Then the number of possible variants of the composition of suppliers in their group for $n=3$ will be $K=2^n-1=7$. For $n=3$, all variants of the composition of arms suppliers within their group can be represented as values of a binary counter:

1. 001
2. 010
3. 011
4. 100
5. 101
6. 110
7. 111

where 1 corresponds to the involvement of the manufacturer in the group of suppliers; 0 – no involvement.

Here, option 1 corresponds to the involvement of only one (third) possible arms supplier in the group of suppliers, option 3 – to the involvement of the second and third suppliers, option 7 – to the involvement of all arms suppliers.

Let's introduce an integer (boolean) variable x_{ijk} that takes the following values:

$$x_{ijk} = \begin{cases} x_{ijk} = 1, \ \textit{if the j-th type of weapon} \\ \qquad \textit{and its k-th supplier are selected for the i-th type of weapon;} \\ x_{ijk} = 0, \ \textit{otherwise}. \end{cases}$$

where $\sum\limits_{k=1}^{P_j} x_{ijk} = 1$, which means the mandatory selection of a specific group of suppliers for the i-th kind and j-th type of weapon, P_j is the number of possible options for suppliers of the j-th type of weapon.

Let's introduce the following indicators to assess the options for the composition of the supplier group:

N – the number of weapons to be sent to the zone of military conflict:

$$N = \sum_{i=1}^{M} \sum_{j=1}^{m_i} n_{ij},$$

where n_{ij} – is the number of weapons of the i-th kind and j-th type to be used in the CZ;

m_i – number of types of weapons of the i-th type;

M – the number of types of weapons to be used in the zone of military conflict.

Taking into account the variable x_{ijk}, we obtain

$$n_{ij} = \sum_{k=1}^{P_j} n_{ijk} x_{ijk},$$

where n_{ijk} – is the number of weapons of the i-th kind and j-th type to be supplied by the k-th variant of the composition of the group of suppliers;

T – time spent on the production and logistics of transportation of weapons to the zone of military conflict:

$$T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} t_{ij},$$

where $t_{ijk} = t'_{ijk} + t''_{ijk}$;

t_{ijk} – time expenses associated with the production and logistics of supply of the k-th variant of the warehouse of the group of producers of the i-th kind and j-th type of weapons;

t'_{ijk} – time for the production of a batch of weapons of the i-th kind and j-th type by the k-th manufacturer's warehouse;

t''_{ijk} – time spent on the logistics of transportation of a batch of weapons of the i-th kind and j-th type by the k-th manufacturer's warehouse.

Taking into account x_{ijk}

$$t_{ij} = \sum_{k=1}^{P_j} \left(t'_{ijk} + t''_{ijk} \right) x_{ijk}.$$

W – expenses for the production and supply of weapons:

$$W = \sum_{i=1}^{M} \sum_{j=1}^{m_i} w_{ij},$$

where w_{ijk} – expences of production and logistics of supplying weapons of the i-th kind and j-th type for the k-th variant of the supplier's warehouse:

$$w_{ijk} = w'_{ijk} + w''_{ijk},$$

where w'_{ijk} – expences of production of weapons of the i-th kind and j-th type for the k-th variant of the supplier warehouse;

w''_{ijk} – are the logistics expenses for the supply of weapons of the i-th kind and j-th type for the k-th variant of the supplier's warehouse.

Then, taking into account x_{ijk}

$$w_{ij} = \sum_{k=1}^{P_j} \left(w'_{ijk} + w''_{ijk} \right) x_{ijk}.$$

R – risks of production and supply of weapons to the military conflict zone:

$$R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} r_{ij},$$

where r_{ijk} – risks of supplying the k-th variant of the warehouse of suppliers of the i-th kind and j-th type of weapons:

$$r_{ijk} = r'_{ijk} + r''_{ijk},$$

where r'_{ijk} – production risks of the i-th kind and j-th type for the k-th variant of the supplier's warehouse;

r''_{ijk} – logistics risks of supply of the i-th kind and j-th type for the k-th variant of the supplier's warehouse:

$$r_{ij} = \sum_{k=1}^{P_j} \left(r'_{ijk} + r''_{ijk} \right) x_{ijk}.$$

Taking into account all kinds and types of weapons that will be sent to the area of military conflict, we will get the following presentation of indicators for evaluating possible suppliers:

$$N = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} n_{ijk} x_{ijk},$$

$$T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(t'_{ijk} + t''_{ijk} \right) x_{ijk},$$

$$W = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(w'_{ijk} + w''_{ijk} \right) x_{ijk},$$

$$R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(r'_{ijk} + r''_{ijk} \right) x_{ijk}.$$

To ensure military parity of forces in a military conflict zone, it is necessary to

$$\max N, \quad N = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} n_{ijk} x_{ijk},$$

taking into account the following restrictions:

$$T \le T', \quad T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(t'_{ijk} + t''_{ijk} \right) x_{ijk},$$

$$W \le W', \quad W = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(w'_{ijk} + w''_{ijk} \right) x_{ijk},$$

$$R \le R', \quad R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(r'_{ijk} + r''_{ijk} \right) x_{ijk},$$

where T' – the time allowed for the production and logistics of arms supply to the area of military conflict;

W' – acceptable expences associated with the production and logistics of supplying weapons to the combat zone;

R' – acceptable risks associated with the production and logistics of arms supply in CZ.

It is known that new weapons (e.g. HIMARS), due to their tactical and technical characteristics (range, accuracy, etc.), can affect the effectiveness of their use in a military conflict zone by creating an asymmetry of military parity of forces (superiority of quality over quantity).

Therefore, it is necessary to take into account the combat capability of each type of weapon on the battlefield.

Let military specialists (experts) estimate the combat effectiveness e_{ij} of each sample of the i-th kind and j-th type of weapon.

Then, for all weapons that will be sent to the CZ, the combat capability is represented as:

$$E = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} n_{ijk} e_{ij} x_{ijk}.$$

To successfully achieve the objectives of a military operation in a conflict zone, it is necessary to

$$\max E, \quad E = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} n_{ijk} e_{ij} x_{ijk},$$

taking into account the restrictions:

$$T \le T', \quad T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(t'_{ijk} + t''_{ijk} \right) x_{ijk},$$

$$W \le W', \quad W = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(w'_{ijk} + w''_{ijk} \right) x_{ijk},$$

$$R \le R', \quad R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{P_j} \left(r'_{ijk} + r''_{ijk} \right) x_{ijk},$$

Note that the estimates for e_{ij}, t'_{ijk}, t''_{ijk}, w'_{ijk}, w''_{ijk}, r'_{ijk}, r''_{ijk} should be submitted by military experts for all types and types of weapons in advance in order to solve the optimisation problem.

A simulation model for studying the logistics supply chains of military equipment in a military conflict zone

To study the dynamic processes in the logistics of supplying weapons, ammunition and spare parts to a military conflict zone, a simulation model has been created that allows to form supply routes under the risks of war, estimate the time required for the transportation of military cargo, and predict the risks arising from the threats of martial law.

Supply routes are formed by military logistics specialists. If it is necessary to optimise delivery time or risks, an algorithm is created to minimise delivery time in a heterogeneous transport network and to form a rational route taking into account wartime risks. For modelling, the Any Logic system was used to create an agent-based simulation model. This model contains the following agents (Fig. 7):

1) agent "formation of the structure of the transport network" (transport hubs and sections of the transport highway);
2) agent "arms supplier"
3) agent "transport hub";
4) agent "section of the transport highway" (TH);
5) agent "time delay"
6) agent "time limit"
7) agent "temporary storage";
8) agent "time stop";
9) agent "combat zone" (CZ);
10) agent "threat";
11) agent "vulnerability"
12) agent "destruction of military munitions";
13) agent "risks"
14) "risk restriction" agent
15) agent "delivery route";
16) agent "optimisation of delivery time";
17) "delivery risk optimisation" agent;

18) simulation control agent;
19) simulation results agent.

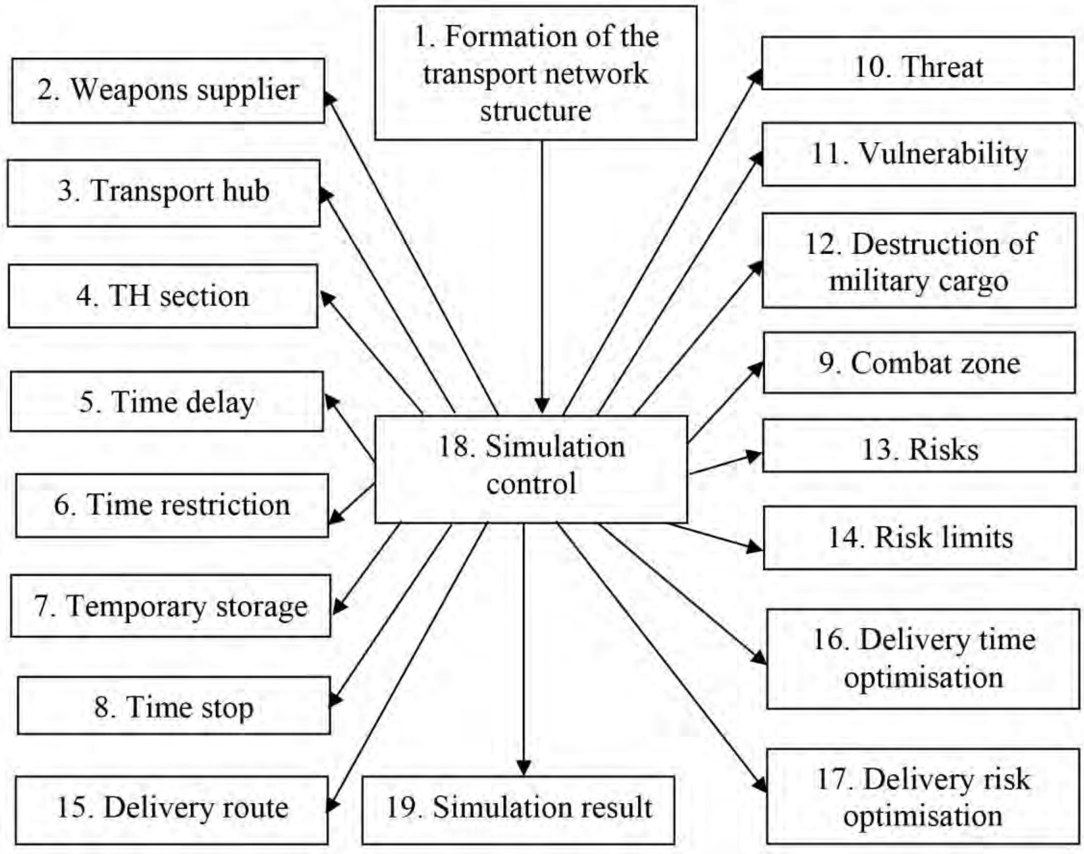

Fig. 7. Block diagram of the agent-based model

Let us briefly describe the modelling algorithm.

First, the transport network is set up using the "transport network structure formation" agent. Then, to simulate the supply route, the supply route agent sets the required route. The "supply of weapons" agent forms a batch of military cargo with weapons in the form of a request in the simulation. The next step is to create a sequence of requests through transport hubs (the "transport hub" agent) and sections of the transport network (the "transport highway section" agent) in accordance with the specified supply route, taking into account delays (the "time delay" agent), as well as stops (the "time stop" agent) and the required time for storage (the "temporary storage" agent). In the process of transporting military cargo, logistics risks are accumulated using the "risks" agent. The "threat" agent is used to study the impact of threats on the logistics of military cargo supply. The occurrence of a threat leads to a perturbation of a critical vulnerability (the "vulnerability" agent), which is associated with critical nodes and sections of the transport route, causing temporary stops of military cargo (the "temporary stop" agent), as well as possible destruction of cargo (the "destruction of military cargo" agent). To solve the optimisation problems of routing in a heterogeneous transport network, the developed route optimisation algorithms are used, which are used to:

1) search for the minimum time route in terms of wartime risks;

2) searching for the minimum risk route in terms of delivery time constraints.

In order to find the minimum time route with due regard to risks, the developed optimisation algorithm observes "waves" of orders and their clones that are formed in the transport nodes of the supply network. When developing a route that minimises the risk of delivery, the main factor taken into account is the risk of delivery. The algorithms for optimising supply routes use the delivery time optimisation and delivery risk optimisation agents, taking into account the constraints set by the time constraint and risk constraint agents.

The modelling results agent generates the following research results:

1) time of movement of military cargo (consignment of weapons) for a given delivery route to the CZ;

2) time of delay of the military cargo in terms of delivery to the conflict zone;

3) accumulated logistical risks of military cargo delivery;

4) the time-optimal route for the supply of weapons;

5) the optimal route for the delivery of military cargo in terms of risk;

6) the term of delivery of cargo to the CZ in the event of a threat;

7) military munitions that have been delayed due to threats;

8) military munitions that were destroyed due to threats.

Formation of a set of military competences for the use of new weapons systems

In order to successfully achieve the objectives of a military operation in a combat zone, it is necessary to form a set of weapons that surpasses the enemy's weapons in terms of their combat capability through the use of modern combat systems (e.g., HIMARS MLRS). This can lead to asymmetry and the advantage of forces in military parity in the zone of military conflict (quality over quantity). The use of new high-tech weapon systems requires the acquisition of new competencies in the military. A structural representation of the competences associated with the use of a new type of weapon is shown in Fig. 8. Here, the basic competences are associated with known types of military equipment and are components of the set of competences inherent in personnel. Special new competences arise in the process of using modern weapons. Acquiring new competences requires training in special training centres to acquire new knowledge (K), develop new skills (S) and strengthen their abilities (A). The training centres are located far from the combat zone, which requires transporting military personnel, especially in the face of military threats. Training centres need to develop new knowledge in a short time by using modern teaching methods (automated training systems, simulators, practical training at special training grounds, etc.). Given the martial law and active hostilities in the conflict zone, it is necessary to reduce the training time for the military to train on new weapons systems and minimise the risks of martial law.

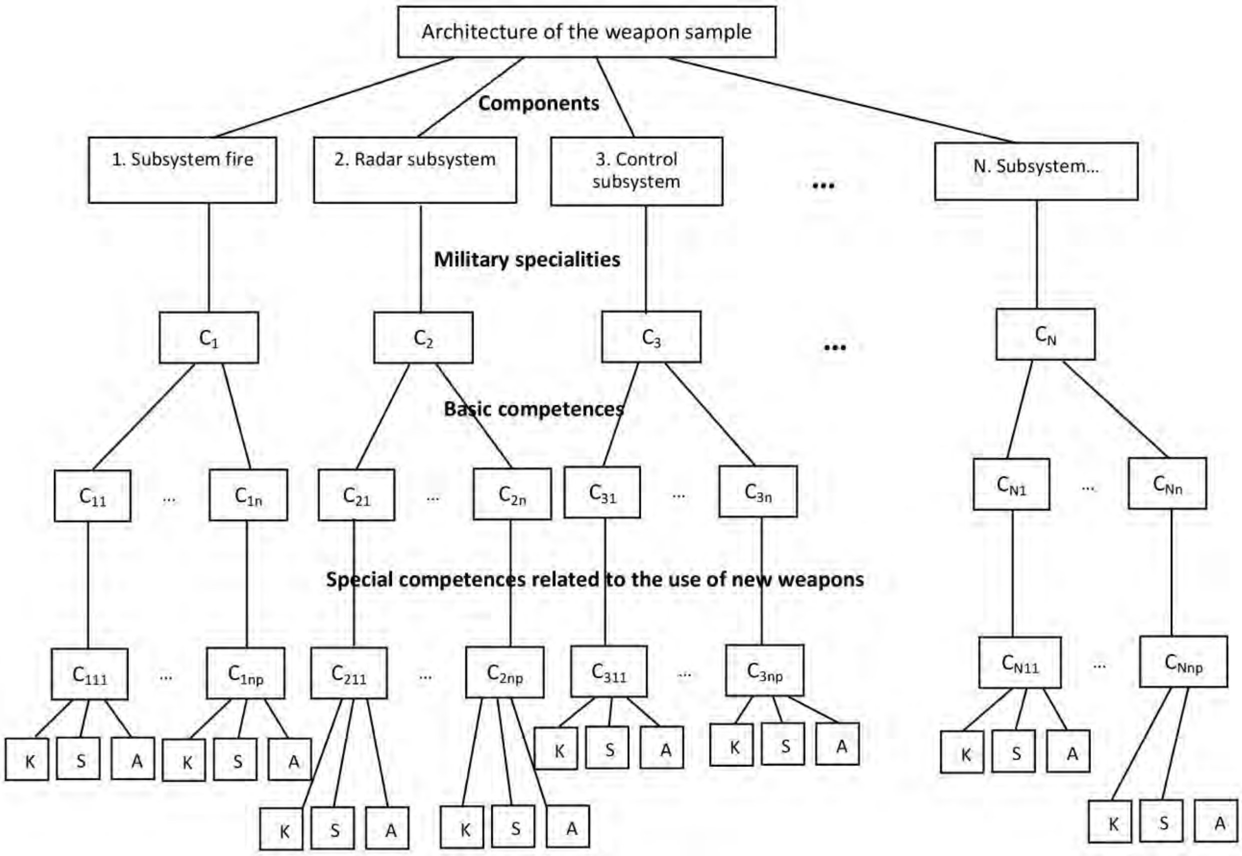

Fig. 8. Structure of competences required by the military to use new weapons

Suppose that there is a gap Δ_{ijk} in the knowledge of the military and the competences required to use modern weapons. It is important to eliminate this difference during the training of the military. It is necessary to choose the right set of competences that will provide effective training. We will measure Δ_{ijk} for the i-th kind of the j-th type of the possible k-th competence composition using military experts' estimates. For example, $\Delta_{ijk} = 0$ means there is no difference between competences, and $\Delta_{ijk} = 10$ (in points) corresponds to a complete mismatch of competences (new competences that the military did not have before). Suppose that military experts believe that after the training, there will be a difference in competences $\Delta'_{ijk} \le \Delta_{ijk}, \Delta'_{ijk} \to 0$, for all i, j, k. Let's introduce an integer (Boolean) variable x_{ijk}, the value of which $x_{ijk} = 1$ means that for the k-th competence set, training is required to master a new type of weapon of the i-th kind of the j-th type. And for $x_{ijk} = 0$, no training is required, because such a composition will not be used or the military knows it.

As the target optimisation function, we will use the total number of points Q, which must be minimised in the process of selecting a possible composition of competences for the acquisition of military skills in the use of new types of weapons. Taking into account all types and types of weapons that will be used in a military conflict zone, we will get:

$$Q = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} \Delta'_{ijk} x_{ijk},$$

where s_j – is the number of possible variants of the composition of competences, from which one must be selected to acquire knowledge of using a new weapon of the j-th type of the i-th kind;

m_i – the number of types of the i-th kind of weapon;

M – number of types of weapons used in the area of military conflict. In this case, $\sum_{k=1}^{s_j} x_{ijk} = 1$, which means that it is mandatory to choose one k-th variant of the competence composition for training in the acquisition of the i-th kind of j-th type of weapon.

In the process of training the military, it is necessary to minimise the total difference in competences:

$$\min Q, \quad Q = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} \Delta'_{ijk} x_{ijk}.$$

When optimising Q, it is necessary to take into account the constraints on training time – T, then on wartime risks – R, and then on the expenses of training centres during training – W:

$$T \le T', \quad T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} t_{ijk} x_{ijk},$$

$$R \le R', \quad R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} r_{ijk} x_{ijk},$$

$$W \le W', \quad W = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} w_{ijk} x_{ijk},$$

where t_{ijk} – is the time to prepare the k-th possible set of competences for studying a new type of weapon of the i-th kind of the j-th type;

r_{ijk} – is the risk of preparing to acquire the k-th set of competences for a new weapon of the i-th kind of the j-th type;

w_{ijk} – is the expence of training the military and acquiring the k-th set of competences to use a new type of weapon of the i-th kind of the j-th type;

T', R', W' – acceptable time, risks and expenses for military training.

If, due to the needs of martial law, it is important to conduct accelerated training of the military, then it is necessary

$$\min T, \quad T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} t_{ijk} x_{ijk},$$

taking into account the restrictions:

$$Q \le Q', \quad Q = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} \Delta'_{ijk} x_{ijk},$$

$$R \le R', \quad R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} r_{ijk} x_{ijk},$$

$$W \le W', \quad W = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} w_{ijk} x_{ijk},$$

where Q' – the permissible difference in the competencies required to use new weapon systems and the competencies that military personnel will acquire through training in training centres.

The logistical task of delivering military personnel to training centres under wartime threats is solved by using the developed method of agent-based simulation modelling.

When studying and using new weapons by the military, we will pay attention primarily to the combat capability of types and types of weapons, which will further increase the effectiveness of weapons in a military conflict zone. In this case, in the formulation of the optimisation problem of military training, it is necessary to take into account the combat effectiveness e_{ij} of each sample of the i-th kind of the j-th type of weapon. At the same time, it is necessary to normalise the value of combat capability e_{ij}:

$$e'_{ij} = \frac{e_{ij}}{\sum_{i=1}^{M} \sum_{j=1}^{m_i} e_{ij}}, \qquad \sum_{i=1}^{M} \sum_{j=1}^{m_i} e'_{ij} = 1.$$

We will use e'_{ij} as a value indicating the need to train the military primarily in the use of the most effective modern weapons. Therefore, taking into account the combat capability of weapons, the following should be included in the training of the military

$$\min Q = \sum_{i=1}^{M} \sum_{j=1}^{m_i} e'_{ij} \left(\sum_{k=1}^{s_j} \Delta'_{ijk} x_{ijk} \right),$$

following the restriction:

$$T \le T', \quad T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} t_{ijk} x_{ijk},$$

$$R \le R', \quad R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} r_{ijk} x_{ijk},$$

$$W \le W', \quad W = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{s_j} w_{ijk} x_{ijk}.$$

An example of selecting the content of competences for the use of a new combat system

Let's consider an illustrated example of the military training for the use of a new multiple launch rocket system (HIMARS) under martial law.

A modern MLRS consists of three main subsystems:

– control

– radar;

– fire.

To use each of the subsystems, it is necessary to train military personnel of the relevant specialities. In particular, it is about acquiring new competencies in the use of modern MLRS. For the convenience and simplicity of comparing possible variants of the competencies required for training the military, we will use qualitative assessments in the form of values of linguistic variables: training time – x_1, risks associated with the logistics of training the military – x_2 and expenses required for the operation of the military training centre – x_3:

$$x_1 = \begin{cases} A - \textit{minimum training time;} \\ B - \textit{satisfactory training time;} \\ C - \textit{acceptable training time;} \\ D - \textit{maximum training time.} \end{cases}$$

$$x_2 = \begin{cases} A - \textit{minimum training risk;} \\ B - \textit{satisfactory training risk;} \\ C - \textit{acceptable training risk;} \\ D - \textit{maximum training risk.} \end{cases}$$

$$x_3 = \begin{cases} A - \textit{minimum expences} \\ B - \textit{satisfactory expences;} \\ C - \textit{acceptable expences;} \\ D - \textit{maximum expences.} \end{cases}$$

The difference in competences will be estimated as a percentage.

There are three main types of competences that military personnel need to acquire to use the new MLRS in the form of knowledge, skills and abilities:

1) basic principles of subsystem operation (knowledge);

2) detailed presentation of the subsystem's combat operation (skills);

3) regulations on the use and operation of the subsystem (abilities).

Table 2 shows the assessments of military specialists (experts) on possible variants of the content of competences for the study of the main MLRS subsystems by the military.

Let us analyse the results of the experts' assessment of possible options for the content of competences to justify and select the best option necessary for military training.

When analysing the options for the content of competences for the three main MLRS subsystems, the experts excluded from consideration options 2, 4, 6 for all subsystems. This is due to the absence of the third competence in the competence structure, related to the skills of using the subsystem in combat conditions.

In addition, due to the low and unacceptable D scores in some variants of the competence composition, the experts excluded the following variants of the competence content from further consideration:

– in the management subsystem

Option 3 due to unacceptable values of expenses (D);

Option 7 due to unacceptable values of time (D) and risks (D);

– in the radar subsystem:

Option 3 due to long training time (D);

Option 7 due to unacceptable values of time (D) and training risks (D);

– in the fire control subsystem:

Option 3 due to unacceptable values of training time (D);

Option 7 due to unacceptable values of time (D), risks (D) and training expenses (D).

Table 2

Evaluation of options for the content of competences for military training

Subsystems	Variants	Competences			Difference in competencies (%)	Training time	Training risks	Training expences
		1	2	3				
1. Control	1	–	–	+	35	A	A	A
	2	–	+	–	–			
	3	–	+	+	20	C	B	D
	4	+	–	–	–			
	5	+	–	+	25	B	B	C
	6	+	+	–	–			
	7	+	+	+	10	D	D	C
2. Radar	1	–	–	+	30	A	A	A
	2	–	+	–	–			
	3	–	+	+	20	D	C	B
	4	+	–	–	–			
	5	+	–	+	25	B	B	B
	6	+	+	–	–			
	7	+	+	+	10	D	D	C
3. Fire	1	–	–	+	25	A	A	A
	2	–	+	–	–			
	3	–	+	+	10	D	C	B
	4	+	–	–	–			
	5	+	–	+	15	B	B	B
	6	+	+	–	–			
	7	+	+	+	5	D	D	D

Furthermore, the experts noted a large unsatisfactory difference in competences:

1st variant of the competencies content in the control subsystem (35%),

1st variant of the competencies in the radar subsystem (30%).

These options were also removed from further consideration. As a result, the following options for the possible composition of competencies required for the military to study the main subsystems of the new MLRS remained:

5, 5, 1

5, 5, 5

These variants have the following scores (see Table 1):

5, 5, 1:
25 %, B, B, C;
25 %, B, B, B;
25 %, A, A, A.

5, 5. 5:
25 %, B, B, C;
25 %, B, B, B;
15 %, B, B, B.

Finally, variant 5, 5, 5 was chosen to prepare the military for the use of MLRS.

The study of this subsection is related to the modelling of the logistics process of supplying and studying new weapons by the military to successfully achieve the goals of a military operation in a combat zone. The problems of using various weapons were identified. A systematic representation of the logistics of weapons supply to a military conflict zone has been created, which is used in the future to solve the main tasks of the study. The issue of optimal selection of suppliers of weapons, spare parts and ammunition for combat operations is identified and resolved, taking into account the effectiveness of the use of weapons, time, expences and logistical risks. In this case, the use of several possible manufacturers of military equipment for the same kind and type of weapon is taken into account. An agent-based simulation model was created in the Any Logic environment, which takes into account the main components of the logistics process of supply: transport network, time delays, and supply routes. The article optimises the choice of a supply route in the face of threats and perturbations of critical vulnerabilities in the supply process in a heterogeneous transport network. Using a simulation agent model, a rational route for the supply of weapons and military equipment is formed, the time and expences of supply are estimated, and the impact of threats on the delivery time is taken into account. To ensure the effective use of new weapons and military equipment, the article examines the process of training military personnel using a set of competencies that must be mastered in training centres in a short time under the threats of martial law and logistical risks. An example of training the military to use modern weapons such as MLRS is presented.

The proposed approach makes it possible to plan the supply of new and diverse weapons to the area of military conflict in order to select a rational composition of military equipment manufacturers.

Modelling the formation of the necessary stocks of high-tech military equipment

The subsection solves a systemic problem related to the modelling of the logistics of stockpiling weapons and military equipment (WME) for the successful execution of combat operations. The relevance of the study is related to a comprehensive solution to the problem of stockpiling WME to meet the objectives of a military operation, taking into account the capabilities of arms suppliers, the complex logistics of transporting WME to the conflict zone and military threats. The purpose of the study is to create a set of models that allow to prioritise the types of WME in stockpiling; to formulate requirements for the volume of stocks; to choose a rational structure of logistics supply channels, taking into account the risks of military threats, which ensures the success of combat operations in the conflict zone.

The escalation of hostilities in a military conflict zone requires constant replenishment of the WME, which ensures effective combat operations against the aggressor. The current inventory theory, whose methods are used in the production of sophisticated equipment, is associated with the planned replenishment of components and raw materials to fulfil orders from high-tech enterprises and ensure the continuity of the production cycle.

Analysis of the problems of stockpiling in wartime

Under martial law, the availability of WME stockpiles is one of the key requirements for effective combat operations. The enemy's opposition to the formation of WME stockpiles (war of stockpiles) is one of the manifestations of the so-called hybrid warfare. Lack of the required amount of WME stocks can lead to deaths of military personnel, disruption of defence and engineering structures, transition from offensive to defensive actions, etc. Therefore, the requirements for the formation and replenishment of WME stocks and their size differ from the requirements for the formation of stocks in peacetime. The aggressor's actions in the process of stockpiling in a modern hybrid war, which uses the most advanced types of WME, are aimed at destroying both logistics and stockpiles (war of logistics and stockpiles).

There are a number of problems associated with the formation of stocks and management of WME supply logistics, which are covered in publications on this topic. Let us consider these problems.

1. WME stockpiles are formed by a large number of manufacturers (suppliers) that can supply weapons in small batches. This complicates the management of WME supply logistics. Publications consider the supply of WME in peacetime to form planned stockpiles in case of war, but not during hostilities [18].

2. The supply of WME to a military conflict zone involves long logistics chains in a heterogeneous transport environment, which require a lot of time for supply and stockpiling. In publications, planning and stockpiling is often considered in the process of supplying weapons by developers located at a short distance from the zone of military conflict, and therefore does not require the formation of long logistics chains [19].

3. In long logistics supply chains, the formation of WME stockpiles creates many possible vulnerabilities caused by the emergence of military threats. Publications consider logistics vulnerabilities that arise mainly in peacetime. Little attention has been paid to the study of the impact of military threats on logistical vulnerabilities in the supply of weapons to the CZ [20].

4. Under martial law, a number of supply risks arise due to military threats. This leads to a disruption in the formation of the necessary volumes of WME stocks for use in the CZ at the right time. The increase in the number and variety of risks associated with martial law has received little attention in existing publications [21].

5. In the heterogeneous environment of WME supply to the combat zone, a large number of transshipment of military cargo occurs, which leads to delays and increased time for the supply of weapons. Publications consider transshipment in peacetime, without the influence of military threats [22].

6. The formation of insurance and planned stocks in peacetime differs from the formation of WME stocks for use in the CZ during martial law. In the publications, insurance stockpiles are linked to peacetime arms production plans in accordance with the state's military doctrine. The size of the reserve stockpile of weapons in the CZ and its replenishment in wartime depends on the situation at the front and the objectives of the military operation [23].

Consequently, there is a contradiction between the requirements for successful operational and tactical actions by the military in the zone of military conflict using the available stocks of weapons, as well as their prompt replenishment, and the imperfection of existing methods of planning and managing WME stocks in wartime conditions. This requires the development of a set of models and applied information technology aimed at studying the formation and operational replenishment of WME stocks.

Therefore, it is relevant to create a set of models that will allow analysing the logistics of stockpiling, taking into account the required volume, justifying logistics supply channels in a heterogeneous transport environment in the face of threats during martial law in the country to ensure the effectiveness of combat operations and fulfil the objectives of a military operation in the CZ [24]. In accordance with the research objective, the following tasks need to be solved:

1) to analyse the priority of weapon types for the formation of military equipment stocks in the combat zone;

2) to develop an optimisation model for the formation of weapons stocks, taking into account the capabilities of manufacturers and suppliers;

3) to list the set and justify the structure of logistics supply channels for the formation of the necessary stocks of weapons;

4) to form the necessary stocks of weapons in the area of military conflict, taking into account the combat capability of individual models;

5) give an example of modelling the logistics of stockpiling weapons and military equipment, considering the risks of wartime.

Analysing the priority of weapons types in the process of forming stocks of military equipment in the combat zone

The requirements for the formation of WME stocks are linked to the plans of operational and tactical actions of the military, as well as the current situation at the front. Therefore, the nomenclature of WME, its quantity and the ability to train military specialists to use the weapon will be determined in each specific area of the front depending on the requirements for establishing military parity of forces.

Given that effective and powerful modern WME systems (e.g., HIMARS, NASAMS, etc.) can be used in a certain area of the frontline, by creating an asymmetry in military parity of forces (quality over quantity), it is possible to conduct successful combat operations with fewer weapons.

Therefore, it is important to determine the most effective models for the formation of WME stocks for successful use in a particular combat zone.

Let us use the method of planning an experiment, which allows us to determine the most effective weapons for use in the CZ by using expert (military) assessments and conducting virtual experiments.

Table 3 shows the plan of a full factorial experiment (FFE), in which the factors are the types of weapons that can be used in a zone of military conflict.

Each row of the plan represents a possible combination of weapons used.

In Table 3, "–" indicates the absence of a factor, "+" – its presence.

The total number of variants of factor composition: $N = 2^n$, where n is the number of factors.

The experts' ratings are presented in the rightmost column of the FFE (points or % can be used).

Table 3

Full factorial experiment to assess the combat effectiveness of weapons

№	Factors			Feedback (combat capability)
	x_1	x_2	x_3	
1	–	–	–	0
2	–	–	+	3
3	–	+	–	2
4	–	+	+	6
5	+	–	–	5
6	+	–	+	8
7	+	+	–	7
8	+	+	+	10

As a result of the virtual experiment, using expert assessments, a regression dependence is formed in the form $(n = 3)$:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{123} x_1 x_2 x_3 .$$

The coefficient b_j, $j = \overline{1, n}$ indicates the significance of the factor x_j. We will form a series according to the decreasing significance of the coefficient b_j. This way, we can form the most priority types of weapons that should be used in a particular CZ. For example, let the factor x1 be related to the HIMARS MLRS, x_2 to the JAVELIN anti-tank system, and x_3 to the CAESAR self-propelled artillery system.

After the experts' assessment of the possible variants of the weapons composition, the following simplified linear regression relationship can be obtained:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 = 5.1 + 2.4 x_1 + 1.1 x_2 + 1.6 x_3.$$

After analysing the obtained dependence, it can be concluded that the most important factor for use in the CZ is x_1 (HIMARS), less important is x_3 (CAESAR) and the least important is x_2 (JAVELIN).

Therefore, taking into account the priority weapons, it is necessary to build up WME stocks in the CZ.

An optimisation model of weapons stockpile formation taking into account the capabilities of manufacturers and suppliers

In peacetime, the formation of arms stocks is carried out in accordance with state defence procurement plans. To ensure successful implementation of arms production plans, stocks of components, materials and raw materials (CMRM) Z are formed in the range of:

$$Z_{\max_{\min}},$$

where $Z_{\min}$ corresponds to the CMRM safety stock, the current value of Z corresponds to the planned CMRM stock, taking into account the safety stock, and $Z_{\max}$ corresponds to the stock, the value of which is associated with minimising risks of various nature (including logistics) that may lead to possible disruptions or interruption of the production cycle.

In wartime, the formation of weapons stockpiles is carried out in the context of military threats in accordance with tactical plans and operational actions in the conflict zone. In addition, it is necessary to take into account the limited capabilities of WME suppliers (manufacturers) (small batches of manufactured weapons, long production cycle, small production stocks, etc.), which leads to difficulties in supplying the required quantity in the required time frame. In turn, this can lead to deaths of military personnel, changes in hostilities, damage to defence and engineering structures, etc. Therefore, it is important to solve the problem of forming the required level of WME stocks, taking into account the requirements for types of weapons, volumes and terms of supply. Given that for each j-th type of WME, not one supplier but a set of no suppliers can be used in the process of stockpiling, which is associated with the possibility of producing and supplying military products, the task of choosing a rational composition of suppliers to form the required level of stocks Z, where $Z_{\max_{\min}}$, arises. Here, the value of the stock $Z_{\min}$ corresponds to the insurance level of stocks in time of war, which guarantees the establishment of military parity of forces in the face of military threats. The value of the reserve $Z_{\max}$ ensures minimisation of the risks associated with military threats and creates a possible asymmetry in the military parity of forces, which contributes to the successful achievement of the objectives of the planned combat operation. The limited capabilities of arms manufacturers and suppliers (small batches) must be taken into account when forming the $Z_{\max}$ stockpile.

Variants of the composition of WME suppliers can be generated by a full search of $N = 2^n - 1$, where n is the possible number of WME suppliers.

Let's introduce a Boolean variable x_{jk}:

$$x_{jk} = \begin{cases} 1, \textit{ if the k-th variant of the supplier's warehouse} \\ \quad \textit{was used for the j-th type of WME;} \\ 0, \textit{ otherwise}. \end{cases}$$

We will use the following indicators in the process of forming the WME stock Z, $Z \max_{\min}$, taking into account wartime risks:

Z is the value of the WME stock formed in the CZ;

T is the total time spent on the formation of WME stockpiles in the CZ;

R is the risk of military threats arising in the process of stockpiling WME in the CZ during martial law.

Due to the long front line, there may be not one but several CZs in the area of military conflict. Therefore, the volume of Z stocks is

$$Z = \sum_{i=1}^{M} z_i,$$

where z_i – corresponds to the WME stock for the i-th CZ;

M is the number of WME in a CZ.

Taking into account all WME in the CZ, as well as the types of weapons entering the conflict zone, we obtain the following expression:

$$Z = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{n_i} l_{ijk} m_{ijk} x_{ijk},$$

where $Z_{\max_{\min}}$;

l_{ijk} – is the size of the supply batch associated with the k-th supplier warehouse for the j-th type of WME to form stocks in the i-th CZ;

m_{ijk} – is the number of supply batches associated with the limited capacity of WME suppliers for the k-th warehouse of suppliers of the j-th type of WME for the i-th CZ.

Let us introduce the variable x_{ijk}:

$$x_{ijk} = \begin{cases} 1, \textit{if the k-th supplier warehouse is selected} \\ \quad \textit{for the j-th type of WME, for the i-th WBD;} \\ 0, \textit{ otherwise.} \end{cases}$$

Then the total time to build up WME's inventory in CZ is

$$T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{n_i} m_{ijk} t_{ijk} x_{ijk},$$

where t_{ijk} – is the time spent on the supply of one batch of WME by the k-th supplier warehouse for the j-th type of WME for the i-th CZ.

Risks of WME stockpiling associated with possible threats of martial law:

$$R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{n_i} m_{ijk} r_{ijk} x_{ijk},$$

where r_{ijk} – is the risk of supplying one batch of WME by the k-th supplier warehouse for the j-th type of WME to form stocks in the i-th CZ.

It is necessary to maximise the level of WME stocks in CZ

$$\max Z, \quad Z = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{n_i} l_{ijk} m_{ijk} x_{ijk},$$

subject to compliance with restrictions:

$$Z_{\max_{\min}}$$

$$T \le T', \qquad T = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{n_i} m_{ijk} t_{ijk} x_{ijk},$$

$$R \le R', \qquad R = \sum_{i=1}^{M} \sum_{j=1}^{m_i} \sum_{k=1}^{n_i} m_{ijk} r_{ijk} x_{ijk},$$

where R' – acceptable overall risk;

T' – acceptable time of delivery and formation of weapons stocks.

The problem can be solved by a complete search of all options for the WME's supplier warehouse, or, for a large problem dimension, by using one of the branches and boundaries methods in integer (Boolean) optimisation.

List of the set and justification of the structure of logistics supply channels in the process of forming the necessary stocks of weapons

We will conduct a structural analysis of possible supply channels for weapons and military equipment to form stocks in the zone of military conflict.

In order to form a sufficient level of WME stocks in CZ Z, $Z_{\max_{\min}}$, possible structural logistics elements are used, for example

– WME producers and suppliers;

– vehicles;

– suppliers' warehouses;

– intermediate warehouses for temporary storage of WME;

– transshipment centres;

– distribution centres;

– consolidation centres for the formation of batches of weapons and their components;

– WME warehouses in the CZ, etc.

Given the long length of the front line, the process of forming WME's stocks creates a set of possible structures for organising logistics supply channels, which requires solving the combinatorial problem of listing possible options. To analyse the set of variants of logistics supply chain structures, it is necessary to:

1) to conduct a quantitative analysis of possible options for creating logistics supply channels for WME in the CZ;

2) to form (generate) options for further analysis and comparison;

3) use the methods of combinatorics and enumeration theory to solve the task.

In the theory of enumeration, options arise when one set (e.g., A) is mapped to another (B). In our case, the set of logistics elements A is mapped to the set of vertices of the graph of the logistics structure of supply channels G. For the list of options, it is necessary to form the so-called cycle indices (CI), which characterise the peculiarities of the composition of logistics elements A, as well as the peculiarities of representing the structure of logistics supply channels in the form of a graph G:

$$Z(G) = \frac{1}{|G|} \sum_{g} \left(t_1^{c_1} t_2^{c_2} t_3^{c_3} \dots t_n^{c_n} \right) g,$$

where c_i is the number of cycles of length i arising from the mapping of one set to another;

t_i – an auxiliary variable related to c_i;

g – a separate component of CI.

The formation of CI for the graph of the logistics supply chain structure is associated with the analysis of the topology of the graph G. As an analysis, groups of substitutions for the vertices of graph G are used. The most commonly used groups of substitutions are as follows:

– symmetric S_n;

– cyclic C_n;

– dihedral D_n ;

– unit E_n,

where n is the number of vertices of graph G.

The obtained CIs for the groups of substitutions of the vertices of graph G are used to quantitatively analyse possible variants of the structures of logistics supply channels. In this case, the following formulas are used to recalculate the options in the form of the results of Poy and De Bruijn's theorems.

For the simplest cases of recalculation, when we are interested only in possible warehouse options, the problem is simplified and transformed into a special case – a formula for calculating combinatorial analysis. For example, we have three possible logistics elements for creating supply channels in the process of building WME stocks:

– a warehouse for temporary storage of military equipment;

– WME distribution centre;

– a consolidation point for different types of WME for further transport to the CZ.

The number of possible variants of the composition of elements in the logistics supply channel using combinatorial analysis is as follows

$$K = L^M - 1,$$

where L – number of types of logistics elements $(L = 3)$;

M – number of possible supply channels (for example, $M = 2$).

For our case, the number of possible warehouse options: $K = 3^2 - 1 = 8$.

The L-th counter can be used to form (generate) variants of the composition of WME's logistics supply channels in the CZ.

For example, this is a ternary counter. Then the set of warehouse options for WME's logistics supply channels in the CZ can be represented as follows:

1. 0 1
2. 0 2
3. 1 0
4. 1 1
5. 1 2
6. 2 0
7. 2 1
8. 2 2.

When using the graph G of the logistics supply chain structure, it is necessary to take into account the possible types of structure topologies that are used quite often (Fig. 9).

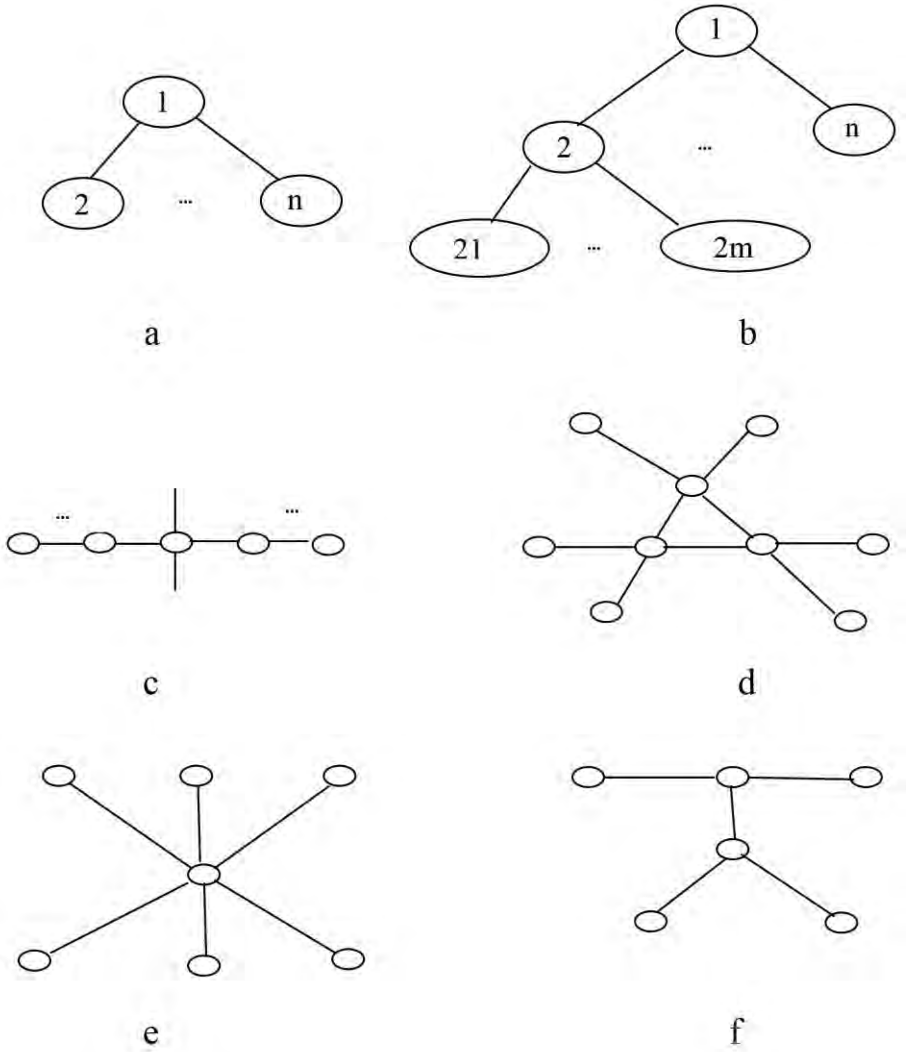

Fig. 9. Typical structures of the system topology:
a – radial structure; b – tree structure;
c – iterative; d – radial-ring structure of the first type;
e – radial-ring of the second type; f – radial-ring of the third type

In practice, mixed structures are often used, which are a combination of the types of topologies that have been considered. For any of the considered types of topologies, it is possible to form a group of vertex replacements of the graph G according to the structure topology, and then build the CI. The cycle index is the basis for recalculating the variants of logistics channels, taking into account the possible set of composition of logistics elements. In this case, one of the possible theorems of the enumeration theory is used.

As an example, let's determine the number of options associated with the mapping of possible logistics elements to the vertices of the radial structure of logistics supply channels in graph G (Fig. 9, a).

The group of substitutions of the vertices of the radial structure of graph G can be represented as follows:

$$H = E_1 + S_2,$$

where E_1 – a single group of substitutions associated with the vertex of a radial structure;

S_2 – is a symmetric replacement group associated with the two lower vertices of graph G.

The cyclic index of graph G is composed as a composition of two cyclic indices:

$$Z(H) = Z(E_1) Z(S_2) .$$

Let the number of types of logistics items be 3. Then

$$Z(H) = \frac{1}{2!} x_1 \left(x_1^2 + x_2 \right),$$

where variables x_1 and x_2 are associated with the vertices of graph G.

To recalculate the options for the structure of WME's logistics supply channels in the Czech Republic, we will use the result of the second theorem of Poy and De Bruijn:

$$K = \left\lfloor Z\left(G'; \frac{\partial}{\partial z_1}, \frac{\partial}{\partial z_2}, \ldots \right) Z\left(H, 1 + z_1, 1 + z_2, \ldots \right) \right\rfloor_{Z_1 = Z_2 = \ldots = 0},$$

where G' – is a group of replacements of the vertices of graph G;

H – a group of replacements associated with the composition of types of logistics supply elements;

$\frac{\partial}{\partial z_1}, \frac{\partial}{\partial z_2}, \ldots$ – differential operators (partial derivatives) that act on groups of vertex replacements of graph G.

In this case, the condition is met that all auxiliary variables are $z_1 = z_2 = \ldots = 0$.

For our sample:

$$K = 3 \cdot \frac{1}{2} \left(3^2 + 3 \right) = \frac{3 \cdot 12}{2} = 18 .$$

The obtained variants of WME's logistics supply chain structures in the process of inventory formation in CZs will be further evaluated and compared in order to select a rational option depending on the values of the selected logistics indicators.

We will assume that each logistics supply channel is associated with a specific CZ. It is necessary to form logistics supply chains taking into account the requirements of WME stocks in CZ $Z \llbracket \; Z_{\max} \rrbracket_{-} \min$ for the successful completion of combat missions.

Individual links in the supply chain may include:

– transport sections of the highway;

– transport hubs;

– transport interchanges.

In order to solve the problem of choosing the rational composition of the logistics links of the arms supply channels in the CZ for the formation of WME stocks, we will use integer programming with Boolean variables y_{ik} :

$$y_{ik} = \begin{cases} 1, \textit{if the k-th warehouse of the supply chain links} \\ \quad \textit{is selected for the i-th channel to form WME stocks in CZ;} \\ 0, \textit{ otherwise}. \end{cases}$$

where $\sum_{k=1}^{l_i} y_{ik} = 1$.

In this case, the time taken to supply WME to form inventory in CZ is

$$T = \sum_{i=1}^{L} \sum_{k=1}^{l_i} t_{ik} y_{ik},$$

where L – number of WME at CZ;

l_i – is the number of possible options for the warehouse of the WME logistics supply chain for stock formation for the i-th CZ;

t_{ik} – is the time spent on supplying WME by the k-th warehouse of the logistics links of the supply chain for the i-th CZ.

Risks of military threats related to supply and stockpiling in CZ:

$$R = \sum_{i=1}^{L} \sum_{k=1}^{l_i} r_{ik} y_{ik},$$

where r_{ik} – risks of military threats associated with the use of the k-th warehouse of logistics supply chain for the i-th WME supply channel to form stocks in the CZ.

Logistics expences associated with the supply of WME for stockpiling in the CZ:

$$W = \sum_{i=1}^{L} \sum_{k=1}^{l_i} w_{ik} y_{ik},$$

where w_{ik} – logistics expences associated with the choice of the k-th variant of the composition of the logistics links of the WME supply channel in the i-th CZ.

Other formulations of the problem related to the formation of logistics links in WME's supply channels in CC are possible.

1. Minimise the delivery time for the formation of WME stocks in CZ

$$\min T, \quad T = \sum_{i=1}^{L} \sum_{k=1}^{l_i} t_{ik} y_{ik},$$

taking into account possible restriction:

$$Z_{\max_{\min}},$$

$$R \le R', \quad R = \sum_{i=1}^{L} \sum_{k=1}^{l_i} r_{ik} y_{ik},$$

$$W \le W', \quad W = \sum_{i=1}^{L} \sum_{k=1}^{l_i} w_{ik} y_{ik},$$

where R', W' – acceptable values of risks and expences.

2. Minimise supply risks for the formation of WME stocks in CZ

$$\min R, \quad R = \sum_{i=1}^{L} \sum_{k=1}^{l_i} r_{ik} y_{ik},$$

Taking into account the restrictions:

$$Z_{\max_{\min}},$$

$$T \le T', \quad T = \sum_{i=1}^{L} \sum_{k=1}^{l_i} t_{ik} y_{ik},$$

$$W \le W', \quad W = \sum_{i=1}^{L} \sum_{k=1}^{l_i} w_{ik} y_{ik}.$$

3. Minimise the logistics expences associated with the supply of WME stocks in CZ

$$\min W, \quad W = \sum_{i=1}^{L} \sum_{k=1}^{l_i} w_{ik} y_{ik}.$$

taking into account the restrictions:

$$Z_{\max_{\min}},$$

$$T \le T', \quad T = \sum_{i=1}^{L} \sum_{k=1}^{l_i} t_{ik} y_{ik},$$

$$R \le R', \quad R = \sum_{i=1}^{L} \sum_{k=1}^{l_i} r_{ik} y_{ik}.$$

Formation of the necessary stocks of weapons of certain models in the area of military conflict

Modern weapons have high combat capability (accuracy, range, area of effect, etc.). In the process of forming WME stockpiles, this allows for an asymmetry in the military parity of forces in a particular CZ (quality over quantity). Therefore, it is relevant to study the formation of WME stockpiles in a CZ in terms of the combat capability of weapons. Let us consider the formulation and solution of the problem of distributing a batch of weapons in a CZ, in which the formation of WME stocks is carried out taking into account the combat capability of individual types.

Let N be the number of WME in the CZ. As a result of the arrival of a batch of WME in the CZ, it is necessary, taking into account the types of weapons, j $\left(j=\overline{1,P}\right)$, to distribute them to individual CZs in accordance with their combat capability. In this case, it is necessary to take into account the total combat capability of all weapons in the CZ, taking into account the one we have at the moment.

Let's introduce an integer variable:

$$x_{jk}=\begin{cases}1, \textit{if for the selected } k\textit{-th warehouse of the CZ stocks} \\ \quad \textit{for the } j\textit{-th type of WME are formed;} \\ 0, \textit{ otherwise.}\end{cases}$$

where $\sum_{k=1}^{n_j} x_{jk}=1$ – This means that the incoming batch of weapons will definitely be used to form stocks of the j-th type of WME in the CZ. Then we have the following results.

1. Stocks formed in CZ:

$$W=\sum_{j=1}^{P}\sum_{k=1}^{n_j} w_{jk}x_{jk}\sum_{j=1}^{P}\sum_{k=1}^{n_j} w'_{jk} \ ,$$

where P – number of WME types;

n_j is the number of possible options for allocating WME to CZs to form stocks of the j-th kind of weapon;

w_{jk} is the quantity of WME of the j-th kind used for inventory formation;

w'_{jk} – is the number of weapons of the j-th kind that are currently available in the k-th warehouse in the CZ where the weapons stocks are formed.

2. Combat capability of the WME in the CZ:

$$Q = \sum_{j=1}^{P}\sum_{k=1}^{n_j} w_{jk} q_j x_{jk} + \sum_{j=1}^{P}\sum_{k=1}^{n_j} w'_{jk} q_j x_{jk},$$

where q_j – combat effectiveness of a single sample of the j-th kind of WME.

3. Time spent on the formation of WME stockpiles in CZ:

$$T = \sum_{j=1}^{P}\sum_{k=1}^{n_j} t_{jk} x_{jk},$$

where t_{jk} – is the time spent on the formation of WME stocks of the j-th kind for the k-th WME warehouse in CZ.

4. Logistical risks of WME stockpiling in the CZ related to the wartime period:

$$R = \sum_{j=1}^{P}\sum_{k=1}^{n_j} r_{jk} x_{jk},$$

where r_{jk} – the risk of military threats associated with the logistics of stockpiling the j-th type of WME for the k-th warehouse in the WME in the CZ.

In order to create military parity of forces (as well as the possibility of creating asymmetry), it is necessary to maximise the combat effectiveness of the use of WMEs, taking into account the stocks of weapons currently available in the CZ:

$$\max Q = \sum_{j=1}^{P}\sum_{k=1}^{n_j} w_{jk} q_j x_{jk} + \sum_{j=1}^{P}\sum_{k=1}^{n_j} w'_{jk} q_j x_{jk},$$

taking into account the restrictions:

$$W \sum_{j=1}^{P}\sum_{k=1}^{n_j} w_{jk} x_{jk} + \sum_{j=1}^{P}\sum_{k=1}^{n_j} w'_{jk}{}_{\max_{\min}},$$

where $W_{\min}$ – WME stocks that ensure that the nature of hostilities in the conflict zone is not disturbed, taking into account military threats;

$W_{\max}$ – WME stocks that ensure the successful achievement of the objectives of a military operation by creating an asymmetry in the military parity of forces.

$$T \le T', \quad T = \sum_{j=1}^{P}\sum_{k=1}^{n_j} t_{jk} x_{jk},$$

$$R \le R', \quad R = \sum_{j=1}^{P}\sum_{k=1}^{n_j} r_{jk} x_{jk},$$

where T', R' – acceptable values of time and risk of stockpiling weapons and military equipment.

An example of modelling the logistics of stockpiling weapons and military equipment

Let's consider the logistics of stockpiling weapons for effective combat operations on the example of supplying the HIMARS multiple launch rocket system using four possible suppliers $(n = 4)$. In this case, the number of possible options for the composition of suppliers for the formation of stocks of MLRS HIMARS in the area of military conflict is as follows $N = 2^n - 1 = 2^4 - 1 = 15$.

Table 4 shows the options for the composition of suppliers for the formation of HIMARS stocks. The following indicators are used to compare and eliminate unnecessary options for the composition of possible suppliers:

– the number of batches of HIMARS supplies from the i-th supplier for the formation of weapons stocks – n_i;

– volume of the HIMARS supply batch for the i-th supplier – l_i;

– is the volume of the HIMARS MLRS stockpile formed after using the receipts from the k-th supplier warehouse – W_k;

– is the time spent on the supply of weapons by the k-th supplier of HIMARS MLRS – T_k;

– wartime logistical risks associated with the supply of HIMARS weapons to the k-th supplier warehouse – R_k.

Table 4

Evaluation of options for the composition of the HIMARS MLRS supplier

№	List of suppliers				W, stock volume	T, stock formation time	R, logistics risks
	1	2	3	4			
1	–	–	–	+	6	B	A
2	–	–	+	–	4	A	A
3	–	–	+	+	10	C	B
4	–	+	–	–	3	A	A
5	–	+	–	+	9	C	B
6	–	+	+	–	7	B	B
7	–	+	+	+	13	C	C
8	+	–	–	–	3	B	A
9	+	–	–	+	9	C	C
10	+	–	+	–	7	C	B
11	+	–	+	+	13	D	D
12	+	+	–	–	6	B	B
13	+	+	–	+	12	C	D
14	+	+	+	–	10	C	C
15	+	+	+	+	16	D	D

To estimate the volume of the MLRS HIMARS stockpile being formed in the area of military conflict, we will use quantitative estimates, and to estimate time and risk, we will use qualitative estimates for the convenience of military experts:

$$T_k = \begin{cases} A - \text{ minimum time;} \\ B - \text{ satisfactory time;} \\ C - \text{ acceptable time;} \\ D - \text{ maximum time;} \end{cases}$$

$$R_k = \begin{cases} A - \text{ minimum risk;} \\ B - \text{ satisfactory risk;} \\ C - \text{ acceptable risk;} \\ D - \text{ maximum risk .} \end{cases}$$

For the example under consideration:

$$m_1 = 1, \quad l_1 = 3,$$
$$m_2 = 3, \quad l_2 = 1,$$
$$m_3 = 2, \quad l_3 = 2,$$
$$m_4 = 2, \quad l_4 = 3.$$

Table 4 was built as a result of the military experts' assessment of possible options for the formation of MLRS HIMARS stockpiles.

To analyse the results, we will take into account the fact that the most important indicator is the stockpile formation – W, $W_{\max_{\min}}$ where $W_{\min} = 6$, which corresponds to the MLRS HIMARS insurance stockpile, and $W_{\max} = 20$, which ensures the successful achievement of the objectives of the military operation due to the asymmetry in military parity of forces. The values of $W_{\min}$ and $W_{\max}$ were determined by experts in the field of military logistics.

Let the next most important indicator be the time T, which is necessary for the timely formation of MLRS HIMARS stockpiles. Possible risks in the context of military threats in the process of building up the MLRS HIMARS stockpile are taken into account using the R indicator, which, according to military experts, will be the third most important.

To compare and choose the best option for the formation of MLRS HIMARS stockpiles, we will use the options presented in Table 4, taking into account the importance of indicators.

A preliminary list of options for forming stockpiles of MLRS HIMARS (see Table 4) will look like this:

1. 6, B, A
2. 4, A, A
3. 10, C, B
4. 3, A, A
5. 9, C, B
6. 7, B, B
7. 13, C, C
8. 3, B, A
9. 9, C, C
10. 7, C, B
11. 13, D, D
12. 6, B, B
13. 12, C, D
14. 10, C, C
15. 16, D, D.

After the lexicographical ordering of the options for the formation of stockpiles of MLRS HIMARS, considering the priority of indicators, we get:

15. 16, D, D
7. 13, C, C
11. 13, D, D
13. 12, C, D
3. 10, C, B
14. 10, C, C
5. 9, C, B
9. 9, C, C
6. 7, B, B
10. 7, C, B
1. 6, B, A
12. 6, B, B
2. 4, A, A
4. 3, A, A
8. 3, B, A.

After analysing the list of options, the military experts decided that the indication of the delivery time D and the value of the risk D were unacceptable for the formation of the MRLS HIMARS stockpile. Taking into account the value of the $W_{\min}$ constraint, we get a list of possible options for the formation of MLRS HIMARS stockpiles:

7. 13, C, C
14. 10, C, C
5. 9, C, B
9. 9, C, C
6. 7, B, B
10. 7, C, B
1. 6, B, A
12. 6, B, B.

After analysing the list of options and comparing them, military experts concluded that the seventh option for building up the MRLS HIMARS stockpile is the best. It corresponds to a stockpile of 13 HIMARS MLRS, and is characterised by an acceptable time and risk of stockpile formation.

The subsection examines the modelling of the logistics process of stockpiling weapons and military equipment for the successful conduct of combat operations in the conflict zone. The article analyses the problems of stockpiling weapons in wartime, which differ from stockpiling in peacetime: weapons suppliers located at a great distance from the zone of military conflict; small batches of WME supplies; long supply chains in a heterogeneous transport environment; military threats and vulnerabilities; and martial law risks. The analysis of the formation of weapons stocks has shown that the volume of stocks is formed in the interval $Z_{\max_{\min}}$, where $Z_{\min}$ corresponds to the insurance stock of weapons that will not disrupt the nature of hostilities in the context of military threats and logistical risks of the country's martial law, and $Z_{\max}$ ensures the successful achievement of the objectives of a military operation by creating an asymmetry in the military parity of forces. The article analyses the effectiveness of the use of certain types of weapons in the combat zone depending on military threats. For this purpose, the method of the theory of planning experiments is used, with the help of which priority types of weapons are selected to form the necessary stocks.

An optimisation model for the formation of WME stocks is proposed, taking into account the limited capabilities of manufacturers and suppliers and wartime logistical risks. In this case, small batches of arms supplies, delivery time and possible composition of suppliers are taken into account. A systematic analysis of logistics supply channels is carried out and options for composition and structure are listed using the methods of enumeration theory.

An optimisation model for selecting logistics links in arms supply channels was created in accordance with the expences and risks of martial law. The optimisation of the volume of weapons stocks is carried out, taking into account the combat capability of certain types, which allows creating a possible asymmetry in the military parity of forces for the successful achievement of the goals of a military operation.

An example is provided to confirm the effectiveness of the proposed approach. The example analyses possible options for the composition of suppliers for the formation of stocks of MLRS HIMARS. In this case, both quantitative estimates of weapons stocks and qualitative estimates of time and logistical risks of supply under martial law are used. To select the best option for the composition of suppliers in the formation of stockpiles of MLRS HIMARS, the composition of arms suppliers, their capabilities and the amount of required safety stocks are analysed. For this purpose, a lexicographical ordering of options for the formation of weapons stockpiles is used.

The main scientific contribution of the study is related to the development of a set of original optimisation models, models of the list of options for the structures of logistics supply channels, which allows scientifically sound formation of requirements for the volume of WME stocks.

Mathematical methods and modelling techniques used: system analysis; methods of expert evaluation of options; methods of the theory of planning experiments; integer (Boolean) optimisation; methods of Poy and De Bruijn's enumeration theory; method of lexicographic ordering of options; method of qualitative evaluation of options.

The proposed approach makes it possible to take into account the variety of weapons, their combat capability, small batches of supplies, a large number of options for the composition of suppliers, limited capabilities of suppliers, the amount of insurance stocks, delivery time and logistics of forming weapons stocks in the context of military threats in the process of forming stocks of weapons and military equipment in a military conflict zone.

Modelling the logistics of high-tech enterprises evacuation in a special period

The unit solves a complex multi-criteria task related to the justification of the location of the enterprise to be evacuated. The logistics process of evacuation is modelled in the context of wartime threats and vulnerabilities. The relevance of the study is related to the substantiation of a possible production location for a high-tech enterprise, taking into account the process of transporting technological equipment to the rear in the face of complex logistics. The article considers the process of placing and setting up the production of an evacuated enterprise at a new location. The purpose of the study is to model the logistics process of evacuating an industrial enterprise to the rear in the face of wartime threats and vulnerabilities.

Given the aggressor's military actions on the territory of the country, an acute problem arises related to the evacuation of high-tech industrial enterprises (aerospace, machine-building, instrument-making industries, etc.) from the frontline zone to the rear [25]. In this case, it is necessary to carry out a whole range of measures (dismantling of technological equipment, transportation, preparation of a new territory, placement and installation of technological equipment, etc.) in a short time with minimal risks and taking into account wartime threats. Therefore, the relevance of the study is due to the fact that it sets and solves the task of modelling the logistics process of evacuating an industrial enterprise from the frontline zone to the rear, taking into account the risks and time for moving to a new place of production. As is well known, evacuation consists of a number of stages that must be planned in advance and implemented within the required timeframe, which depends on the situation at the front [26]. The main stages to be studied:

– selection of the location of the industrial enterprise to be evacuated;

– dismantling of technological equipment;

– preparation for the transport of technological equipment;

– transporting the process equipment;

– preparation of a new territory for the location of technological facilities of the industrial enterprise;

– placement of process equipment on the new territory;

– installation of process equipment;

– establishment of communication channels for the operation and management of technological equipment;

– carrying out a set of commissioning works to resume production of the actual products of the evacuated high-tech enterprise.

The analysis of publications on this topic showed that the main attention is paid to individual stages of evacuation without a comprehensive study of the entire process [27]. The logistical nature of evacuation, risks and threats arising from wartime requirements are not taken into account [28].

Thus, there is a complex scientific and applied task of a multicriteria nature related to the successful conduct of evacuation measures in wartime [29].

To achieve the purpose of the study, the main criteria are used: evacuation time, expences, and risks arising in wartime.

To achieve this goal, it is necessary to solve the following tasks:

1) to substantiate and select the location of the evacuated enterprise, taking into account the threats and vulnerabilities of wartime;

2) to build an agent-based simulation model to study the logistics process of evacuation of a high-tech enterprise;

3) to formulate rational routes for transporting technological equipment to a new location of a high-tech enterprise;

4) to solve the problem of optimal placement of the evacuated high-tech enterprise at a new location.

Justification and selection of the location of the evacuated enterprise, taking into account the threats and vulnerabilities of wartime

The choice of a new location for a high-tech enterprise to resume production of relevant military products depends on a number of factors, including

– time spent on moving the enterprise to a new location;

– possible wartime threats and vulnerabilities at the new location of the high-tech enterprise;

– availability of engineering infrastructure for the normal operation of the high-tech enterprise at the new location (supply of the required volumes of electricity, water, gas, etc;)

– time spent on the placement and installation of high-tech equipment at the new location of the enterprise;

– expenses related to the relocation of a high-tech enterprise to a new place.

The task under consideration in this paper is multivariate in nature, taking into account the possible contradiction of criteria (time, expenses, risks) and requires a compromise solution.

Wartime threats depend on the presence of possible vulnerabilities at the new location of the industrial enterprise (availability of defence and repair plants, military command posts, storage facilities and warehouses for military equipment, ammunition, fuel, etc.) Therefore, it is necessary to assess the level of threats by evaluating the impact on existing vulnerabilities. To analyse the level of threats and vulnerabilities, we will use expert assessments (specialists in the field of military logistics). For the convenience and simplification of expert assessment, we will use qualitative assessments in the form of linguistic variables. For each possible location of the evacuated enterprise, we will form a set of threat assessments based on vulnerabilities. To assess the level of threats, we will use the qualitative values of vulnerabilities at the new location of the enterprise. For example, the qualitative values of vulnerabilities can be presented as follows:

1) presence of military command points:

A – absent;

B – present;

2) presence of weapons, military equipment, ammunition depots:

A – absent;

B – present;

3) presence of fuel storage facilities:

A – absent;

B – in a small amount;

C – in large quantities;

4) presence of defence enterprises:

A – absent;

B – in a small amount;

C – to a large extent.

Then each possible location of the evacuated high-tech enterprise can be represented as a list of linguistic variables ("word"), where the first place in importance, for example, is the value of the linguistic variable "military command posts", the second place is the presence of "weapons, military equipment and ammunition warehouses", the third place is the presence of "fuel storage facilities", and the fourth place is the presence of "defence enterprises".

Suppose that the experts offer 10 possible locations for the evacuated high-tech enterprise. For each of them, military experts assessed the impact of vulnerabilities. Let us present the options with their assessments in the form of an unordered list of "words":

1. A B A B
2. A A C B
3. B A B A
4. A B A A
5. B A A A
6. A A C C
7. A A B B
8. B A B C
9. B A A B
10. A B A C.

Given the significance of the vulnerabilities represented by the position of the corresponding linguistic variable in the "word" of the option, it is possible to identify the most promising options for the relocation of the evacuated enterprise to a new territory by lexicographically ordering the "words". We get:

7. A A B B
2. A A C B
6. A A C C
4. A B A A
1. A B A B
10. A B A C
5. B A A A
9. B A A B
3. B A B A
8. B A B C.

The options located at the top of the list have a greater advantage for choosing the location of the enterprise to be evacuated. Finally, the experts chose the seventh option for the location of the enterprise, which has no military command posts, no weapons, military equipment and ammunition depots, but small amounts of fuel storage facilities and small amounts of defence enterprises.

The analysis was limited to assessing the impact of vulnerabilities for the purpose of selecting the location of the industrial enterprise to be evacuated. To take into account such indicators as the level of threats – V , the availability of engineering infrastructure – W , the time to move – T , and the expence of moving – Z , we use the method of integer (Boolean) programming.

Let us assume that for each possible location of the evacuated high-tech enterprise, the following indicators have been quantified by military experts:

v_i – is the level of threats to the i -th location of an industrial enterprise;

w_i – engineering infrastructure for the i -th location;

t_i – is the time spent on moving an industrial enterprise to the i -th location;

z_i – expences associated with the relocation of an industrial enterprise to the i -th location.

For further optimisation, it is necessary to normalise the quantitative assessments of experts, i.e. to transfer them to a relative scale (0...1) as follows:

$$\overline{v_i} = \frac{v_i}{v_{\max}\ \overline{w_i} \frac{w_i}{w_{\max}\ \overline{t_i} \frac{t_i}{t_{\max}\ \overline{z_i} \frac{z_i}{z_{\max}}}}}$$

where $v_{\max_{\max_{\max_{\max}}}}$ – are the maximum values of the scores in the set of options under consideration.

Let's introduce a Boolean variable x_i:

$$x_i = \begin{cases} 1 - \textit{if the i-th variant of the enterprise location is selected,} \\ 0 - \textit{otherwise.} \end{cases}$$

In this case $\sum_{i=1}^{M} x_i = 1$, where M – is the number of possible locations for the evacuated high-tech enterprise.

For comprehensive optimisation and search for compromise solutions, we introduce the criterion Q as an additive convolution of local criteria:

$$Q = \alpha_V V + \alpha_W W + \alpha_T T + \alpha_Z Z,$$

where $\alpha_V, \alpha_W, \alpha_T, \alpha_Z$ – weights (significance) of local criteria V, W, T, Z. In this case

$$\alpha_V + \alpha_W + \alpha_T + \alpha_Z = 1,$$

$$V = \sum_{i=1}^{M} \overline{v}_i x_i,$$

$$W = \sum_{i=1}^{M} \overline{w}_i x_i,$$

$$T = \sum_{i=1}^{M} \overline{t}_i x_i,$$

$$Z = \sum_{i=1}^{M} \overline{z}_i x_i.$$

It is necessary to find min Q subject to the following constraints $V \le \hat{V}$, $W \le \hat{W}$, $T \le \hat{T}$, $Z \le \hat{Z}$, where $\hat{V}$, $\hat{W}$, $\hat{T}$, $\hat{Z}$ – acceptable values of the criteria.

Development of an agent-based simulation model to study the logistics process of evacuation of a high-tech enterprise

Given the dynamic nature of evacuation of a high-tech enterprise, the study uses simulation modelling of the main events of this process.

The main events in the simulation modelling of the logistics process of evacuation of an industrial enterprise are as follows:

– start of dismantling of technological equipment of a high-tech enterprise;

– completion of dismantling;

– start of transporting technological equipment to the rear;

– arrival of equipment (submitted as a request in the simulation) at a transport hub of a heterogeneous transport network;

– the request leaving the transport hub;

– receipt of a request to a section of a transport main line;

– the request leaving the section of the transport main line;

– commencement of the placement of technological equipment at the new location of the enterprise;

– completion of the placement of technological equipment;

– start of installation of technological equipment;

– completion of the installation of the process equipment;

– start of commissioning at the plant;

– completion of commissioning works at the enterprise;

– start of serial production of relevant military products at the new location of the high-tech enterprise (the final event).

Events are implemented in time, the scale of which is set at the beginning of the simulation (hour, day, week, etc.).

The sequence of events in the logistics process of evacuation corresponds to the cause-and-effect relationships and ensures the effectiveness of simulation modelling.

For example, the event of starting the installation of technological equipment causes a consequence. The consequence is the event of completion of the installation of technological equipment. Events are scheduled on a specified time scale in accordance with predefined cause-and-effect relationships.

The event-based simulation model is implemented in an agent-based view in the Anylogic environment, where there are agents associated with specific cause-and-effect events.

The control agent is separately identified, which provides event planning in a given time scale and generates a sequential list of events, in which the earliest event is located first.

Here are the components of the set of agents.

1. Agent for describing a diverse transport network.
2. The agent for starting the simulation (starting agent).
3. Equipment dismantling agent.
4. Agent for starting the transport of equipment.
5. Agent associated with a transport hub of a diverse transport network.
6. An agent associated with a section of a transport highway.
7. Agent for the placement of technological equipment.

8. Agent of equipment installation.
9. Agent for commissioning.
10. Risk agent.
11. Simulation control agent.
12. The agent for starting mass production (finishing agent).
13. The agent of simulation results.

The main results of the simulation are:

– time spent on evacuation of the industrial enterprise;

– time to start mass production;

– delay in the start of mass production;

– the route of technological equipment in a diverse transport network (a sequence of transport hubs and sections of a transport highway). The route can be set in advance, or an algorithm can be developed to determine the optimal route in terms of time or risk;

– the value of the final risk associated with the evacuation of the enterprise (the risk is accumulated in the case of transporting technological equipment in the hubs and sections of the transport route).

Fig. 10 shows a block diagram of the agent-based simulation model.

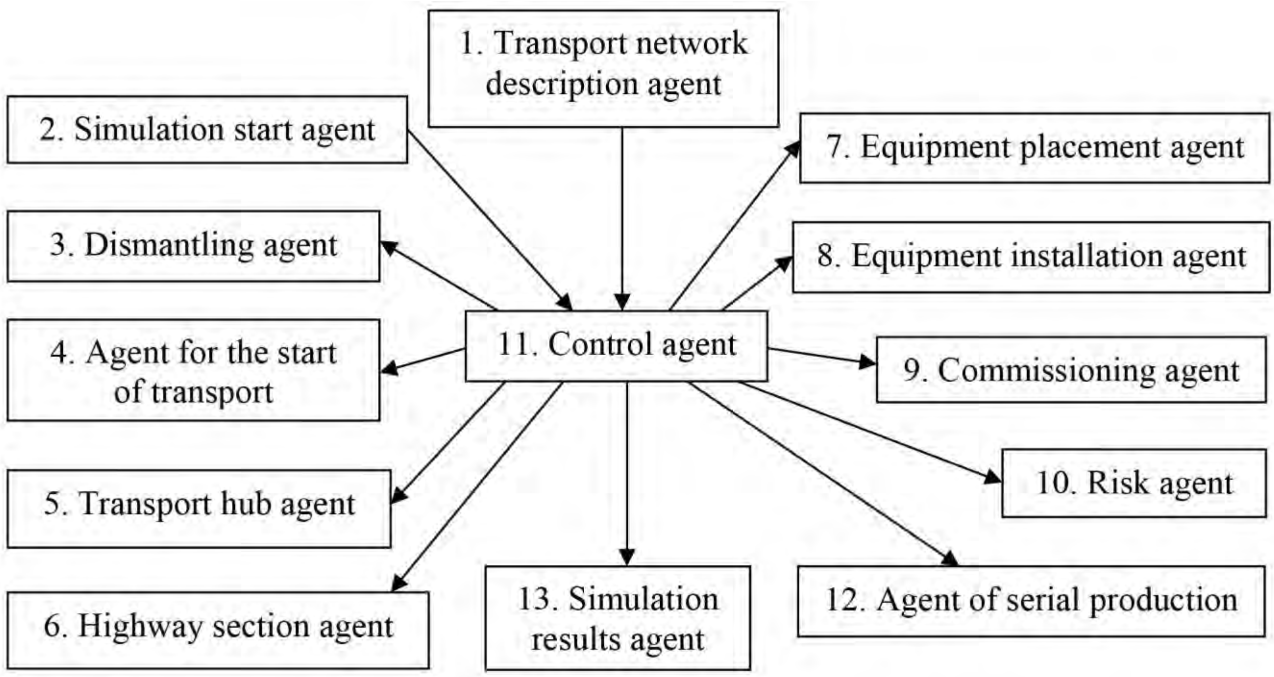

Fig. 10. Block diagram of the agent-based simulation model

A method for finding rational routes for technological equipment transportation to a new location of a high-tech enterprise

To find rational routes for transporting the technological equipment of an evacuated enterprise, an original routing algorithm was developed and implemented within an agent-based simulation model. The algorithm is based on the propagation of requests (clones) in the form of technological equipment in the graph G, which is a heterogeneous transport network used to move technological equipment to a new location of the industrial enterprise. Taking into account the special purpose of the cargo, as well as its characteristics (dimensions, weight, requirements for concealment of transportation, etc.), not all transport hubs and sections of the transport network can be used to move technological equipment. Therefore, military experts must determine in advance the permitted transport hubs and sections of the transport network that can be used to evacuate a high-tech enterprise. The movement of requests (clones) of technological equipment in column G of the transport network, taking into account the permitted nodes and sections of the transport highway, is carried out as follows: the beginning of transportation is associated with the exit of the request from the transport node to which the evacuated technological equipment was received. Then, by the method of multiplication of applications (emergence of application clones), they are transported along all possible sections of the highway associated with this transport hub. If an order (clone) enters a neighbouring transport node, it marks it with the number of this order. If a request (clone) reaches a designated node, its movement is stopped because the request (clone) has already passed through this node, so it is not promising in terms of choosing the optimal route in terms of time. Upon reaching the finishing node (arrival of the process equipment at the new location of the enterprise), the time of the end of the process equipment transportation is recorded. Then, by moving back through the designated nodes, a route is formed that is minimal in time and takes into account the features and special mode of operation of the heterogeneous transport network used to evacuate the technological equipment of a high-tech enterprise.

In order to find a route with minimal risk of transporting technological equipment, it is necessary that before starting the modelling, military experts assess the possible risks of technological equipment passing through individual nodes and sections of the transport route. In the course of modelling, as the applications (clones) move along the nodes and sections of the transport route, individual risks accumulate and the final risk associated with the logistics of transport services for the evacuated enterprise is formed. To model risks and find a route with minimal risk, the main factor in managing simulation modelling (control agent) is the value of the accumulated risk.

The developed algorithm can be used both to find the optimal (minimum) evacuation route for technological equipment in terms of time and to find a safe route with a minimum risk value. The final choice of the route for evacuating the technological equipment of the evacuated high-tech enterprise is recognised by experts in the field of military logistics using the developed agent-based simulation model.

A method of optimal placement of an evacuated high-tech enterprise at a new location

The successful relocation of a high-tech enterprise to a new territory depends on the following factors:

1) the need for space for the placement of technological equipment;

2) earthworks to prepare the territory for the placement of technological equipment;

3) availability of engineering infrastructure on the new territory (electricity, water, gas, etc.);

4) availability of communications to organise the interaction of technological facilities and equipment management;

5) the duration and expences of preparing the new territory for the placement of the evacuated facility's technological equipment;

6) risks associated with the placement of the enterprise's technological equipment on the new territory.

The main criteria for assessing the location of an evacuated high-tech enterprise in a new territory are

– time spent on the location of the enterprise in the new territory – T ;

– expences associated with the location of the enterprise in the new territory – W ;

– risks of locating the enterprise in the new territory – R .

The availability of alternative options for the location of a high-tech enterprise, as well as the use of not one but several criteria for evaluating the location, leads to the need to formulate and solve a multi-criteria, multi-variant problem of finding a rational location option.

Suppose that military experts and the management of an enterprise determine in advance a set, M , of possible locations for a high-tech enterprise that is being evacuated to the rear. For each possible location, the time, expences, and risks associated with the location of the evacuated enterprise's technological equipment at the new location are estimated.

We present the criteria in the following form:

$$T_k = t_{k_1} + t_{k_2} + t_{k_3},$$

$$W_k = w_{k_1} + w_{k_2} + w_{k_3},$$

$$R_k = r_{k_1} + r_{k_2} + r_{k_3},$$

where T_k, W_k, R_k – are, respectively, the time, expences and risks associated with choosing the k-th option of locating the enterprise at a new location;

$t_{k_1}, w_{k_1}, r_{k_1}$ – time, costs and risks associated with earthworks to prepare the territory for the location of a high-tech enterprise for the k-th location option;

$t_{k_2}, w_{k_2}, r_{k_2}$ – time, costs and risks associated with the preparation of engineering infrastructure for the location of the enterprise, for the k-th location option;

$t_{k_3}, w_{k_3}, r_{k_3}$ – time, costs and risks associated with the organisation of communication channels for technological equipment for the k-th location option.

To find rational options for the location of a high-tech enterprise, we will use the method of integer (Boolean) programming. Let's introduce the variables x_k, the values of which are:

$$x_k = \begin{cases} 1 - \textit{if the k-th option for the placement} \\ \quad \textit{of technological equipment is selected;} \\ 0 - \textit{otherwise.} \end{cases}$$

Then, taking into account the variables x_k, the criteria for assessing the location of a high-tech enterprise will be as follows:

$$T = \sum_{k=1}^{M} \left(t_{k_1} + t_{k_2} + t_{k_3} \right) x_k,$$

$$W = \sum_{k=1}^{M} \left(w_{k_1} + w_{k_2} + w_{k_3} \right) x_k,$$

$$R = \sum_{k=1}^{M} \left(r_{k_1} + r_{k_2} + r_{k_3} \right) x_k.$$

There are two possible formulations of the problem of optimal location of an evacuated high-tech enterprise in a new territory.

1. Single-criteria optimisation. In this case, the optimisation of individual local criteria $(T,\ W,\ R)$ is carried out, taking into account the constraints in the form of acceptable values T', W', R'.

For example, it is necessary to find:

$$\min T,\ \ T=\sum_{k=1}^{M}\left(t_{k_1}+t_{k_2}+t_{k_3}\right)x_k,$$

subject to the restrictions:

$$W\le W',\ \ W=\sum_{k=1}^{M}\left(w_{k_1}+w_{k_2}+w_{k_3}\right)x_k,$$

$$R\le R',\ \ R=\sum_{k=1}^{M}\left(r_{k_1}+r_{k_2}+r_{k_3}\right)x_k,$$

$$\sum_{k=1}^{M}x_k=1.$$

2. Multi-criteria optimisation to find a compromise solution for the location of the evacuated enterprise. In this case, we use the complex criterion P:

$$P=\alpha_T\hat{T}+\alpha_W\hat{W}+\alpha_R\hat{R},$$

where $\alpha_T+\alpha_W+\alpha_R=1,$

$$\hat{T}=\frac{T-T^*}{T'-T^*},\ \ \hat{W}=\frac{W-W^*}{W'-W^*},\ \ \hat{R}=\frac{R-R^*}{R'-R^*},$$

where T^*, W^*, R^* – are the optimal values of T, W, R determined by the previous single-criteria optimisation.

It is necessary to find:

$$\min P,\ \ P=\alpha_T\hat{T}+\alpha_W\hat{W}+\alpha_R\hat{R}=$$

$$=\frac{\alpha_T}{T'-T^*}\left[\sum_{k=1}^{M}\left(t_{k_1}+t_{k_2}+t_{k_3}\right)x_k-T^*\right]+$$

$$+\frac{\alpha_W}{W'-W^*}\left[\sum_{k=1}^{M}\left(w_{k_1}+w_{k_2}+w_{k_3}\right)x_k-W^*\right]+$$

$$+\frac{\alpha_R}{R'-R^*}\left[\sum_{k=1}^{M}\left(r_{k_1}+r_{k_2}+r_{k_3}\right)x_k-R^*\right],$$

subject to the restrictions:

$$T\le T',\quad W\le W',\quad R\le R',$$

$$\sum_{k=1}^{M}x_k=1,$$

$$\alpha_T+\alpha_W+\alpha_R=1,$$

where $\alpha_T, \alpha_W, \alpha_R$ – the significance of the criteria T, W, R, set by experts in the field of construction of high-tech enterprises.

The study is related to modelling the logistics process of evacuating a high-tech enterprise in wartime. The preliminary analysis has revealed the shortcomings of existing approaches that study individual stages of evacuation of a high-tech enterprise without a comprehensive analysis of logistically related stages, without taking into account the dynamic nature of evacuation in the face of possible threats and vulnerabilities. The choice of a new location for the evacuated high-tech enterprise is substantiated on the basis of multivariate analysis and qualitative assessments of military experts in the form of linguistic variables. An agent-based simulation model for studying the logistics process of evacuation has been developed, which helps to determine the rational and optimal routes for transporting the technological equipment of the evacuated enterprise in the context of wartime risks. The article solves the problem of optimal placement of technological equipment of a high-tech enterprise at a new location, taking into account time, expenses and risks, using integer (Boolean) linear programming. In order to find compromise solutions in the process of placing technological equipment of a high-tech enterprise, a complex criterion in the form of an additive convolution of local criteria of time, expenses and risks is used.

The research was based on modelling the process of evacuation of an industrial enterprise in wartime, which involves justifying the new location of a high-tech enterprise through expert assessment, developing an agent-based simulation model to study the logistics of the evacuation process under conditions of risks, and optimising the placement of technological equipment of an industrial enterprise in a new territory. In the course of the study, the goal was fully achieved. The mathematical methods and modelling techniques used are: system analysis, expert evaluation using linguistic variables, agent-based simulation modelling, integer (Boolean) programming.

The proposed approach makes it possible, in the process of planning the evacuation of a high-tech enterprise, to reasonably choose a new location, to form rational (optimal) routes for transporting technological equipment during evacuation, and to rationally place technological equipment in a new territory, taking into account time, expenses and risks.

Conclusions

The chapter examines the logistics processes of production of high-tech enterprises during the special period associated with martial law in the country. The author describes the logistical problems that arose in the production and supply of high-tech defence products:

– transfer of production to the manufacture of weapons and military equipment;

– evacuation of high-tech enterprises from the frontline zone to the rear;

– the emergence of military threats and vulnerabilities related to the aggressor's actions, which affects the logistics of production;

– complications in the supply of high-tech enterprises due to long supply chains in wartime;

– delivery of high-tech components under difficult martial law conditions, as well as losses due to delays in delivery;

– supply of high-tech military equipment to the zone of military conflict to establish military parity of forces;

– formation of the necessary stocks of high-tech weapons in the area of military conflict for the successful fulfilment of the objectives of a military operation.

The logistics of military cargo supply in a heterogeneous transport network is modelled to find rational routes that will ensure timely delivery of military equipment to the combat zone, as well as minimise losses due to possible delays. A model has been created that allows analysing the logistical actions to establish military parity of forces, as well as possible asymmetry due to the use of high-tech weapons (quality over quantity). The sequence of actions related to the emergence of military threats (threat – vulnerabilities – losses) is investigated, which allows planning preventive measures to reduce the consequences of threats. With the help of an agent-based simulation model, the terms of supply of weapons and military equipment under martial law threats are determined. The method of forming rational routes for the supply of military equipment in a distributed transport environment with long logistics chains is developed. The logistics of training military personnel to acquire new competencies necessary for the use of high-tech military equipment are investigated. Considerable attention is paid to the formation of the necessary stocks of weapons in the area of military conflict, which are formed in the range from insurance stocks to the maximum, which ensures the successful achievement of the goals of a military operation in the face of complex supply logistics and limited capabilities of manufacturers and suppliers of high-tech military equipment. The author modelled the logistics processes of evacuation of high-tech enterprises in wartime by creating an optimisation model for estimating the logistics costs of transporting technological equipment and relocating the enterprise to a new location in the face of military threats.

Mathematical methods and modelling techniques were used: system analysis to present the logistics of military equipment supply under martial law; optimisation models of integer (Boolean) programming to estimate the time, risks and expenses in the production and supply of high-tech enterprises in the face of military threats;

the method of the theory of experiment to identify significant threat factors, priority of types of weapons in the area of military conflict; the method of expert evaluation using linguistic variables and lexicographic ordering of options to select the nomenclature and quantity of military equipment necessary to create military parity of forces in the combat zone; a method of simulated agent-based modelling to study long logistics chains for the supply of military equipment to a military conflict zone in the face of threats and perturbations of vulnerabilities in transport supply networks; a method of enumeration theory to form a set of possible logistics channels for the supply of weapons and military equipment to a military conflict zone.

The scientific results obtained in this section:

– the method of creating military parity of forces has been improved due to the timely supply of modern military equipment to the zone of military conflict, preparation of the military for its use in conditions of limited capabilities of manufacturers and risks of martial law;

– the method of stockpiling products of high-tech enterprises under special conditions and possible military threats has been improved, which allows planning the necessary stocks of military equipment for the successful implementation of operational and tactical actions;

– the method of logistical actions for the relocation of a high-tech enterprise was improved by optimising costs and reducing time, which allows planning the logistics of transferring production to a new location in the face of military threats.

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FORMING THE INVESTMENT ATTRACTIVENESS OF INNOVATIVE INVESTMENT PROJECTS ON THE BASIS OF INCREASING THEIR COMMERCIAL POTENTIAL IN THE FIELD OF ENGINEERING SERVICES

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The study deals with the formation of the investment attractiveness of innovative projects in the activities of Ukrainian enterprises with the involvement of engineering companies. The necessity of coordinating the goals of the enterprise and the motives of investors is substantiated. It is noted that the basis for cooperation and pooling of efforts can be the determination of an integral indicator of investment attractiveness – the commercial potential of an innovation-investment project. Modern approaches, the essence and components of the formation of commercial potential are considered. The role and importance of engineering companies in increasing the commercial potential of innovative and investment projects is shown on the example of the innovative technology «Simatic System Audit» of Siemens Corporation. The marketing component in increasing the commercial potential of an innovation-investment project has been studied. The role and importance of engineering companies in promoting this technology to the Ukrainian market of industrial enterprises is emphasized.

Introduction

The relevance of the research topic is due to the need to attract investment for the post-war revival of Ukraine. After all, as a result of the war, the country's economy was practically destroyed. And the task of scientists is to conduct research that could help the rapid and high-quality restoration of the state. On this path, it is innovative projects that will play the main role, causing innovative development.

The direction of Ukraine to the EU opens up opportunities to attract European investors and funds. But there is a problem of creating an investment-attractive climate in the country, the interest of potential investors. The first step in this direction is the formation of investment attractiveness of innovative projects. Considering the search for and attraction of investors, the second important step is to study the problem of increasing the commercial potential of innovative projects.

Thus, the object of research is the process of formation of investment attractiveness. The subject of the research is theoretical and practical approaches to increasing the commercial potential of innovative projects through the activities of engineering companies.

The aim of the study is modern approaches to the development of investment attractiveness based on increasing the commercial potential of innovative investment projects (IIP) to attract and effectively invest resources in the post-war revival of the country's economy.

For this, the following tasks are set:

– to determine the parameters of the investment attractiveness of IP through a comparison of the objectives of attracting and motives for investing;

– to analyse approaches to the formation of investment attractiveness of IIP;

– carry out a study of the concepts of the commercial potential of IIP, both from the point of view of the producer and the consumer of innovative technologies;

– substantiate the role and importance of engineering companies in the promotion of innovative technologies as an element of increasing the commercial potential of an innovative investment project;

– consider the process of promoting the innovative technology «Simatic System Audit» by Siemens Corporation using a specific example.

The issues of the essence and formation of the investment strategy were dealt with by such leading scientists as R. Akoff, I. Ansoff, I.O. Blank, B. Karlof, D. Kliland, P. Masse, A.R. Sterlinh, A.A. Tompson, A. Dzh. Striklend, V.D. Shapiro, N.M. Huliaieva, A.A. Peresada, D. Chervanov and other.

Considerable attention in scientific works is paid to the issues of assessing investment attractiveness at the micro level – investment portfolios, projects, at the meso level – enterprises, industries, at the macro level – the region, the state, such authors as V. Berens, L. Hitman, Dzh.Soros, U. Sharp, A. Sheremet, I. Blank, A. Peresada, V. Shevchuk, P.Rohozhyn, A.Hoyko, M.Kreynina and other.

The concept of the commercial potential of innovations has been studied by leading scientists such as P. Pererva, T. Kobieleva, O. Butnik-Siverskyi, P.M.Tsybulova, A.S. Romashko and other.

The issues of formation of investment attractiveness of innovative projects on the basis of increasing their commercial potential in the field of engineering services remain unresolved.

Research methodology

The theoretical and methodological basis of the study under consideration are the scientific methods of economic theory in the field of assessing investment attractiveness and commercial potential using an abstract-logical approach in the process of studying economic processes and phenomena, in particular:

– scientific generalization, when considering the place of commercial potential in the process of forming the investment attractiveness of innovative projects in the field of engineering, through consistent actions to build specific single facts into a single whole in order to identify typical features and patterns inherent in the phenomenon under study. This will reflect the general features of the process of formation of investment attractiveness as the main factor in raising funds and the priority implementation of such a project at the enterprise. The versatility of the components that make up the investment attractiveness of an innovative project and the inclusion of commercial potential in this process as a necessary element involves dividing it into components using generalizing indicators – indicators that determine it;

– a dialectical method, thanks to which the economic phenomena of commercial potential are considered as an integral indicator for evaluating an innovative project at all stages to minimize risks in their continuous movement, interconnections and interaction, when the accumulation of quantitative changes entails qualitative changes based on change management, and the source of sustainable development of the enterprise is the successful implementation of innovative projects, in determining the place and role of the commercial potential of innovation in the strategic management of an enterprise;

– a genetic approach in studying the macroeconomic environment, world experience and determining the stages of the formation of commercial potential, based on the principles of the dialectic of unity and integrity;

– the metaphysical method requires a focus on the static state of the object of economic research, outside of its connections with other objects, on its functioning, and not development. Within the framework of the so-called functional approach, investment attractiveness is assigned the status of a function, and variable arguments are the criteria that affect it. Thus, the functional relationship between them is investigated (when establishing the mathematical dependence of the influence of factors in the evaluation of an investment project);

– scientific abstraction, using only a part of the set of relevant data about an innovative project and adding new information to this part, regarding the commercial potential that does not directly follow from this data;

– the theoretical provisions of system analysis when decomposing the activities of both an engineering company and a customer's enterprise into different subsystems and groups of indicators; in the development of innovative projects and their implementation, in particular:

– methods of system analysis, both formal and informal, such as "brainstorming" methods for searching for new ideas, expert assessments, for assessing the investment attractiveness of innovative projects, diagnostic methods for studying the system, involving its division into its component parts –

subsystems make it possible to identify internal structure, properties, features, functions, etc. in order to improve the forms and methods of its work, it allows to identify weaknesses, problem areas, to which investment funds should be directed for the implementation of innovative projects, which ensures the achievement of the overall goals of the enterprise's sustainable development strategy;

– economic and mathematical modeling when building a model that allows simulating market conditions within alternative scenarios for the formation of the commercial potential of an innovative project. A causal structure is established, one or more scenarios are developed, and the return on investment is evaluated for each scenario chosen. The causal structure is established and verified experimentally, in conditions subject to objective observation and measurement.

The structure of the study is formed on the basis of understanding the innovative activity of the enterprise, the need to develop and implement innovative projects, the formation of their investment attractiveness, the role and place of engineering companies in the implementation of these projects and the increase in commercial attractiveness, shown in Fig. 1.

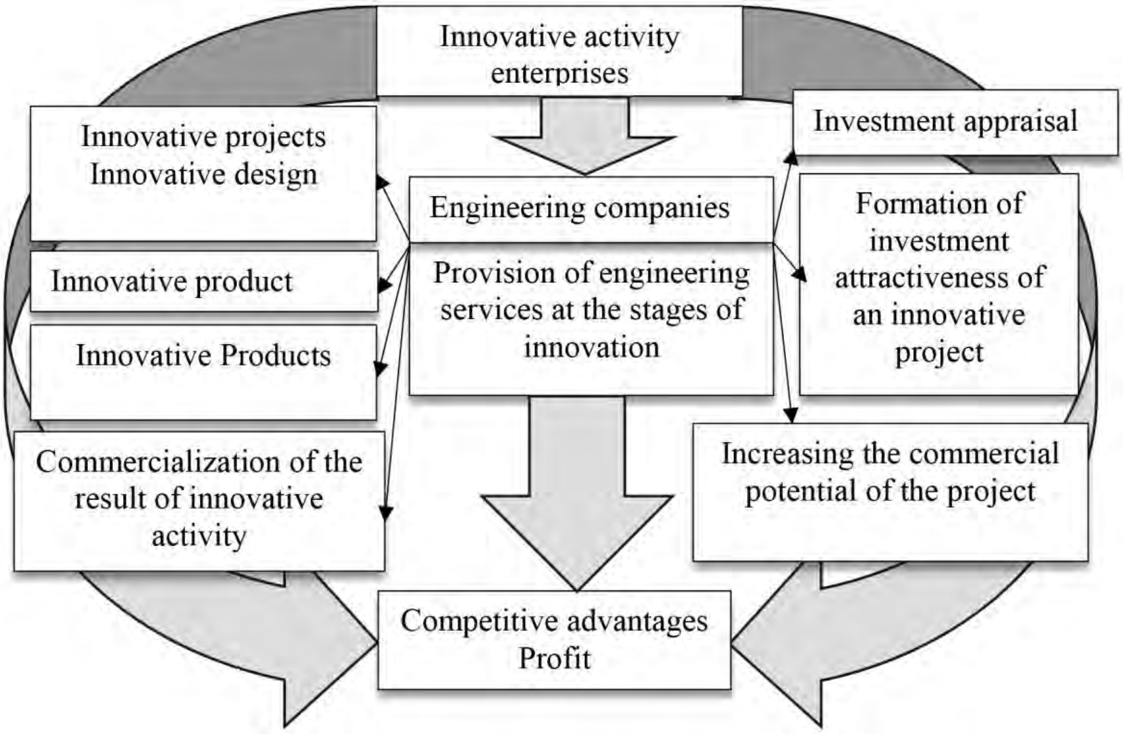

Fig. 1 The role and place of engineering companies in increasing the commercial potential of innovative projects (*developed by the authors*)

As can be seen from the figure, engineering companies play an important role both in the development and implementation, and in shaping the attractiveness of innovative investment projects for investors. This is due to the fact that such companies are both active players in the market of industrial enterprises and in the market for the transfer of innovative technologies. In addition, their activities in the market make it possible to form investment attractiveness and increase the commercial potential of innovation and investment projects through the marketing component. It is these questions that this study is devoted to.

Results of the research

Engineering companies work in the market with enterprises acting as customers of services. Therefore, the task for such companies is to find customers who would be interested in the innovative renewal of their enterprises in accordance with the phase of the life cycle, that is, they were ready to implement innovative projects. But IIP always needs investment resources. The attraction of which is possible only under two conditions:

– firstly, the company has such opportunities and is ready to invest;

– secondly, the enterprise does not have resources and seeks to obtain funds from outside.

Unfortunately, as a result of hostilities on the territory of the country, domestic enterprises found themselves in a difficult situation, so the first condition is impossible for most enterprises. There is a problem of finding investors. In this case, the management of the enterprise-customer of the innovative project must take into account all aspects that are important for the investor. That is, in other words, to form in a certain way the investment attractiveness of an innovative project that needs to be implemented at the enterprise.

The assessment of investment attractiveness itself includes many factors, so it is often difficult for enterprises to determine exactly those that would satisfy a particular investor and provide him with a certain justification for the expediency of investing. This is due, first of all, to the fact that the goals that the enterprise-customer of the IIP sets for itself and the goals of the investor may not coincide somewhat. So, when implementing an IIP, an enterprise focuses on achieving specific goals related to a certain phase of the enterprise's life cycle, as a rule, these are long-term strategic goals of sustainable development.

But an investor (portfolio or strategic investor, credit organization, venture company, etc.) is engaged in the fastest way to get investment results, that is, he asks what are the potential opportunities of an innovative project, whether its implementation will be able to generate a return on invested capital. Therefore, the task of forming such parameters of the investment attractiveness of an IIP that could combine the goals of an enterprise that seeks to raise funds and an investor, taking into account the possibilities of the post-war revival of the country, is relevant.

Investment attractiveness is a set of factors, the analysis of which indicates the possibility of investing in a particular object and obtaining a certain effect from a completed operation, that is, it is a set of features that allow a potential investor to assess how much an investment object is more attractive than others, for investment of available funds [1].

The investment attractiveness of an innovation and investment project is formed taking into account the resources and goals that all participants in the process seek to achieve. So, the factors that form the investment attractiveness of IIP:

– the prospects of the investment project, that is, the amount of income from the implementation of the project; market trends are studied and evaluated and its development in a certain period is analyzed;

– the investor's opportunities for the development of the enterprise: the opening of new diversified areas of activity, the selection and training of personnel, the improvement of material and technical equipment;

– the presence of real and potential competitors in the market, the presence of competitive advantages and the ability to withstand competition in the future;

– the ability to optimize the production process, the introduction of new technologies and scientific inventions [2].

If approached from the point of view of assessing the feasibility of investing funds by investors, then a model should be considered that includes two criteria: the commercial potential of the project and the risks of investing capital.

For example, an assessment of the commercial potential of an SMPS may include the following blocks:

1) scientific and technical potential;

2) resource potential;

3) market potential;

4) economic and social potential [3].

When assessing the commercial potential, the authors focus on the market component, i.e. effectiveness of the marketing system; in particular, on the active market behavior of both the enterprise-developer, the enterprise-customer (consumer) and the engineering company.

Since the study is specifically about the provision of engineering services, the objects of investment, in addition to tangible assets, are also intangible ones: intellectual property (IP) objects (patents, licenses, know-how, software), rights to use land and other resources, property rights, staff development expenses, etc.

There are two types of investments in innovative technologies: financial and scientific and technical (intellectual). Intellectual investments are made in the form of:

1) acquisition of exclusive rights of use – the purchase of patents, licenses for inventions, industrial designs, trademarks;

2) the acquisition of information services through the hiring of various kinds of specialists – scientists and practitioners under a contract or through a one-time acquisition of information services;

3) the acquisition of scientific and technical products, that is, intellectual goods in material form;

4) investment in human capital, that is, the cost of education, training and retraining of personnel, training, etc. [4].

As far as investment risks are concerned, valuation reduces the risk of loss and helps to predict compensation and/or profits for all participants in the process. The object of analysis is not the project itself, but the cash flows associated with it. The implementation of the project is a complex and multifaceted process, and it is very difficult to calculate and predict the scenarios in detail. For the analysis, economic and mathematical models, expert methods of collecting information are used. First of all, the following are subject to evaluation: risk and profitability indicators that affect the results of the investment project; payback periods [2].

The scientific and technical potential that has developed at the enterprise (expressed through product and technological characteristics) and the possibilities of international technology transfer require the search for the optimal combination of own research and development work (R&D) and borrowed scientific and technical results. Such a connection is manifested in the selective scientific and technological development of innovative enterprises. In those areas of science and technology that are not within the sphere of specialization of an individual enterprise, an increase in the technical level is achieved through technology transfer. The acquisition of technology compensates for the lack of R&D spending in non-core industries [4].

The technology marketing management process consists primarily of the planning of innovative projects in the enterprise. This means that at this stage it is necessary to decide what innovations or technologies are needed, to decide whether to develop it independently by the R&D department, or, more appropriately, to invest in relevant innovations. The information system should have an appropriate technology and innovation marketing subsystem to explore the best practices of leading companies based on a benchmarking approach. The manager receives comprehensive information and decides which technologies should be purchased and which ones will be developed at the enterprise. The second stage is the evaluation of investment investments, that is, making a decision regarding investments for each considered innovative project [5].

The main forms of technology transfer commercialization are:

– sale of technology in a materialized form: automatic and electronic equipment, technological lines, etc.;

– direct investments and accompanying documentation in the construction, reconstruction, modernization of enterprises, firms, industries;

– portfolio investments, including joint ventures, as well as leasing;

– sale of patents;

– sale of licenses for all types of patented industrial property, except for trademarks, service marks, etc.;

– sale of licenses for non-patented types of industrial property: know-how, production secrets, technological experience, instructions, drawings, diagrams, specifications, technological maps, as well as training of specialists, consulting support, expertise, etc.;

– joint implementation of the R&D, scientific and industrial cooperation;

– engineering and reengineering [6].

Engineering is aimed at obtaining the best results from investments in the implementation of projects through the achievements of science. Through engineering, projects can be shortened, investments can be reduced, production costs per unit can be reduced, and investment efficiency can be improved. Engineering has a close relationship with science, which consists in a single process of creating, testing and implementing technical and technological achievements, advanced solutions and developments. Science learns, generates new ideas and solutions, and engineering brings them to practical use [7].

That is, the role and importance of engineering companies in technology transfer within the framework of IIP is becoming increasingly important due to the functions they perform.

In the world, there are certain regulatory documents on engineering services in various industries that Ukrainian enterprises should take into account, for example, the "Guidelines for the use of engineering services" developed by the American Society of Civil Engineers (ASCE). In addition, the United Nations Economic Commission for Europe, a little later, also developed a "Guidelines for the drafting of international agreements on consulting engineering", in which it defined the various types of engineering. A large amount of work on the unification of engineering was carried out under the auspices of the World Bank and the European Bank for

Reconstruction and Development, which made it possible to formulate a unified approach to justifying investments and making decisions based on engineering developments, taking into account economic and social factors [8].

As functions of engineering as a scientific approach to solving practical problems, the following functions can be distinguished:

1. Research. The study of mathematical and general scientific methods, means and concepts, experiments and logical tools for the initial study of problems, the search for the latest principles and actions.

2. Development. Application of research results for practical purposes, creative use of scientific knowledge to create new models in various subject areas – technological processes, production equipment and enterprises in general.

3. Design. Detailed (working) design of a product or production system, definition of methods and processes of production and operation, determination of the materials used, decision-making on the form and structure of a product or system, determination of the technical characteristics and functions necessary to solve a problem, ensuring compliance with requirements and satisfying needs and expectations.

4. Costing, Budgeting & Financing. This function involves the development of budgets and estimates for the project, the preparation and holding of competitions, as well as the creation of new financial instruments and operational schemes.

5. Construction. The creation of the material infrastructure necessary for the implementation of the designed processes, in the general case, involves the development of a construction site, the creation of construction products, i.e. passive fixed assets, organization of quality control and preparation of project products for operation.

6. Production. Determination of the layout of production processes, selection and purchase of the necessary equipment, determination of materials, raw materials, components necessary for production, and sources of their supply, integration of all production processes, testing, commissioning and inspections, personnel training, organization of pilot production.

7. Operation. Control over the functioning of machines, processes, factories and plants, organization of material and energy support, organization of transport and communications, determination of procedures for the implementation of technological processes and their improvement, control over the activities of personnel, development of skills and abilities of personnel in the implementation of technological processes, quality management of processes and products [7].

The engineering company "SR LTD" – is an official **partner of Siemens Ukraine** (wholly-owned subsidiary of Siemens AG, Germany) of Department "Industry Automation & Drive Technologies" (IA&DT). The company is engaged in the supply, engineering, commissioning and maintenance of industrial electrical equipment, and has extensive experience in practical work. Employees have been working with Siemens equipment since 1985 [2].

That is, such firms take part in all stages of innovation activity and unite an enterprise-developer of innovative technologies and an enterprise-consumer, which, in fact, orders an innovative project and introduces certain innovative technologies.

Thus, the commercial potential of IIP should be considered from two sides: from the side of the company creating innovation and from the side of the consumer enterprise. Let's consider this issue using the example of Siemens and its representative office in Ukraine, a subsidiary of Siemens-Ukraine, and their system integrator, SR LTD.

So, Siemens Corporation has developed an innovative technology "SIMATIC System Audit" as part of the provision of industrial services for enterprises [10]. This technology improves the availability of systems through detailed information about the state of the equipment.

The main requirements of the SIMATIC automation system are to ensure maximum productivity and efficiency of equipment throughout the entire life cycle, including in the face of increasing equipment complexity and increasing cost pressure. As a result, the importance of the availability and serviceability of automated systems to ensure the productivity of equipment is increasing. For perfect coordination of products, systems and services, detailed information about the condition of the equipment is essential. The SIMATIC system audit comes to the rescue, providing the necessary basis for the conceptual design of maintenance strategies, effective equipment modifications and lifetime maintenance. Over time, many manufacturing plants need to adapt to new conditions, expand or modernize for various reasons. Such interventions in the original equipment and automation concept affect all system components and can interrupt the production process due to undefined systems. The reasons for these violations may be, for example, different procedures used by third-party service providers or the lack of systematic maintenance of the automation system. The SIMATIC system audit provides complete transparency on the current status and health of the SIMATIC automation system in use. System audit should be applied even in the absence of current problems, as it will be the basis for determining future service strategies and awarding a lifetime service contract. SIMATIC Lifetime Maintenance from

Siemens optimizes the availability and maintainability of systems and plants. A comprehensive set of services covers the entire life cycle – from planning and development to operation and modernization. The perfect coordination of these services with SIMATIC automation products and systems plays a decisive role in protecting investments and ensuring the efficiency of customer systems and installations [10].

In a transfer, the developer of the IIP, Siemens Corporation, transfers the developed technology to a licensee, an enterprise that consumes the technology. Engineering companies can take on not only the development of the project and its implementation, but also the promotion of technology in terms of the formation of a marketing mix, that is, the commercial potential of an innovative technology directly depends on the Marketing activities of an engineering company.

Conclusions

Using the example of the innovative technology proposed by Siemens Corporation, we will consider the problems and possibilities for overcoming them due to the role of an engineering company. Features of the analysis of demand for technology and the creation of an information base for its implementation are specific in each case. So, based on the experience of cooperation between the Firm "SR LTD" with leading large industrial enterprises, it can be concluded that the innovative technology "SIMATIC System Audit" has not yet won supporters of its implementation in domestic enterprises.

So, what is the reason for this and how an engineering company can help increase the commercial potential of the technology is given below.

1. Lack of awareness of consumer enterprises regarding the quality of technology, design features and properties, as well as compliance with state industry standards, significantly reduces demand. After all, the role of engineering companies here can hardly be overestimated. So, the system integrator of the company, in our study, is the SR LTD Firm, which is able to provide all the comprehensive information about the properties of the technology, in addition, it can adapt it to the real state of the customer enterprise, using certain modules and gradually increasing the capabilities of the technology. This allows the consumer to invest in stages and be convinced of the capabilities and effectiveness of the technology.

2. The factor that significantly slows down the demand for Simatic technology and the speed of its distribution is the high price. Indeed, in the realities of Ukraine, the introduction of such technology requires the search for very powerful investors. The engineering company, thanks to the Costing, Budgeting & Financing function,

is able to increase the investment attractiveness of the project, in addition, the reputation of the engineering company plays an important role for the investor, which further increases trust in cooperation with all project participants.

3. The high technical level of the enterprise-developer, unfortunately, does not correspond to the technical level of domestic enterprises-customers of the technology, which automatically entails the need for an accelerated transition to a qualitatively new level of production of Ukrainian enterprises. It is engineering companies that, in the future, ensure the acceleration of the introduction of fundamentally new technologies and stimulate the emergence of demand for them from customer enterprises.

4. The introduction of a lead strategy used by Siemens requires the formation of demand to enter a new segment. Engineering companies, thanks to close cooperation with a large number of enterprises in various sectors of the country's economy, are able to influence the formation of demand in a certain way through their communication policy, which is embodied in participation in conferences, exhibitions, industry meetings, etc. They convey certain ideas to industrialists, thereby increasing the dissemination of information on innovative technology.

5. The transnational level of the industry (firm) has a stimulating effect on the demand for technology. Thus, Siemens-Ukraine and the system integrator Firm SR LTD carry out external integration, which allows attracting more customers to the new technology, accelerates its distribution and increases the demand for it.

6. In order for a technology to be accepted by the market, and therefore to generate demand for it, it is essential to select the most reputable buyer who creates an authoritative opinion about this technology. Such a marketing strategy is called a "strategy of the luminary." Moreover, the first buyers enjoy preferential terms of purchase, helping their authorities to increase demand for new technology [6]. An engineering company is looking for just such a buyer, which is also interested in providing its services.

7. Engineering companies carry out segmentation of the technology market, help to make a choice of a market segment, contribute not only to the targeted formation of demand, but also to the manufacturer taking into account its specifics inherent in a particular consumer enterprise (industry, etc.), the formation of the price level.

Thus, it can be noted that the role and importance of the activities of engineering companies in all of the above aspects, as a result, significantly increase the investment attractiveness and increase the commercial potential of innovative technology of innovative investment projects at domestic enterprises.

The direction of further research is to identify specific marketing tools, through which it is possible to further increase the commercial potential of innovations.

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MANAGEMENT OF SUSTAINABLE INCLUSIVE RURAL DEVELOPMENT PROJECTS

Khomiuk N., Pavlikha N.

The chapter substantiates the theoretical aspects of managing sustainable inclusive rural development projects. It is proved that the sustainable inclusive development of territorial communities in rural areas depends on the availability of natural resources, the location of settlements, and the effective functioning of territorial communities. The author emphasises that inclusive development is not limited to ensuring accessibility and equal opportunities, but also involves building a conscious society. We believe that the main means of ensuring sustainable inclusive development of rural areas is the diversification of rural development. It is noted that in the context of a full-scale invasion, it is necessary to find effective mechanisms to improve the financial condition of communities and achieve sustainable inclusive rural development, which will contribute to the rapid recovery of Ukraine after the war. The main advantages of the project approach are highlighted, which are the ability to focus on specific tasks and results, ensuring monitoring and evaluation of project implementation. It is emphasized that ensuring sustainable inclusive development in the field of public administration requires public involvement in decision-making processes, involvement of NGOs and experts in project planning and implementation, which ensures a more effective and balanced solution to economic, social, and environmental problems. It is substantiated that the effectiveness of any project implementation in rural areas depends on the correctness of management actions, the chosen management model and its successful implementation.

Introduction

Rural areas are an important component for the development of Ukraine's agricultural sector, but this situation has changed dramatically in recent years. The number of rural residents is constantly decreasing, rural settlements are disappearing from the map, and farm incomes are decreasing. To stop this negative trend, it is necessary to implement a new approach to rural development, which includes the concept of sustainable inclusive rural development, stimulating entrepreneurship, diversifying rural employment and rational use of natural resources.

Today's realities demonstrate unequal opportunities for people from different social groups and regions to meet their basic needs. The main reason for this unequal situation is the uneven distribution of economic resources and public goods. Therefore, the Concept of Sustainable Inclusive Development can be an effective tool for solving social problems in rural areas, as it provides for the guarantee of equal rights and opportunities for all members of society. In addition, humanity is facing serious challenges, which are influenced by factors such as population growth, food choices, technological progress, uneven distribution of income, poor state of natural resources, climate change, peace sustainability, etc.

Today, sustainable inclusive rural development is relevant, as it contributes to solving global problems such as climate change, energy and food security. In the context of martial law, the primary task for the Ukrainian agricultural sector is to provide the population with agricultural products.

Theoretical, methodological and applied provisions of rural development are studied by domestic and foreign scholars: O. Borodina, V. Borshchevskyi, L. Gazuda, Y. Hubeni, V. Diesperov, V. Zakharchenko, M. Lendel, Y. Lupenko, M. Malik, O. Pavlov, O. Popova, H. Prytula, P. Sabluk, M. Talavyria, M. Khvesyk, V. Chemeris, and others. However, despite the significant contribution of scholars to the study of this problem, the theoretical foundations of managing sustainable inclusive rural development projects need to be investigated in order to substantiate the prospects for improving the quality of life, empowering the rural population and their active participation in the production and distribution of benefits, and achieving economic, environmental and food security.

The essence of the concept of sustainable inclusive rural development

The state of rural areas is deteriorating, despite the measures taken by the state policy in this area. To formulate the theoretical and practical foundations of sustainable inclusive rural development, it is necessary to clearly define the conceptual and categorical apparatus. Despite the relevance of the study, there is still no single definition of the term "rural area" in the scientific literature. This is due to the fact that this concept is studied in various scientific disciplines: geography, economics, sociology, ecology, etc. Analysing the existing definitions of the term "rural area", we can conclude that they were developed to meet the needs of certain scientific fields.

In accordance with the structural approach to the formation of the holistic concept of "rural territory", it is advisable to define its main components – structure, aggregate, elements that have various functional components. In our opinion, these are social, economic, financial, natural and environmental, and institutional components.

Rural areas have a significant impact on the development of the economy of Ukraine and its regions. They occupy about 90% of the country's total area and a third of the total population lives there [1]. The rural economy, according to M. Drohomyretska, is characterised by a low level of development, lack of jobs, low labour productivity, insufficient requirements for the quality of labour force, which is due not only to insufficient investment in its development, but above all to their irrational focus. Overcoming these negative phenomena in rural areas should be influenced by the rural territorial community, which should first of all identify economic and social priorities, develop mechanisms for both socio-economic and financial support of the functioning of rural territorial communities in order to involve them in the processes of socio-economic growth of the state [2].

The study of the European Union's experience makes it possible to analyse and predict possible ways of rural development, to identify and develop ways to improve it. According to the Europe 2020 Strategy, the EU's development priorities are smart, sustainable and inclusive growth in the areas of employment, innovation, education, poverty reduction and climate/energy (Fig. 1). As a result, a strong and effective economic governance system has been established to coordinate policy actions at the European and national levels.

Today, sustainable and inclusive rural development is relevant as it contributes to addressing global challenges such as climate change, energy and food security.

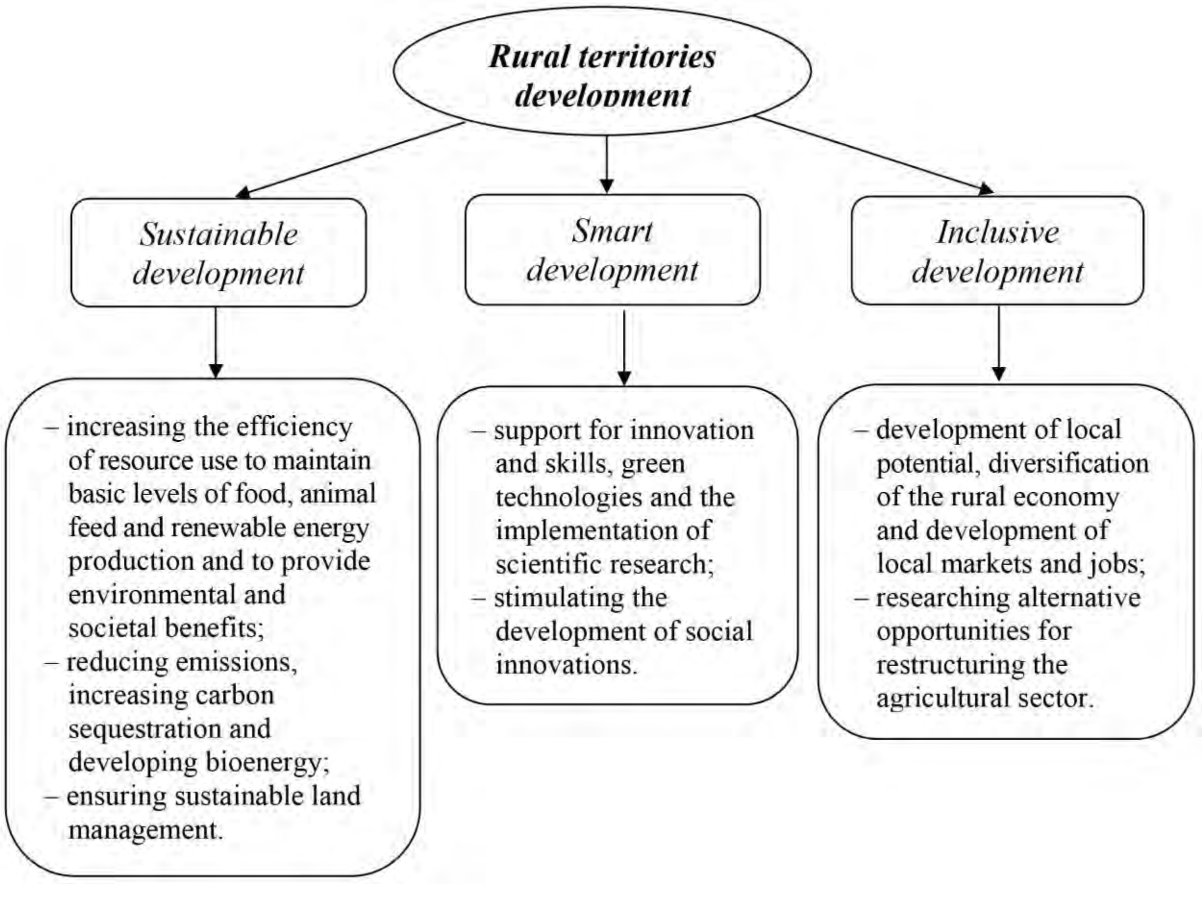

Fig. 1. Rural territories development in the context of the Europe 2020 Strategy

Source: based on [3, p. 26]

According to V. Zahorskyi and Y. Borshchuk, sustainable development of rural areas should be based on the modernisation of production infrastructure, increasing the level of employment of the rural population, reducing labour migration, increasing the competitiveness of agricultural production, improving the quality and safety of agricultural products, improving the environmental situation in rural areas and ensuring a high level of reproduction of natural resources. In addition, a balanced approach to the state regulation of rural development, taking into account its specific features, is important in order to create conditions for self-development and enhancement of human potential [4].

Attracting investment in sustainable rural development, taking into account regional peculiarities, will help create jobs, increase rural incomes, revive local crafts, customs and trades, improve rural amenities and change the mindset of rural residents [5].

For the development of agriculture and rural areas, technological progress, entrepreneurship, the dynamism of agricultural development factors, overall economic growth, and political support are of the greatest importance. It is necessary to revise and form a legal framework that would protect the interests of agricultural producers, create conditions for the effective development of the agricultural sector, and form a favourable taxation system [6].

Y. Lupenko believes that to ensure sustainable development, peasants should be given the opportunity to implement their own entrepreneurial initiative, especially in agriculture, through the development of family farming and multi-stage production. This will result in a qualitatively and quantitatively larger middle class in rural areas, and financially capable, proactive communities will focus their activities on ensuring a high quality of life for rural residents and preserving the environment. According to Yurii Lupenko, these components of the model (peasant-owner, powerful middle class, financially and socially capable rural community) in combination with effective public policy can and should ensure sustainable development of rural areas [7].

Ensuring social inclusion in rural areas involves creating conditions for all residents, regardless of their status, age, nationality, etc. to participate in the social, economic and cultural life of the rural community.

I. Tsymbaliuk notes that inclusive development of a region is a process of achieving complex qualitative and quantitative changes in the spatial system based on the development of the economic sphere by increasing the involvement of economic entities in socially useful activities, forming an accessible infrastructure of the region to create equal opportunities for personal development and ensuring a fair distribution of the results obtained, which is a prerequisite for social upliftment, reducing the level of differentiation of the population and increasing its well-being [8].

T. Zinchuk emphasises that innovative approaches to the formation of the scientific base of agriculture based on inclusive development are a unique opportunity to achieve internal balance, increase the resilience of rural areas and the population by investing in the main areas of the rural economy: socio-economic, educational, healthcare, energy and food security, as well as poverty eradication and, ultimately, access to a progressive, civilised European model of rural development [9, p. 132].

Y. Samsonova notes that in the context of green inclusive growth, environmental protection, rational use of natural resources, food security and solving social problems by involving unequal low-income actors in business to achieve common goals become particularly relevant. Enabling the rural population to participate in the development of agribusiness by creating new institutional approaches based on the principles of environmental protection and efficient distribution of public goods will help to increase the level of well-being of rural residents and their living standards [10].

Inclusive rural development is important for creating an equal society, as it provides equal access to resources for all residents, promotes social interaction, rural sustainability, economic development, improved quality of life and preservation of the cultural heritage and traditions of rural communities [11].

O. Borodina and I. Prokopa consider the issue of inclusive rural development. In their opinion, it should enable all rural residents to use land and other rural resources, the results of economic growth in agriculture and other sectors of the rural economy, participate in socio-political processes and unite social communities on the path of human rights, contribute to poverty reduction and overcome economic and social decline [12].

J. Gupta and other scholars [13] believe that inclusive development will be achieved only through genuine interactive governance that provides tools and creates conditions for adaptive learning and empowerment of marginalised people.

The inclusive development of territorial communities in rural areas in the context of decentralisation depends on the availability of natural resources, the location of villages, the effective functioning of territorial communities, and the correctness of decisions made by the leaders of these communities. Under current reforms, local governments play a key role in managing the inclusive sphere of territorial communities in rural areas. They coordinate the activities of all economic structures, participate in the development and implementation of strategies, programmes and projects [14].

It is important to understand that inclusive development is not limited to accessibility and equal opportunities, but also involves building a conscious society. This can be achieved by creating a dialogue and cooperation between different segments of the population, government officials and scientists, and by involving citizens in the decision-making process on rural development [15].

Under the conditions of martial law in Ukraine, the primary task for the domestic agricultural sector was to provide the population with agricultural products. Since the beginning of Russia's full-scale invasion of our country, the rural areas of the eastern region and the Ukrainian agricultural sector in general have been facing very difficult circumstances. The greatest threat to the economy and the country's survival in the war would have been a complete disruption of the sowing campaign, but this did not happen [16].

Rural areas are mostly used for growing agricultural products, which are one of the main export sectors of the Ukrainian economy. In 2022, Ukraine exported at least $20 billion worth of agricultural products, which is about half as much as in 2021. From the beginning of the full-scale Russian invasion until the end of 2022, agricultural producers supplied 38.94 million tonnes of grains, legumes, oilseeds and processed products to foreign markets. The hostilities have caused significant damage to land resources (mining of territories, increased need for land reclamation), which have been damaged by trenches, shells, military equipment.

The full-scale invasion affected all areas of the country's development, including rural development. On the one hand, the war has resulted in the destruction of agricultural crops, livestock, and infrastructure, which is causing serious difficulties in the agricultural sector. The loss of jobs and lower living standards is another serious consequence of the war for rural residents. Many local residents work in agriculture, and as a result, many workers in this sector have lost their jobs, their wages have been reduced and food prices have risen. This leads to lower living standards and increased poverty in rural communities.

On the other hand, the war has led to an increase in demand for agricultural products. This is due to the temporary restriction of food imports, which forces the state to use its own resources to ensure national security. Thus, rural communities have the opportunity to increase production volumes and receive additional income [17].

Rural communities also help create jobs in other sectors of the economy, such as industry and services. For example, the development of tourism in rural areas will help to create additional jobs and increase the income of local residents.

In addition, infrastructure development in rural communities will help ensure their competitiveness and attract investment. Improved roads, communications and energy infrastructure will make rural communities more attractive to investors and entrepreneurs.

According to O. Zakharchuk, an important condition for the development of the agricultural sector of the economy is an appropriate level of investment support. Investments play a leading role in the technical and technological modernisation of agricultural enterprises and in increasing their competitiveness. Investments are an important prerequisite for innovative growth [18].

Taking into account international standards and requirements, as well as the internal needs of rural areas, it is advisable to implement the principles of sustainable inclusive development of rural communities in national policy, and to focus state support on different areas [19]. For example, in the economic sphere, it is advisable to promote the creation of the following conditions: attracting investment; diversification of agricultural production; diversification of non-agricultural activities; providing state support to small and medium-sized farms; assisting agricultural producers in increasing the added value of agricultural products through storage, processing, trade, marketing, creation and development of cooperatives; improving production, market, and road infrastructures for agricultural development

In the social sphere, it is necessary to promote the creation of the following conditions: creation of a system of cultural and aesthetic education of the community; consulting, training and professional development of rural residents; assistance to young agricultural producers; conclusion and guarantee of compliance with labour contracts of employees with the employer's administration; improvement of infrastructure and material resources in the fields of education and medicine.

In the environmental sphere, it is advisable to promote the creation of the following conditions: development of a system of environmental and patriotic education of the community; responsibility for the state of the environment in the territory of communities; arrangement of rational agricultural landscapes; conservation of degraded low-productive agricultural lands, creation of cultivated pastures and forest plantations on them; work to prevent erosion and landslides; development and implementation of agro-ecological community development programmes.

O. Krupelnytska, O. Gudenko and O. Volynets focus on the fact that sustainable development is based on achieving a balance between the results of socio-economic (in particular, improving the quality of life of the population) and environmental (state of the natural environment) development on the basis of a combination of informatisation and intellectualisation with simultaneous ensuring its social efficiency, aimed at structural and technological restructuring of all sectors of the economy, increasing the welfare of the population and economic growth, building social, market, communication and information systems. In addition, they propose to develop the rural economy by stimulating non-traditional agricultural production, developing a network (in particular, business networks based on marketing projects) for the provision of agricultural innovations as one of the priorities of the "multifunctional" model of sustainable rural development [20].

The main means of ensuring sustainable inclusive development of rural areas, in our opinion, is the diversification of rural welfare, which should be considered as a set of measures aimed at diversifying agricultural and non-agricultural activities, expanding sources of funding for rural development programmes and activities organised by amalgamated territorial communities to expand employment and increase the income of the rural population on the basis of a systematic approach and through information measures.

Therefore, the paradigm of sustainable inclusive development of rural areas is the basis for the development of the concept of diversification of the welfare of these areas, which is based on the principles of complexity, interdisciplinarity and synergy. The concept's target is the effective use of existing and potential opportunities for rural development to improve the quality of life of the rural population; strengthening the competitive advantages of the territories and achieving environmental and food security [21].

One of the areas of sustainable development diversification is the transition to environmentally friendly, i.e. organic, farming, which reduces the negative impact on the environment through the use of organic fertilisers and mechanical processing. In recent years, demand for organic products has been growing in many countries. This creates new opportunities for farmers to switch to environmentally friendly farming and develop this area. In addition, governments promote the transition to organic farming through financial support and training. Another area is the development of sustainable forestry, which ensures the balanced development of forests, preservation of forest cover and reduction of the impact of forestry on the climate and the environment. The use of renewable energy sources, such as solar and wind energy, is relevant in times of war, as it reduces dependence on oil products and reduces carbon emissions [22].

Thus, even in the current conditions of full-scale invasion, it is necessary to find effective mechanisms to improve the financial situation of communities and sustainable inclusive development of rural areas. This will contribute to Ukraine's rapid recovery from the war.

Theoretical foundations of the study of project management for sustainable inclusive rural development

Project management, or project management, is a professional activity based on the combination of the most advanced scientific knowledge and technologies with practical skills. It is focused on obtaining the most effective result in the process of project implementation. Project management is not a dry science, but a living methodology for organising, planning and coordinating the use of human and financial resources throughout the project life cycle. Any project manager, like every aspiring entrepreneur, inevitably faces the fact that in the process of implementing a particular idea, there is always something missing for complete success. In fact, there are three main pillars of success: the quality of the project, its cost and the time it takes to implement it. This "trinity" was called the "trinity of constraints" or "project management triangle" in the USA in the late 50s. Because each side of it is a constraint, and a change in one side inevitably affects the other. The task of project management is to ensure a balance between them [23].

In the rural areas of those communities that have amalgamated and formed self-governing entities, projects are often implemented to improve social infrastructure, which contributes to the quality of life of rural residents. However, it should be noted that not all projects implemented in rural areas are financed by public funds. Grants are the most common form of project funding by donor organisations.

Donors are international organisations, government agencies, commercial entities, public non-profit organisations (religious, scientific, etc.), private charitable foundations or individuals who provide citizens and organisations with the necessary additional resources of various types on a non-commercial, non-refundable basis for the benefit of the whole society [23]. There are many types of donor classifications, which we have systematised and presented in Fig. 2.

The most common source of additional resources (financial and non-financial) for socio-economic projects in rural areas in the European Union is charitable foundations that provide assistance in the form of grants.

The limited funds in both the State Budget of Ukraine and local budgets encourage government agencies, businesses, and the scientific community to look for options to expand the sources of funding for projects in various fields.

Cooperation on international projects and programmes always yields positive results in combining the efforts of small producers to achieve their goals, a transparent mechanism for selecting applicants for participation in the competition, and fulfilling contractual obligations. International projects are being implemented quite successfully in Ukraine. The main donors to Ukraine are the US and the EU.

Significant investments come from Canada, Germany, the Netherlands, Sweden, Switzerland, Japan, Denmark, as well as the UN, the World Bank, the EBRD, and the OECD. Most international projects provide free assistance for the purchase of material and technical resources for enterprises operating in rural areas, but subject to co-financing from various sources. These may include funds from local budgets (oblast, rayon, village, amalgamated territorial communities) and enterprises' own funds [24].

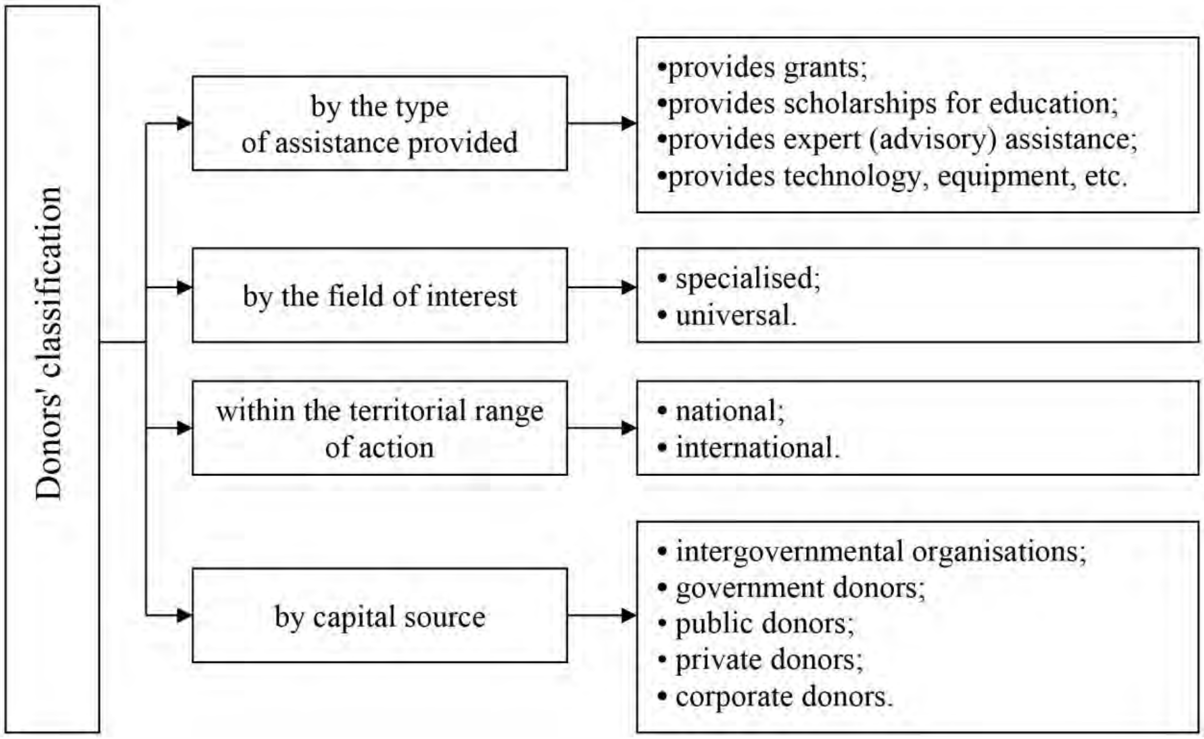

Fig. 2. Classification of project donors
Source: structured according to [23]

Modern project management tools and methods are recognised worldwide and are widely used in all areas of project-oriented activity. Project management is a powerful tool not only for managing the creation of new products and services, but also for implementing targeted changes within individual organisations, companies, and national socio-economic and organisational systems [25].

Project management is "a special type of management activity that consists in the development, preliminary and thorough elaboration of a comprehensive plan (model) of actions aimed at achieving specific goals and its (her) implementation" [26].

Project management is a professional activity based on the application of project culture through the combination of the latest scientific knowledge and technologies with practical skills. With active rural development, through the creation of rural territorial communities, local residents can self-organise, as they are united by a common living space, common aspirations, and most importantly, by the willingness and real actions aimed at improving the economic, social and environmental situation of their native village. In this case, villagers create a so-called local interaction group on their own and elect a leader from among themselves to head it [27].

Effective use of the rural development project management mechanism requires appropriate adaptation, supplementing this methodology with specific approaches, organisational and methodological tools [26]. The scheme of project management for the diversification of the development of rural amalgamated territorial communities is shown in Fig. 3.

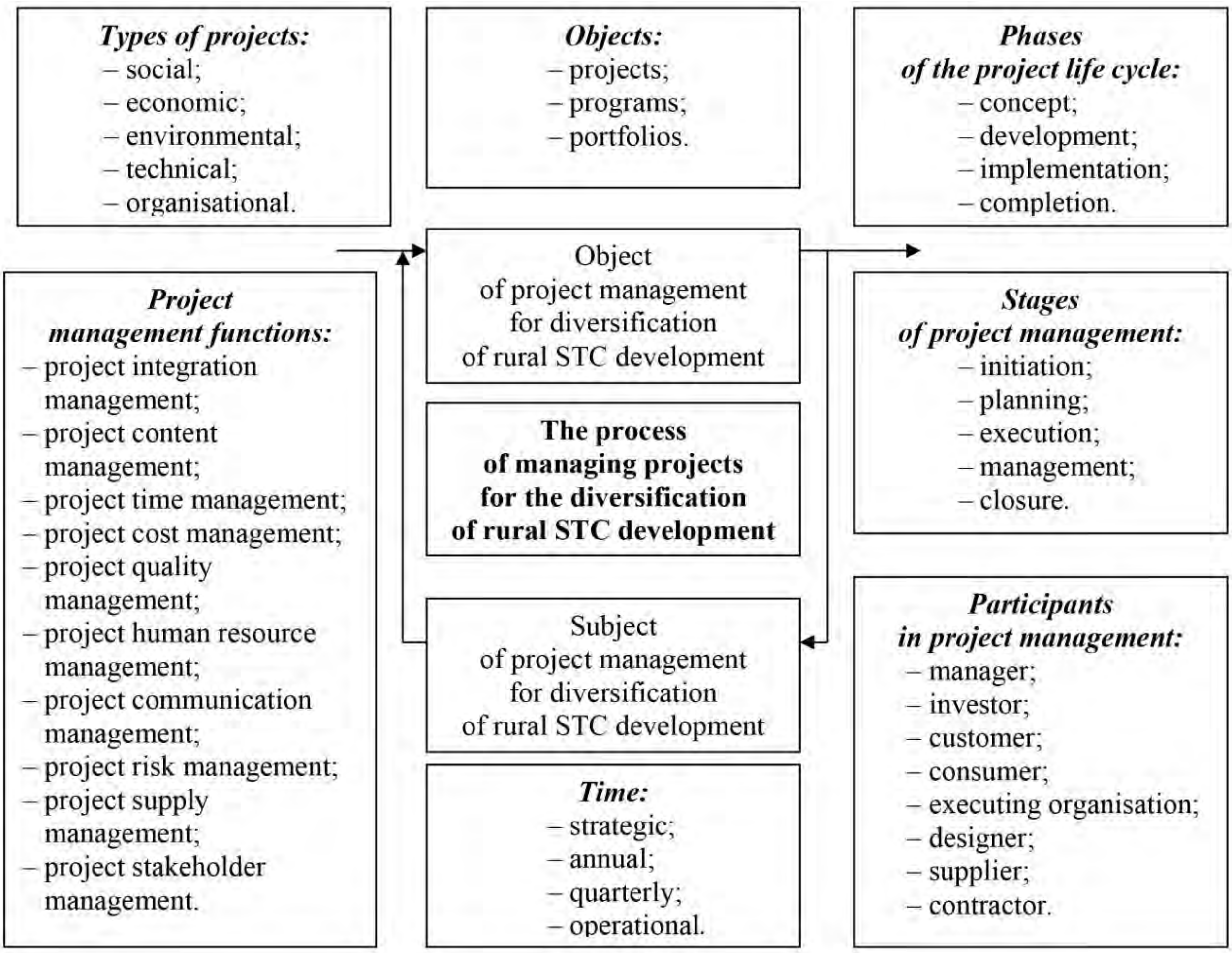

Fig. 3. Management scheme for diversification projects in rural amalgamated territorial communities

Source: developed on the basis of own research

Rural areas are home to not only agribusiness projects, but also non-agricultural activities. Examples include rural (green) tourism or agritourism; timber harvesting and processing; crushed stone and sand extraction; and the construction of processing and food processing facilities.

The development of rural tourism allows for the creation of a comprehensive tourism product that contributes to the development of rural areas. Attracting investment in green tourism will help create jobs; increase rural residents' incomes by providing services to tourists and selling food products; improve village amenities; and revive local folk crafts, customs and traditions.

We agree with the opinions of scientists [28] that promising directions for solving key problems of project implementation, in particular rural development projects, depend on the following factors: creating a favourable institutional climate in Ukraine for implementing innovative projects and attracting foreign investment; economic incentives for the introduction of domestic innovative equipment and technologies; bridging the existing gap between the professional competences possessed by graduates of higher education institutions and those required by employers; ensuring the required number of graduates in line with the real needs for specialists in agribusiness and local self-government.

The main advantages of the project approach are that it allows focusing on specific tasks and results, and ensures monitoring and evaluation of project implementation. The use of the project approach in public administration ensures the efficient and effective use of resources, achievement of specific goals and objectives of sustainable development. In addition, sustainable development in public administration requires public involvement in decision-making processes, the involvement of NGOs and experts in the planning and implementation of sustainable development projects. This ensures a more effective and balanced solution to economic, social and environmental problems [29].

It is worth noting that there are many different project management methodologies. One of the most common is the Waterfall methodology. This is a traditional and logical approach to project management. In the waterfall model, the project process is divided into stages or phases. This approach is effective for projects that can be divided into sequential logical parts, where each stage builds on the previous one. This makes it easy to understand and describe the project logic [30].

The advantages of using Waterfall for sustainable inclusive rural development projects are: it fits projects with precise requirements and defined success criteria; it is suitable for projects with stable and minimal changes in requirements; it provides detailed planning and certainty about project timing and cost.

However, this approach is not suitable for projects with unclear or changing requirements, which is typical for social projects. An additional problem with the waterfall methodology is that it is not suitable for projects with a high degree of uncertainty and change. If each stage is complete, it is difficult to change something after the project has moved to the next stage. This can lead to significant delays and inefficient use of resources [30]. There is also no active interaction with clients or stackholders during the project. This can lead to incomplete satisfaction of client needs or misperception of requirements.

Today, the *Agile* approach is very popular in project management. It is characterised by flexibility and a special approach to management, which involves the provision of a final product at each stage of work, as well as elements of uncertainty at the end of the project [30].

The *Agile* approach provides flexibility and the ability to change project requirements and priorities in response to changing needs, promotes active interaction between the customer and stakeholders throughout the process, and allows for quick response to changes and adjustments to the project during its implementation. However, it requires active participation and involvement of everyone throughout the process. It can also be a challenge for a team that does not have sufficient experience or resources to iterate and adjust on a regular basis.

Given the specifics of sustainable inclusive rural development projects, *Agile* may be the most appropriate approach to use, as these projects often require flexibility to deal with constant change and interaction with stakeholders. This approach allows for quick adaptation to changes and facilitates the involvement of rural residents and stakeholders in the decision-making process for the implementation of the community development project.

Design Thinking is an innovative approach to project management that focuses on understanding the needs and concerns of local people. The approach involves iterative work, development and testing of prototypes, which contributes to the development of new solutions that meet the needs of local communities. This approach allows us to identify the needs and problems of local residents and develop innovative solutions to meet these needs. *Design Thinking* actively involves villagers and other stakeholders in the decision-making process, which provides greater legitimacy and support for the project. The approach also allows for rapid prototyping and testing of solutions, adding changes based on feedback and findings.

Lean is an approach to project management that aims to use resources efficiently and minimise costs. It focuses on defining value for rural people and eliminating unnecessary steps and processes. The advantage of *Lean* for inclusive rural development projects is the efficient use of resources. *Lean* aims to reduce costs and optimise processes, which can be beneficial for projects with limited resources. It also allows you to focus on the real needs of local people and make useful decisions.

Depending on the specific conditions and needs of the project, you can use a combination of different approaches, i.e. apply a *Hybrid Approach*. For example, you can combine elements of *Waterfall* and *Agile*: *Waterfall* is used for the stable stages of a project (e.g. planning and analysis) and *Agile* for the more flexible and iterative stages (e.g. implementation and delivery).

Conclusions

It is important to emphasise that the choice of approach to managing sustainable inclusive rural development projects should be based on the results of the analysis of the need and content of the project, consultations with stakeholders and consideration of available resources. It is better to develop an individual approach that meets the specific needs and characteristics of the project and ensures the successful achievement of the set goals.

Thus, the effective use of the project management methodology for sustainable inclusive rural development requires appropriate adaptation, supplementing it with special approaches, organisational and methodological tools. Therefore, the effectiveness of any project implementation in rural areas depends on the correctness of management actions, the chosen management model and its successful implementation.

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DECISION SUPPORT SYSTEMS FOR FINANCIAL MANAGEMENT CAPITAL OF INDUSTRIAL ENTERPRISES

Khrustalova S., Khrustalev K., Trunova A., Nevliudova V.

The article offers a system of support of decision-making in management of financial capital of production enterprises, which allows to increase efficiency of decision-making in management of financial capital of production enterprises by means of use of specific indicators for calculation of compliance of an enterprise with the strategy of value investment. The system is implemented in the form of a software tool, namely, the code was created using the Vue framework. The interface was created in accordance with the projected design and the needs of the target audience. Testing was carried out according to the most frequent user actions and requests, and in this regard, work was carried out on errors and their correction.

Introduction

Preserving a company's financial capital is a very important part of any business. One of the ways to preserve, and even increase, capital is through investment. Today, there are many investment instruments available: deposits, pension funds, precious metals, real estate, government bonds, cryptocurrencies, etc. But out of all these instruments, shares of large enterprises stand out. Investing in stocks can be very profitable, but this does not mean that buying any company's securities is a safe investment [1–3]. An important part of investing is the fundamental analysis of the securities of companies that can potentially be acquired in an investment portfolio. Automation of this process will improve the quality of analysis, eliminate the human factor from miscalculations, and save a lot of time, which is also useful when analysing hundreds of potential investment portfolio items. Designing systems of this class requires up-to-date and, at the same time, time-tested methods for assessing the financial performance of enterprises. Also, since managers have a great deal of responsibility to the company's employees, it is necessary to be sure that the criteria analysed by the system are reliable. To develop the software tool, the strategy chosen as the basis was the value investing strategy invented by Benjamin Graham, a renowned economist, investor, author and lecturer at Columbia University, whom the most famous investor of all time, Warren Buffett, considers his teacher and whose book The Smart Investor is the best ever written about investments. Since then, the material has been regularly reprinted, and each chapter of the book is accompanied by comments that are relevant to the present day.

The book was translated into Ukrainian and published in 2019 by Nash Format Publishing House [4].

Review and analysis of literature

There are a large number of systems that provide users with up-to-date financial information of enterprises. Such PFMSs offer a large amount of data, charts and historical information not only for companies, but also for government bonds, cryptocurrencies, precious metals, etc. Moreover, the leading giants in this field also offer news related to business, finance and economics. Reference information includes quotes and ratings of securities, press releases and financial reports of companies. Some PFMSs include thematic forums and even offer a range of services for managing personal financial information. One of the largest systems for providing financial information is finance.yahoo.com [5–9], which is a prominent giant in its field. In addition to the browser-based software, the system works on iOS and Android mobile platforms. On the portal (Fig. 1), it is possible to find all the necessary information that may be required not only for fundamental analysis of the enterprise, but also for more complex and narrowly focused calculations.

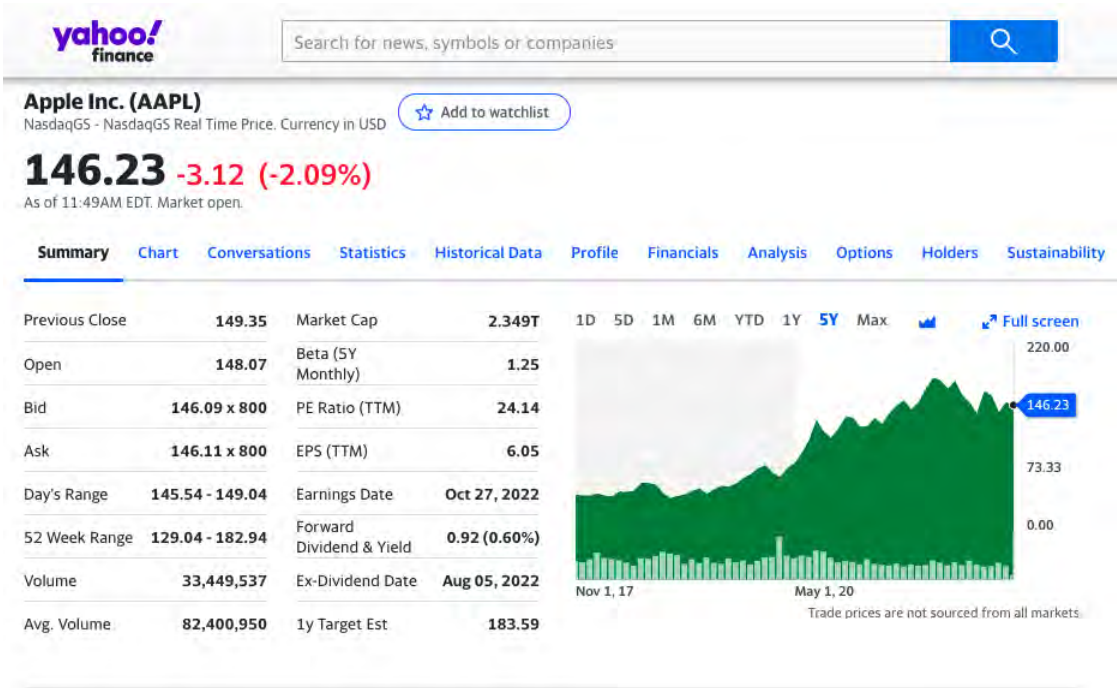

Fig. 1. Primary data of the web resource finance.yahoo.com for the query "Apple Inc"

Also on finance.yahoo.com, users can get information on current economic news, a list of financial instruments that have experienced the biggest rise or fall in the last 24 hours, and some personal finance automation services:

create a personal portfolio that can track up-to-date data on portfolio positions, and get information on taxes and retirement.

Although this service provides the necessary variables for calculating all the indicators of a value investing strategy, it does not have specifically identified strategy indicators that are the basis for finding undervalued stocks.

Another resource that occupies a large part of the financial resources niche is Investing.com, which is a financial platform that provides information on corporate stocks, futures, options, analytics, and economic news. In addition to the website, the system is available on iOS and Android mobile platforms. The product does not currently have a Ukrainian localisation.

Similarly to the previously described Yahoo! Finance resource, the first page of the service has a search box that allows you to find information about the desired company. After the necessary query, we see the screen displaying the data found on the company "Apple Inc.", as well as indicators of the largest stock indices, information on similar tickers, as well as a navigation area, which allows us to display information about the company found (Fig. 2).

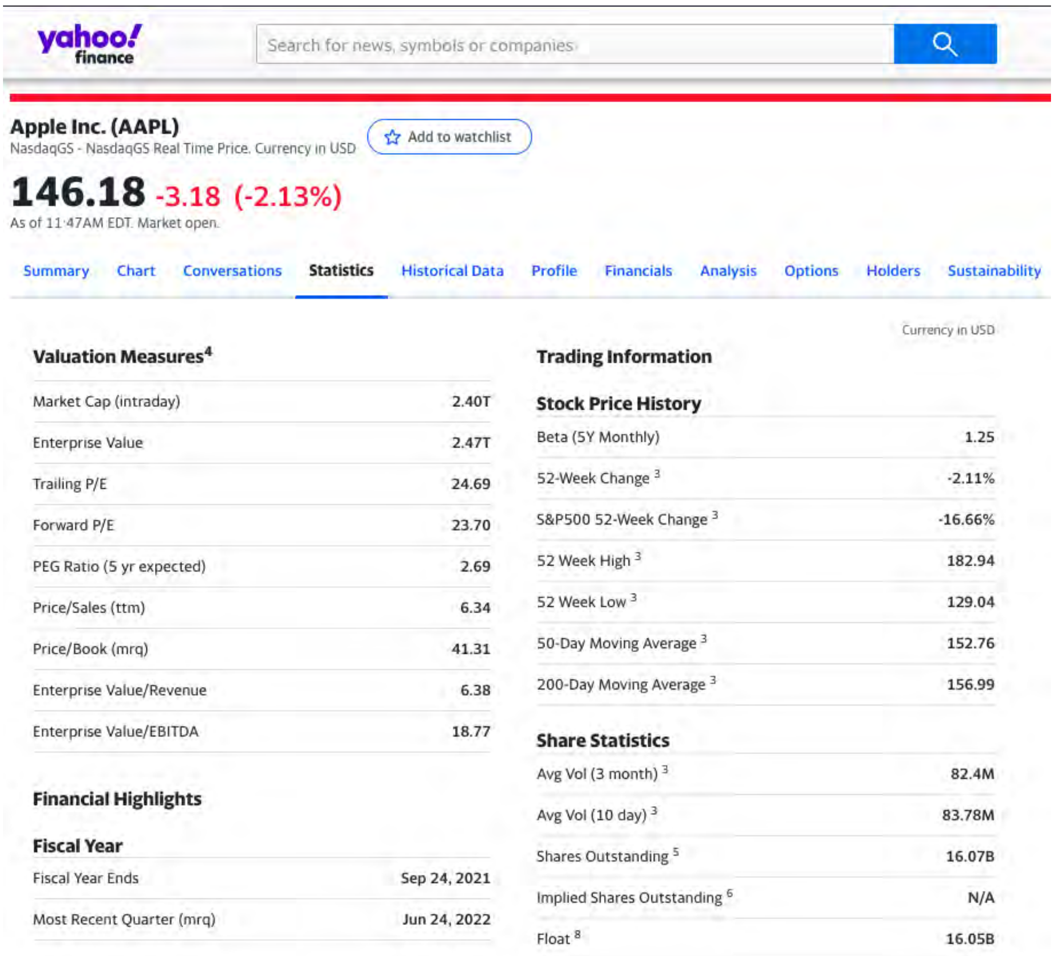

Fig. 2. Fundamental characteristics and indicators of Apple Inc. provided by finance.yahoo.com

On the investing.com platform, in addition to the company's financial information, the user can find information on publicly traded investment funds and bonds, cryptocurrencies, articles on general market analysis or analysis of a specific investment instrument from invited experts, charts, information on brokers, information on investment conferences and webinars, as well as additional paid content with advanced features for managing a personal investment portfolio, which includes advice on potential investments.

It should be noted that this extended tool allows to calculate all the indicators calculated in the developed software tool. However, there are a number of shortcomings that are essential for the development of a unique decision support system adapted to the realities of modern Ukrainian entrepreneurs and investors:

Calculating the status of each indicator. Since the main area of activity of potential users is not investment and the economic sector in general, statuses for each indicator (recommended, satisfactory, unsatisfactory) were developed to help the user make a decision based on a table of correspondences, in which the recommended values were taken from Benjamin Graham's own standards, and satisfactory values are the minimum allowed in miscalculations.

Displaying the necessary information. The investing.com service provides a large amount of complex information, including charts and calculations of complex financial indicators that are not considered in fundamental analysis. The developed software tool allows us to analyse the company fundamentally, thereby filtering out a large share of financially unhealthy companies.

Intuitive interface. Unlike the reviewed investing.com, the developed system has a user-friendly and minimalised interface exclusively for analysing an enterprise from the point of view of a value investment strategy. Each function of the system is understandable for a user of any website or application.

Ukrainian localisation. Since the software application was developed for use by Ukrainian entrepreneurs and investors, it is important that the system provided services in the state language, which is understandable to everyone regardless of their knowledge of a foreign language.

Another resource that is popular among analysts is finviz.com. This service provides information on financial analytics of companies, futures, cryptocurrencies, and news that may affect financial markets. It has become most popular for displaying the state of the stock market through an interactive map (Figure 3), which adapts the size of each company depending on its sector and market capitalisation.

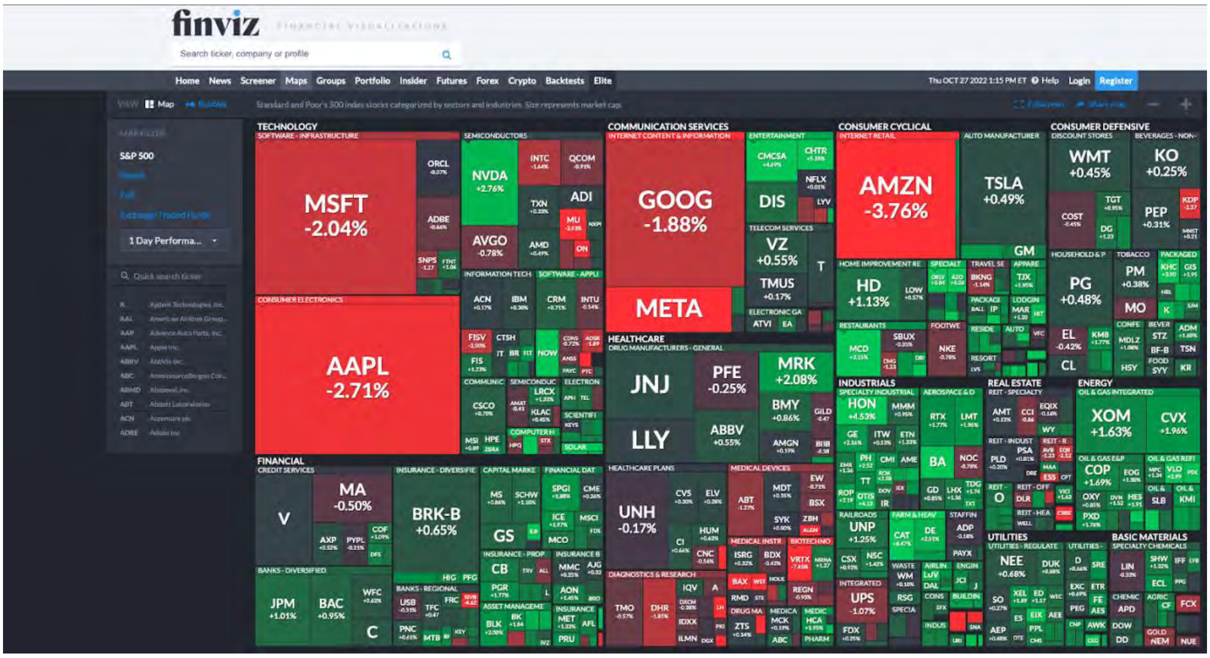

Fig. 3. Stock market map provided by finviz.com

To date, there are no widely available systems that would analyse an enterprise comprehensively and exclusively by the value investment strategy. At this stage, we have considered systems that partially or indirectly calculate one or another strategy indicator separately. This is the main disadvantage of the systems described below, since each indicator does not indicate the reliability of investing in an enterprise, but the comprehensiveness and recommendation of all indicators is the reliability of an enterprise for long-term investment in it.

There are many decision support systems, including economic ones [10–12]. Such systems are implemented in the form of software tools (most often web applications or desktop programs), for example, such as yahoo.finance or finviz. Using these systems, you can find a large amount of historical information, charts, news, expert articles and analytics. However, they do not offer the user any strategy for how to use this information. Therefore, we propose a decision support system that allows the user to analyse the securities of companies using a search field and check whether the company is suitable for a value investment strategy.

Value investing is an investment strategy based on the identification of undervalued securities using fundamental analysis, proposed by Benjamin Graham and David Dodd. Securities eligible for the strategy should have a number of criteria that an investor can use to assess the strategy's suitability: the security should be trading below book value, have a good dividend history, and have low price/earnings and price/book values. Specific recommendation values are listed in the table of correspondence between indicator values and statuses.

Block diagram and algorithm of the decision support system for managing financial capital of manufacturing enterprises

The figure (Fig. 4) shows a block diagram of the decision support system. The input data must be received from the user, most often through the form elements – a search field for entering keywords to find an enterprise for analysis. After the user has entered the data, a list of found enterprises is generated, in which the user can select the desired enterprise. The algorithm of the decision support system for managing the financial capital of manufacturing enterprises is shown in Fig. 5.

The software starts by receiving data from the user using the search field. Upon receiving the data, the client (frontend) of the software tool processes it into a format that the server understands and sends the appropriate requests. The server, in its turn, makes appropriate queries to the database in order to process them and send the client the required response. After the client receives a response from the server, the data goes through two levels of processing – through the indicator service and the status service, where the business logic of the software tool is already running – calculating indicators and comparing each indicator with the correspondence table in order to form the status of the indicator and send the already generated data for rendering in HTML.

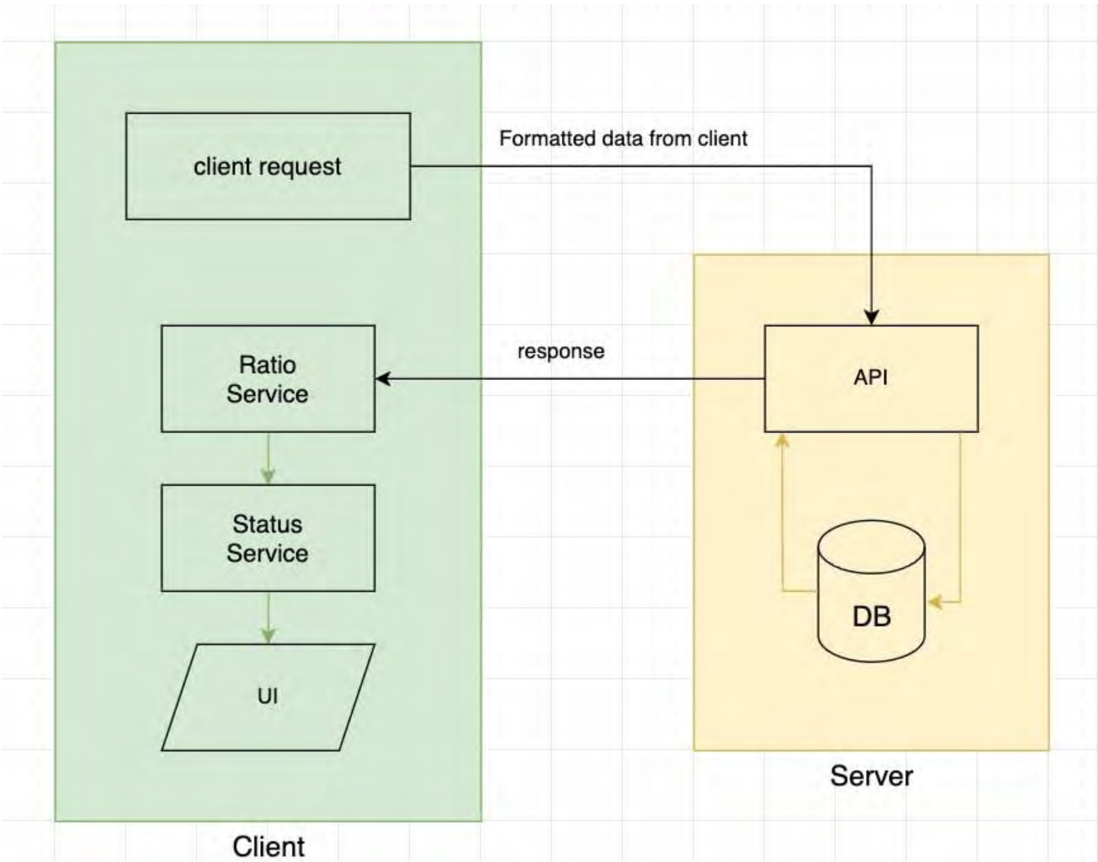

Fig. 4. Technical diagram of the SPRD operation

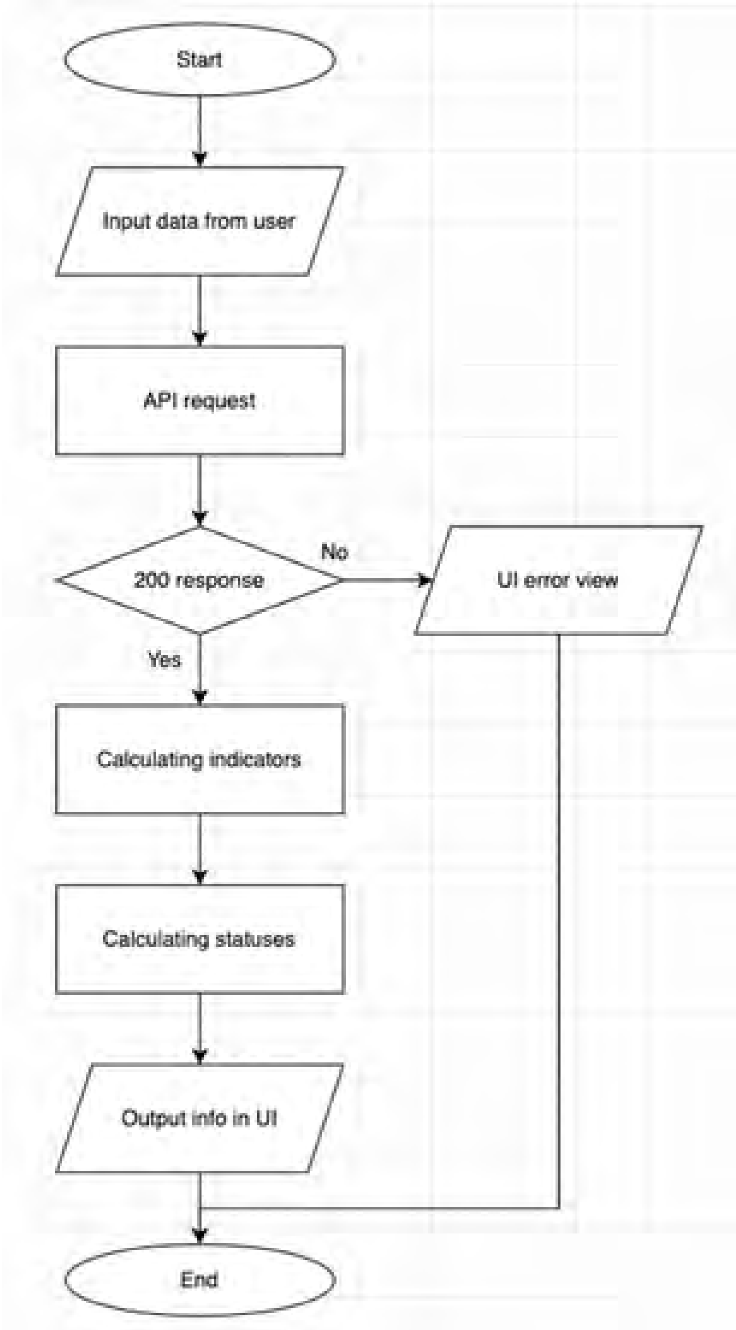

Fig. 5. Algorithm of the decision-making support system
for financial capital management of manufacturing enterprises

After making the appropriate selection, the client receives information about the selected company in an understandable format, thus being able to send a correct request to the server to obtain all the information about the company. The API, receiving requests from the client, returns the relevant data to the client via the HTTPs protocol, using a unique security key, without which it is technically impossible for the server to return data to the client. If the key is missing, the server returns a 403 Forbidden error to the client, which is usually sent by the server due to internal restrictions. After the data is correctly sent to the client, it goes through two levels of processing – through the indicator service and the status service – to perform the necessary formatting so that the system can correctly display the formatted data on the user's screen. After successful formatting, the user sees the system interface – the company has been added to the list of analysed companies, and the right side of the screen displays extended information about the company, graphs and calculated coefficients.

Calculation of ratios

The indicators that Benjamin Graham analysed in his research are still relevant today, as they are fundamental for any company and show how stable, growing and exposed to financial global crises the company's business is. The indicators are presented below.

Current ratio

This indicator describes the extent to which the company is solvent. It indicates the ability of the company to repay its current liabilities, in such a way that the company converts its current assets into money, and this money is used to cover its liabilities. The recommended value is greater than 2. If this indicator is calculated below the recommended value, it indicates that the company has solvency problems, as it has insufficient current assets to meet its current liabilities. The current ratio is a ratio:

$$Current\ liquidity\ ratio = \frac{Current\ assets\ of\ the\ enterprise}{Current\ debts\ of\ the\ enterprise}\ .$$

Obviously, for a potential investor, the higher the value of this indicator, the better. But on the other hand, if the indicator is too high, it indicates an inefficient asset structure, i.e. inefficiency of the company's managers and owners. However, it is worth noting that the calculation should analyse the current liquidity of the company with competitors in the industry, as the recommended value of the ratio may differ in many areas. Over time, the current liquidity of large, successful enterprises is declining. This is due to improved budget planning and faster asset turnover.

Stable company profits

In general, this indicator means that the company should not have had any unprofitable quarters or fiscal years in the last ten years. Stable profit is an important component of any business. The company's profit is the main source of funding for the company's development, ensuring all forms of investment, paying dividends, and improving the material and technical base. All company activities are aimed at stabilising profits at a certain level, or even at ensuring profit growth. Stable profit is an indicator of successful management, the relevance of the products manufactured or services provided by the company.

Dividend history

The company must have been consistently paying dividends to its security holders for the past twenty years. Dividends are a part of net profit distributed among participants (owners) in accordance with their share in the company's charter capital. Dividend history is an important component of a joint-stock company's strategy. This indicator affects the attractiveness of the company for investors, the value of the business, and the company's image. In addition to actual dividend payments, an excellent indicator is the growth of dividend payments per share. This indicates that the company's profit is growing. A stable level of dividend payments signals that the capital invested by investors is working effectively.

Profit growth

The most comprehensive indicator, calculated as the difference between the return on each security in the last and first three years of the decade. Average data for the first and last 3 years of the decade are taken to smooth out frequent market fluctuations caused by the economic cycle. From the point of view of assessing the potential profitability of a company, the average is more reliable and accurate if you compare the indicator only for the last year. Moreover, the advantage of averaging is that it can be used to address the issue of all additional expenses and tax deferrals, which are also part of the company's financial history.

The Graham coefficient is calculated as a ratio:

$$\frac{Company\,assets - company\,debts}{number\,of\;ordinary\,shares}.$$

Benjamin Graham first discussed net present value per share (NCAV) in Security Analysis [4], co-authored with David Dodd. In the book, NCAV is defined as current assets minus all liabilities and claims to be issued. Benjamin Graham was looking for companies whose market value was less than two-thirds of their net working capital. This indicator is one of the key ones for a value investing strategy, because if a company were to cease operations and sell all of its physical assets, the value of these assets would be the liquid value of the company.

The liquid value of an enterprise is the total value of all its physical assets, such as inventory, equipment, and real estate. It excludes intangible assets such as intellectual property and brand awareness.

Thus, a security trading below the Graham ratio allows an investor to buy a stake in a company at a lower price than the value of its current assets. And as long as the company has reasonable prospects, investors are likely to get significantly more than they pay. According to Graham, investors will benefit significantly if they invest in businesses whose share price does not exceed 67% of their Graham's P/E. However, it is important to be clear that not all stocks selected using the NCAVPS formula will have high returns, and that investors should also diversify their assets using this strategy. Graham recommended having 10–30 stocks in a portfolio.

The Graham number is calculated as follows:

$$\sqrt{22.5 \times \frac{market\ capitalization}{annual\ profit\ of\ the\ company} \times \frac{market\ capitalization}{book\ value\ of\ the\ company}}\ .$$

Graham's number measures the fundamental value of a stock, taking into account the company's earnings per share (EPS) and book value per share (BVPS). The Graham number is the upper limit of the price range that a defensive investor should pay for a stock. According to the theory, any share price below the Graham number is considered undervalued and therefore worth investing in. The ratio is used as a general test when trying to identify stocks that are currently selling at a good price. The value of 22.5 is included in the calculation to reflect Graham's belief that the price-to-earnings (P/E) ratio should not exceed 15x and the BVPS should not exceed 1.5x (hence, $15 \times 1.5 = 22.5$). Graham's number is also a key indicator in calculating whether a security is suitable for a value investing strategy, although it does not take into account many of the fundamental characteristics that are considered reliable for finding a potential investment, such as the quality of management, major shareholders, industry characteristics and the competitive environment.

To develop the business logic of the software application, it was necessary to analyse the shortcomings of existing systems to solve a specific task: analysing the enterprise for compliance with the value investment strategy.

The main disadvantages are:

– insufficient data to calculate the necessary indicators;

– lack of statuses on the calculated indicators;

– an intuitive interface;

– Ukrainian localisation.

After analysing the main competitors in the industry, it was necessary to design a table of correspondences, which would help to calculate the status of each indicator (recommended, satisfactory, unsatisfactory). The values in the table for each indicator were taken from Benjamin Graham's recommendations, which he described in his book The Intelligent Investor, as well as the Graham Ratio and the Graham Number, which are calculated to find undervalued and potentially economically successful companies. Table 1 shows the correspondence between the values of the indicators and the statuses displayed by the developed software tool.

Table 1

Correspondence of indicator values and statuses displayed by the developed software tool

Name of the coefficient	Recommended status	Satisfactory status	Unsatisfactory status
Current liquidity ratio	≥ 2	< 2	< 1
Stable profits	No unprofitable years were identified	A loss-making quarter, but not a year, is identified	A loss-making year is identified
Dividend history	The company has been paying dividends for the last 20 years	The company currently pays dividends	The company does not pay dividends
Height profits	Average earnings per share for the last 3 years are at least 33% higher than the average earnings for the first 3 years of the last decade	The average profit for the last 3 years is higher than the average profit for the first 3 years of the last decade	The average profit for the last 3 years is lower than the average profit for the first 3 years of the last decade
Profit growth			Over the ten-year period, a loss was recorded
Graham's coefficient	Current share price within 50–70% of the ratio	Current share price within 40–80% of the ratio	The current share price is not within 40–80% of the ratio
Graham's coefficient			Negative value of the ratio
Graham's number	The Graham number is greater than the current share price	–	The Graham number is less than the current share price
Graham's number			The set of P/E and P/B ratios is greater than 22.5

Development of a decision support system for managing financial capital of manufacturing enterprises in the form of a software tool

To develop the decision support system, the Visual Studio Code programming environment was used. This is a free tool for creating modern software tools. It is positioned as a lightweight code editor for cross-platform development of software applications.

The development of browser-based software applications is usually divided into front-end (development of the client side of the software tool) and back-end (development of the server side of the software tool), although this division is rather superficial. In fact, the development of a software tool consists of several large stages beyond programming.

A programming language is the most important tool for any developer. It is used as a tool to create programmes that control the behaviour of machines. In fact, a programming language is similar to a foreign language, but it can be used to convey information to a computer rather than a person. Continuing to draw parallels between a foreign language and a programming language, we can say that the goal of a programmer is to use the language so that the computer understands the developer.

The developed software tool was created using the Vue.js frontend framework, which was written in the JavaScript programming language. JavaScript is a dynamic, object-oriented, scripting prototyping programming language. It is most often used on web pages to make the interface dynamic, but it can also be used to develop desktop, backend, and mobile applications.

It should be added that the development of client applications in a browser is impossible without the use of such languages as HTML (HyperText Markup Language) and CSS (Cascading Style Sheets). HTML is a hypertext markup language that absolutely every browser understands and then interprets the code into an interface that is displayed on the monitor screen. CSS, in turn, is a style language used to describe the appearance of HTML documents. These languages cannot be used to express a specific algorithm of actions to be performed by a computer, but they are very important for web development, because it is thanks to them that the user sees a convenient and understandable interface that is already dynamically working with the help of the JavaScript programming language. All these three languages are the main technologies of the World Wide Web.

If we describe only frontend development separately, JavaScript programs are called scripts that are embedded in the HTML code of a page and executed by the browser. Scripts are executed as plain text, so they do not require a compiler or other additional processing. JavaScript does not provide low-level access to memory or CPU, as it was originally created as a language that could add dynamics to software applications in the browser. Today, JavaScript is the only programming language for client-side applications, as it has two significant advantages: full integration with HTML/CSS and support for all modern browsers.

The design of the software tool (Fig. 6) was based on the assumption that most users will not be experienced in fundamental analysis of the enterprise, and therefore the interface should be as simple and intuitive as possible for any user [13]. Each calculated coefficient is displayed in a geometric shape with a colour corresponding to the status – green, yellow or red. It is known from the school curriculum that red means danger, while green, on the contrary, is perceived calmly and symbolises safety. Yellow, in the context of a software tool, is an intermediate status between recommended and not recommended, not radically perceived by the user as a negative value, but also makes them pay attention and weigh their decision further. The price of one share of the company is shown in a neutral blue figure, because only after analysing the coefficients of the value investment strategy can the user understand whether the price of the security is fair.

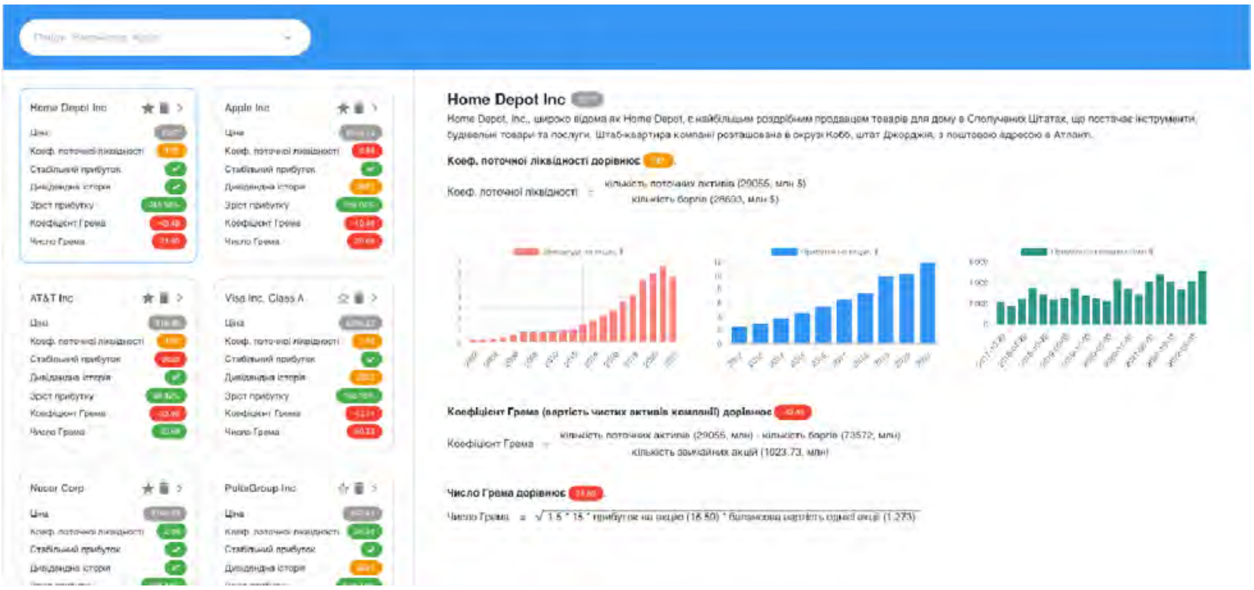

Fig. 6. Interface of the software tool

At the top of the screen, there is a search box that allows users to use keywords to the ability to find the required company for analysis. After entering the keyword, the application sends a request to the server and receives a list of companies that were found for the corresponding query in the Alpha Vantage database (Fig. 7).

The user can select any of them, and after that the company will be added to the list of analysed companies (Fig. 8) Information about each enterprise is displayed in the form of a card (Fig. 9), which contains the name of the enterprise, icons for quick actions, such as adding to favourites, removing from the list and making it active, as well as the name and value of the coefficient with the corresponding status. The active enterprise is the one that the user added to the list last or selected by clicking on the corresponding icon. On the interface, the active company is highlighted by a blue frame, which is the main colour of the application – it is used for the top part of the application, as well as the colour of the EPS chart. The blue colour is more neutral than the colours used for statuses, so it will not distract the user from the main functionality of the application, but adds a corporate identity and separates the application interface from the top of the browser interface itself.

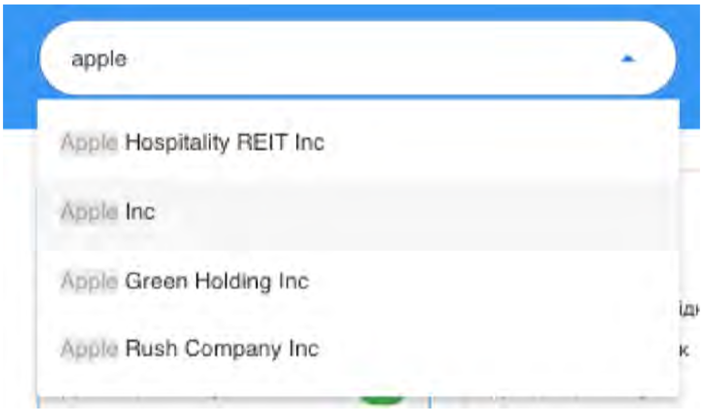

Fig. 7. List of companies found by the query apple

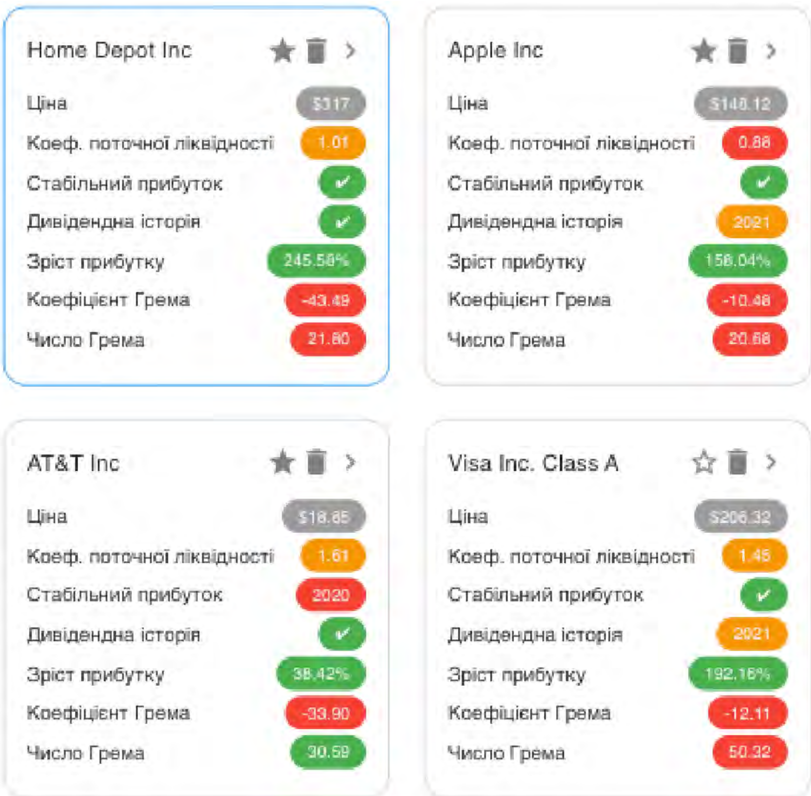

Fig. 8. List of analysed companies in the current user session

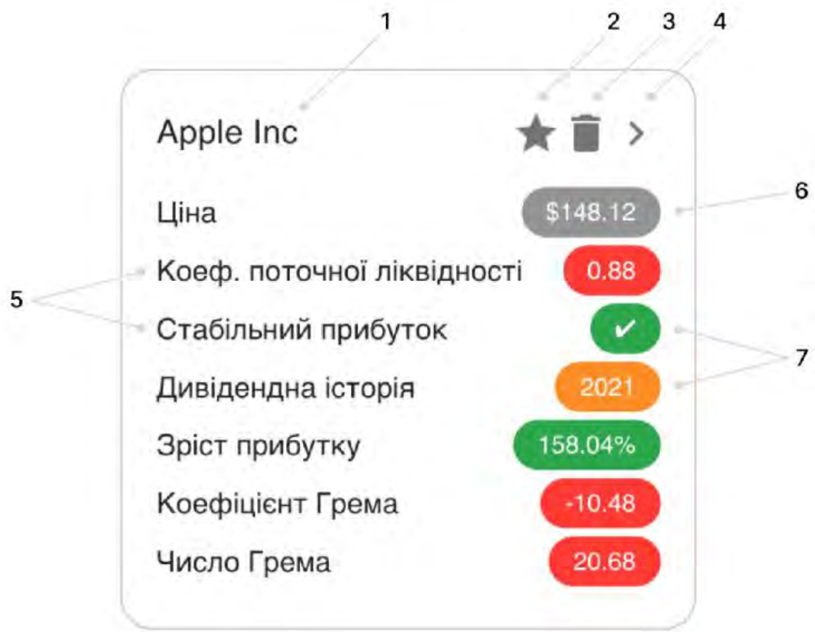

Fig. 9. Card with general information about the company

Card with general information about the company, where:

1 – Full name of the company. The layout is designed in such a way that if the name is too long to fit on the card, the name is cut off and the last characters are replaced with an ellipsis.

2 – Icon for adding a company to the list of favourite companies. If the company is already in the list, the icon is greyed out, otherwise only the silhouette of the icon is displayed, which indicates that the company is not added to the list of favourites. After reloading the page, all information about the enterprises that have been added to the favourites list will be loaded again with the most up-to-date data.

3 – Delete icon. It removes the company not only from the list of analysed cards of the current browser session, but also from the list of selected companies.

4 – Icon for setting the enterprise to the active position. When you click on the icon, a blue frame is added to the card, indicating that the company is in the active position. On the right side of the screen detailed information about the company will be displayed: dividend schedules for per share, earnings per share, profit for the quarter, as well as detailed information on the calculation of the value investing strategy ratios.

5 – Names of coefficients.

6 – Share price. When you hover over the price, a message appears with information about the last update of the price of one share of the company.

7 – Calculated coefficients, according to the names, as well as with automatic calculated statuses, such as recommended, satisfactory and not recommended,

with colours corresponding to the status name. On the right side of the screen, the user can see extended information about the calculated coefficients (Fig. 10), as well as a short description of the analysed company. Each coefficient corresponds to either a formula that was used to calculate the coefficient or a graph showing the data used to form the coefficient value. This data is very important for the user, as it allows him or her to check the correctness of calculations, make sure what data is needed for the fundamental analysis of the company, and see the regularity in the graphs, for example, in which quarter the company receives the largest profit or what is the movement of dividend payments. When analysing several companies with similar ratios, this can play a key role in decision-making.

Fig. 10. Extended information on the company's ratios

After the user has entered a keyword to search for a business and clicked on any business in the provided match list, a request is sent to the API to receive a response from the server with the relevant information. The program code checks whether the response contains a 200 status, and only in this case the application continues to calculate the data from the server. In any other case, the user will see a message on the interface that the server is unable to return the correct data. In this case, the user can try to repeat their actions or try to select another company in the email displayed after entering the search keyword.

Conclusions

Investments are currently one of the most popular and effective ways to preserve and increase financial capital and generate passive income. The first step in analysing a potential investment is a fundamental analysis of the company, which allows you to draw initial conclusions about the company's business, which is the basis for making a decision on investment. Automation of this process is a necessity, as searching for company data for fundamental analysis is a time-consuming process, and the human factor can play a key role in analysing a large amount of data. Thus, the proposed decision support system for managing the financial capital of manufacturing enterprises allows to increase the efficiency of decision-making in the management of financial capital of manufacturing enterprises by using specific indicators to calculate the compliance of the enterprise with the strategy of value-based investment.

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USING IT-MARKETING PRODUCTS IN COMMERCIAL REAL ESTATE PROJECTS

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The commercial real estate market in Ukraine has changed significantly over the past few years. This article focuses on commercial real estate, in particular, shopping and entertainment centers (SECs).. Ukrainian SECs have suffered significant losses due to the COVID-19 pandemic, and then some more suffered serious damage during the full-scale war. However, most of the SECs have resumed or are resuming their operations, and new SECs are being unfrozen. The unstable situation in the country, massive population movements within the country and the departure of many Ukrainians abroad make the management of SECs to revise their development plans and marketing strategies. Modern marketing strategies for promoting SECs require the use of innovative tools. This paper considers the problem of using special software for marketing automation. The authors have selected the most well-known marketing automation platforms for any project and conducted a comparative analysis of them.

Introduction

Now, when our country is facing a more terrible disaster – the war – after a long quarantine caused by the COVID-19 epidemic, Ukrainians need any positive emotions, rest and entertainment more than ever. Despite the fact that these are not essential services, the demand for entertainment has not disappeared, and after our victory it should grow significantly. One of the places that Ukrainians prefer to relax or buy necessary things is the SEC. Shopping and entertainment centers are quite profitable commercial real estate projects from an economic point of view.

The commercial real estate market has frozen in most Ukrainian cities due to the aggressor's invasion. Many commercial real estate objects were destroyed, and those that were not damaged still felt the negative impact of the war. Therefore, the commercial real estate market will not be the same after the war.

According to the Ukrainian Council of Shopping Centers (UCSC), SEC's direct losses, calculated as the cost of repairing the damage, amount to $350 million. As of the beginning of June, 23 SECs in Ukraine suffered significant damage [3].

The largest share of destroyed SECs falls on the East – 12 buildings were damaged to the tune of $250 million. In Kyiv and the region, 6 SECs were damaged to the tune of $68 million. In the South, 5 SECs were destroyed to the tune of $29 million. A diagram of damaged SECs by region is shown in Fig. 1.

The most affected SECs are Port City (Mariupol), Nikolsky and Karavan (Kharkiv), Retroville (Kyiv), and Fabrika (Kherson).

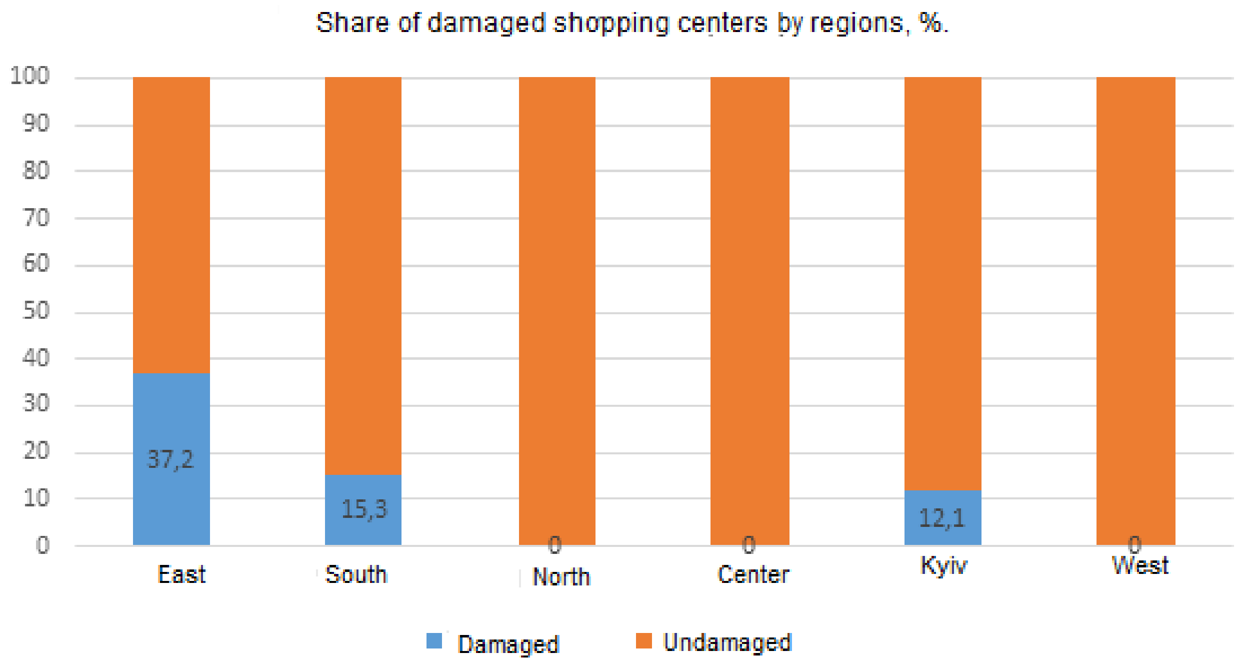

Fig. 1. Share of damaged SECs by region

Almost immediately after the full-scale invasion of the Ukrainian SEC market, all Russian-linked chains began to withdraw, which led to the release of a significant amount of space and a rapid increase in the average market vacancy rate.

The limited range of goods and lack of development reserves caused almost all SEC management companies to have difficulty finding alternative operators of a comparable scale.

In addition, the war has also changed the consumer profile in many regions of Ukraine: local residents have left and been replaced by IDPs, most of whom are in difficult financial situations. This has led to a mismatch between the structure of the brands offered and the incomes of the population.

However, despite the martial law and risks, most foreign chains have not only not left Ukraine, but continue to operate actively: McDonald's, LPP group (Cropp, House, Reserved, Mohito), LC Waikiki, DeFacto, Decathlon, New Yorker, Adidas, Reebok, JYSK, Leroy Merlin, Auchan.

Global solidarity and loyalty to our country give us hope that many popular brands that had previously ignored our market may enter Ukraine immediately after the war is over: Uniqlo, Starbucks, Peek & Cloppenburg, Abercrombie & Fitch, C&A.

Features of marketing automation in retail projects

Today, the owners of shopping centers, regardless of whether they have been damaged or not, are faced with the task of revising their business to meet new consumer needs and market conditions. In addition, even before the war ends, some developers plan to start building new shopping centers that will immediately be oriented towards the new face of the Ukrainian consumer.

Competent decisions and the ability to follow current trends are becoming a key factor in the organization of retail operations and the success of the company.

Consumers are changing, and in the face of a long-term crisis, a big name and attractive advertising are no longer enough. When costs are rationalized and "emotional" expenses are reduced, people need to be offered something more than "a place to buy food, clothes and a new smartphone."

The consumer should be interested in coming and staying for a long time, and then returning and bringing new customers with them.

Promotion of a shopping center is among the most important activities required by any SEC regardless of its size, launch date, concept or anything else. As you know, one of the key indicators of the success of a shopping center is its attendance. It is high attendance rates that allow tenants to earn money, and the owner to earn money as well.

The problem of promoting and developing retail projects is solved by modern marketing tools. In general, there are three ways in which SECs can be promoted: improving operational efficiency; creating new formats such as online-offline hybrids; and personalization - managing the customer journey.

Recently, the process of marketing digitalization has been observed in all areas of business. This problem was first raised by Western scholars in their works: Cham, Dara, Grewal, Hulland, Herhausen, Järvinen, Nguyen Ngoc Hien, Pascucci, Royle, Silva [1, 2, 4–9, 11, 12, 14]. Ukrainian researchers have also paid attention to the digitalization of business, including marketing [10, 13].

According to the author of [7], marketing automation as an ideology is increasingly being used by marketers to automate traditionally manual tasks, including managing and delivering content and personalized marketing communications, as well as to increase conversion rates (the ratio of the number of visitors to a company's website who perform certain actions to the total number of visitors).

Marketing automation software enables marketers to customize content, align messages, and optimize their workflows. It also helps to speed up and improve the quality of reports, coordinate the work of marketers with sales managers, which will help to achieve higher performance and business growth in general.

The main goal of marketing automation is to deliver the right content to the right person at the right time so that they perform the action required by the company. Thanks to the rapid development of this technology, it has become available not only to large but also to small and medium-sized businesses. Today, the average cost of using such technologies per month is $9–15, and the number of companies that automate marketing reaches 140 thousand worldwide.

Marketing automation is data-driven, so any marketing automation system needs effective data management tools. The most important data that such a system needs is the data that fully reflects consumer behavior, tastes, and needs. Only if you have accurate information about potential and existing customers can the system promptly provide the necessary information.

But collecting data alone is not enough, as it can quickly become outdated. Companies close down, change their place of registration, are merged with other companies, and individuals change their phone numbers, email addresses, jobs, and statuses. Changes also occur at the state level: mergers of departments or, conversely, the emergence of new government agencies, changes in the names of cities and streets, etc. Every day there are some changes that must be reflected in the system, and only then can it be called effective.

Analysis of modern marketing automation programs

Automated marketing has already proved its superiority over manual marketing. Table 1 shows its main advantages for promoting retail projects, including SEC.

Table 1

The main advantages of using marketing automation (MA) tools in SEC promotion

№	Name of the advantage	What is the benefit?
1.	High conversion rate	The clear and truthful data obtained through MA allows you to send targeted messages to the right people who are more likely to be interested in what the SEC has to offer.
2.	High quality control over business performance	MA is a good way to demonstrate which marketing activities are effective and which are not. This makes it possible to reallocate the budget in such a way as to increase the scale of effective marketing tools and abandon ineffective ones.
3.	Marketing work becomes more streamlined	MA helps to coordinate all marketing activities and keep everyone involved working towards common goals.
4.	Motivation and productivity of the marketing department	Automation of some processes significantly saves the team's time on labor-intensive monotonous tasks. This frees up time that can be used for some creative work. It also prevents employee fatigue and human error.
5.	Increased customer retention rate	The task of marketing is to ensure that after the first purchase from SEC, the customer returns there again. MA helps maintain customer relationships through various loyalty and reward programs. For example, the program will send personalized messages, individual offers, and various surveys to the customer, thereby encouraging a person to engage in a dialogue and gaining their trust.

There are a lot of different marketing automation software available today. The most popular ones are HubSpot, SalesForce, Microsoft Dynamics 365, and many others.

Let's take a look at the features of each of the most used software and find out which ones are more suitable for retail real estate projects (Table 2).

Table 2

Comparison of various well-known marketing automation software

№	Software name	Software description	Features	Price
1.	Salesforce	Universal cloud-based CRM system designed for large multitasking projects.	Sales forecasting; workflow automation; powerful analytics; collaboration and project management tools.	Minimum $25 for up to 10 users per month.
2.	HubSpot	The system has a lot of free features, including an online library, training resources, and various free courses.	Contact and opportunity management; sales forecasting; workflow automation; analytics; collaboration and project management tools.	Paid plans start at $50 per month per user.
3.	Microsoft Dynamics CRM	Helps organize sales, services, and marketing. Easily integrates with other Microsoft products.	Manage contacts, support, sales, marketing, and other data in one system; automate data processing processes with scripts; create Word and Excel file templates for quick reports; iOS, Android, Windows, and web apps available.	From $65 per month per user.
4.	Apptivo	A simple online CRM system for sending reminders, storing contacts, files, and message history. You can add more complex features as needed.	Storing contacts and related communication history; employee management; monitoring the development of business processes; time tracking.	The minimum paid tariff for 1 user per month is $8.
5.	Worksection	CRM service for organizing project data: tasks, performers, deadlines, documentation, etc.	Data warehouse; systematization of work processes; deadline control; communication; time tracking; Gantt chart; report generation.	The minimum paid tariff is $29 for 10 users and projects per month.
6.	TerraSoft Sales Creatio	Cloud-based CRM system for professional sales management and related business processes.	Order and invoice management; corporate social network; internal telephony; document management; contact database segmentation; search for a contact's profile in social networks; business process automation; product cataloging.	From $22 per user per month.

As you can see from the table, most of the well-known marketing automation software is universal and meets the requirements of projects in any field. However, in our opinion, the following platforms are more effective for projects in the field of retail real estate, in particular for the promotion of SEC: Salesforce, Apptivo, and TerraSoft Sales Creatio. All of them allow the marketing department to better communicate with customers, manage business processes, and control a huge document flow.

Conclusions

Despite the fact that the retail real estate market, like all other markets in Ukraine, first faced restrictions due to the COVID-19 pandemic, and then the losses and risks associated with the full-scale invasion of Ukraine by Russia, it continues to develop actively and sets new goals. The concept of SEC's development is changing somewhat, reorienting it towards a "new" consumer. This requires changes in marketing strategies. Today, more and more projects use automated tools that greatly facilitate marketing work. A comparative analysis of popular marketing automation platforms has shown that the following types of software are more effective for commercial real estate projects: Salesforce, Apptivo, and TerraSoft Sales Creatio.

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INFORMATION SYSTEMS IN PROJECT TEAMS

Kovalchuk O.

In conditions requiring demand for highly qualified specialists, it is important to have an effective system that will help select the best candidates for the growth of projects. The design of an information system for the selection of candidates in the project is of strategic importance, it provides functionality and integration with the recruitment process. The article describes the key stages of designing an information system, starting with the analysis of requirements and the definition of functionality. Aspects such as the creation of a candidate database, automated resume and candidate tracking, tools for assessing skills and abilities, and means of communicating with applicants are covered. Special attention is paid to the integration of the information system with the hiring process. The possibilities of connecting to recruiting platforms, automated notification of the status of applications and data exchange with the company's internal systems are considered. The use of an integrated system contributes to increasing efficiency and reducing the time required for the selection of candidates. In addition, the article considers the importance of compliance with the principles of confidentiality and protection of candidates' data in the process of working with the information system. The need to implement appropriate measures to ensure the security and confidentiality of personal information is emphasized. The article emphasizes the importance of training and supporting users when using an information system to select candidates for the project. Briefings, training materials and ongoing support contribute to the effective use of the system and the achievement of the best results in the selection of candidates for projects in a safety-oriented system.

Introduction

New external challenges and the integration of the civil defense system of Ukraine to European standards prompt the State Emergency Service to implement innovative projects (automation of activities, process reengineering, infrastructure development), as well as to apply flexible adaptive management to improve interaction between units, effective distribution and management of resources. Analysis of existing project management methodologies (IPMA, PMI, P2M, PRINCE) showed that a characteristic feature of modern methodologies is the use of limited project life cycle models.

Since the management of human resources is one of the most important and, at the same time, poorly formalized processes, the development of new life cycle models of team development is an urgent issue.

HR (also known as human resource management) teams strive to use a variety of recruiting tools that help optimize the selection of a set of required candidates (higher education graduates) from the general pool of applicants. Critical parameters in the process of team formation are time and the quality of the candidate's competencies. Therefore, the risks during the selection process increase, and accordingly, the methods of assessment and selection of applicants for project teams, which are most optimal for the organizational structure and tasks, are important.

Special attention is paid to the integration of the information system with the hiring process. The possibilities of connecting to recruiting platforms, automated notification of the status of applications and data exchange with the company's internal systems are considered. The use of an integrated system contributes to increasing efficiency and reducing the time required for the selection of candidates.

Analysis of recent research and publications

The problems of project-oriented management in complex systems were investigated by many scientists, in particular Bushuev S.D. [1], Chumachenko I.V. [8], Zachko O.B. [11] and others.

In the work of S.D. Bushuyev [2], the processes of project knowledge management were studied. A conceptual model was developed, which contributes to the structuring of data with subsequent transformation into a knowledge base. These developments should be taken into account when developing new models of assessment and selection of higher education applicants with specific study conditions in the civil defense system. In the future, these human resource management systems in the field of safety-oriented system should be applied to present data in the information environment.

In the monograph I.V. Chumachenko [8] multi-projects and applicants who were selected for inclusion in the team were studied. These developments are relevant in a complex socio-technical system. The complexity of candidate analysis and selection methodologies for such projects is constantly increasing. Accordingly, it requires a better solution for the selection and formation of teams in a turbulent and dynamic environment. The quality of the interaction of system components between stakeholders and the distribution of resources is an urgent task.

In the work of Doctor of Technical Sciences D.E. Lysenko [9], methods and models for evaluating and selecting candidates for the project team were investigated, using the theory of precedents as a basis of accumulated experience for selection based on the similarity of project members. The qualitative assessment model allows for a comprehensive analysis of candidates. The database of precedents and their assessment contributes to successful selection for team building. These methods are relevant for a security-oriented system and should be considered for recruiting and selection of resources.

In the work of Professor S.D. Bushuyev [3], important questions regarding the phases and groups of periodization of project knowledge management, which significantly affects the achievement of success in projects and programs, are highlighted. However, there is no emphasis on investigating the relationships of the life cycle of stakeholders, especially with the features of SOS (also known as safety-oriented system).

Doctor of Technical Sciences I.V. Kononenko [7] in his work "Formation of a project team for the development of information and communication technologies" more meaningfully considers an important aspect of the requirements for the competencies of project members. This contributes to the level of quality of execution and satisfaction of stakeholders, and the issue of the life cycle is not fully covered. This, in turn, requires the study of a group of life cycle processes in perspective.

Professor V.V. Morozov [10] achieved significant achievements in life cycle issues in the work "Functional-role approach to the description of the life cycle of projects of project-oriented corporations". In his work, he focuses on development project corporations and highlights the key eight stages of the life cycle and their relationship with the formation of key documents, the definition of the organizational structure, functions and roles of project members as the basis for successful implementation and achievement of the set goals.

But given the specifics of the field of development projects and programs, we cannot fully use this methodology in a security-oriented system.

The bulk of research

Harvard psychologists demonstrated that personal qualities have a directly proportional effect on success in projects (by 85%), because they are embedded in a person's character from an early age and it is almost impossible to change a person's temperament. And professional abilities, knowledge and experience come over the years, change and supplement. When selecting American companies, more than 90% of applicants are selected at the stage of in-depth interview results and interviews, and supplementing them with other assessment and selection methods allows you to make an effective decision for HR (also known as human resource management).

Below is Figure 1, which shows an analysis of staff turnover by the level of productivity of project team members. The vertical axis shows the level of employee turnover, the horizontal axis shows the time scale by year.

More skilled workers are less likely to leave their jobs than non-productive ones due to a better level of relationship with project management.

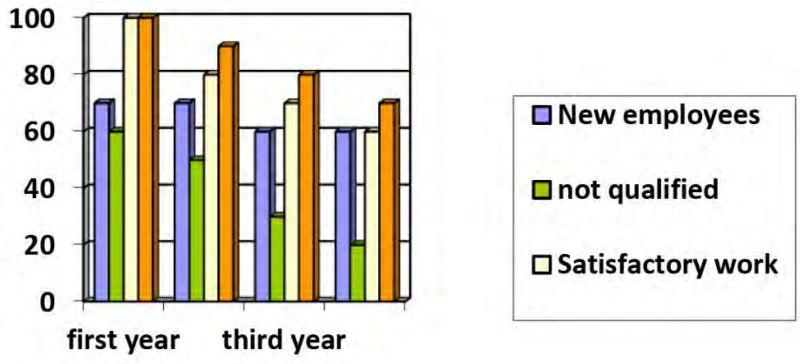

Fig. 1. Analysis of staff turnover by the level of employee productivity

Source: [8]

The choice of an information system for human resources management depends on a number of criteria, such as the cost of implementing the system, the strategy and specifics of organizations, the implementation period, the number of employees, operational features and the need for additional modules, such as recruiting.

Outdated methods of personnel management lead to the deterioration of activity and efficiency of activity as a whole, due to the complexity of coordination, monitoring and control of the processes of the accumulated organizational structure, as a result: low speed of feedback, inefficient performance of tasks and lack of data analysis for management and follow-up of the selected mission, strategy, achievement of set goals. Below is a comparative Table 1 of human resource management with new and standard methods.

One of the priority conditions for team effectiveness is the form of management. It is coordinated with each team member at the initiation stage. Project managers must combine traditional and non-standard methods of assessment and selection for successful team formation. The extension of the methods facilitates a comprehensive study of the behavior of the candidate in different conditions in order to simulate its results during the adaptation phase. Traditional selection methods include the following tools: resume, pre-selection interview, questionnaire, assessment centers, interview, professional test, test, reference check and job list. Non-standard methods of personnel selection include "shock interview", brainteaser interview.

The main purpose of the preliminary selection interview is to determine the personal qualities, beliefs and assessment of the level of education of the applicant. Candidates who have passed the preliminary interview are allowed to fill in the application data. It is during the phase of analyzing the questionnaire data that a standardized assessment of the applicant is carried out. A popular HR management method is benchmarking, which compares data and selects the best results.

Table 1

Comparative analysis of human resource management between standard and new methods

Source: own elaboration [13]

(HR standarts): standard methods of human resources management	(HRIS): implementation of the human resources management information system
Definition of system and document flow requirements	The project management toolkit is adapted to the goals, mission and strategy of the system in the conceptual core
Human resources for managing the stages of selection, adaptation, and training are allocated to individual projects	Management of human resources, recruitment and the main stages of the life cycle of project team members is carried out in a single information environment, which allows you to free up resources, direct them to other tasks, quick feedback and more effective organization of work compared to manual administrative management of HR standarts
Salaries, staff turnover, management of control and monitoring depend on individual managers, whose interaction slows down the speed of information transmission	Management of rewards, staff turnover, monitoring and control are interconnected in the information system, which allows comprehensive assessment and analysis of management results and efficiency.
Risk management is difficult to operate and analyze potential consequences based on data that does not reflect reality	Thanks to a single module of reporting and analysis of the information space, it is possible to compare planned indicators with planned ones, which allows you to achieve the goals of projects in complex socio-technical systems.

The implementation of the competitive selection for study at the Central is the process of forming a team (the term of which is 4–5 years, which is the term of training). That is, selection takes place in the project team, which is disbanded upon completion, and its members implement the acquired competence in other projects (in practical units). In the process of selecting applicants, experts analyze the results of personal, business, psychological and physiological parameters for compliance with the requirements. These criteria can be summarized in soft skills ("soft" skills), hard skills ("hard" skills), physic skills (physiological skills and indicators).

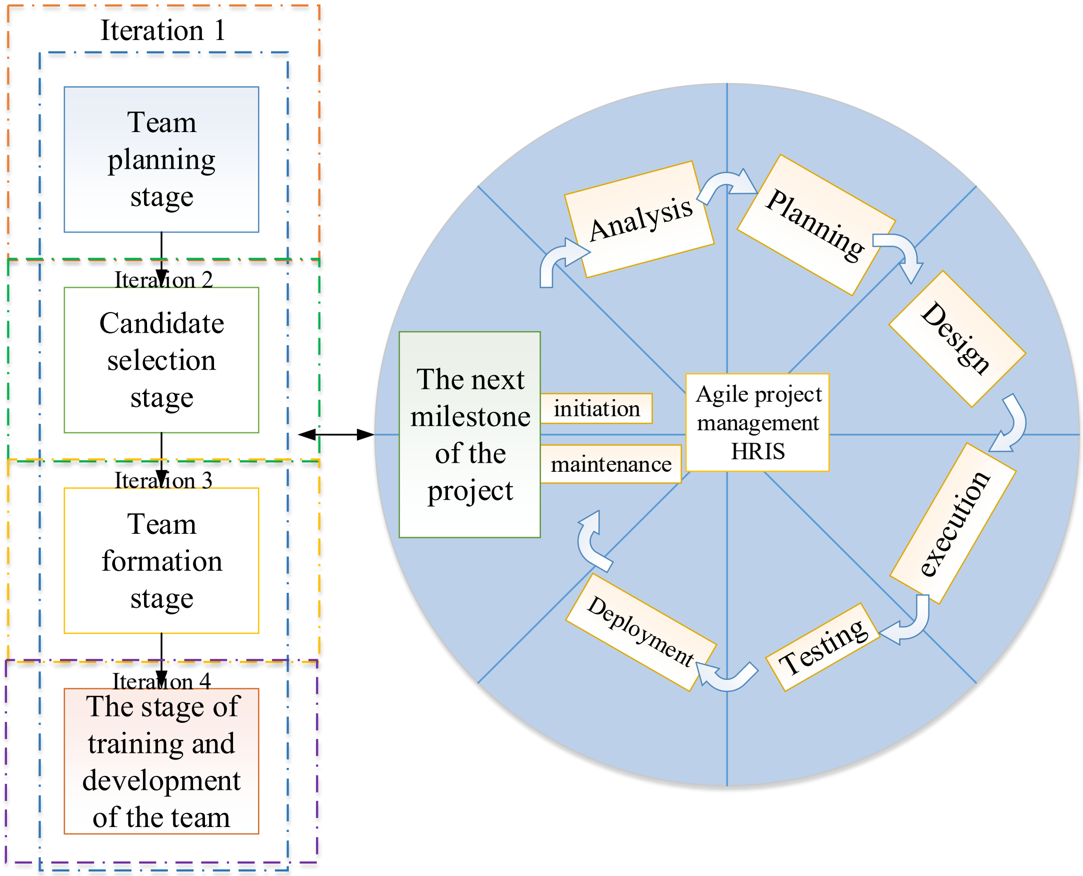

Fig. 2. Scheme of Agile formation of project teams in the field of civil protection
Source: own elaboration [13]

The effectiveness and transformation of OBS (also known as Organizational Breakdown Structure) is determined by the influence of internal and external environmental factors on the organizational system. The process of organizational design consists of three stages: the choice of technology, the development of a management structure, and the development of management mechanisms.

In order to solve the task of finding the optimal organizational structure, it is necessary to define efficiency criteria according to which a comparative analysis of organizational structures will be carried out, for example, such a criterion can be the manager's expenses for the formation of a project team.

Let the set of candidates be given P, variants of the organizational structure $Os \in Os(P)$ and the cost function of creating an organizational structure $f(s): Os[0;+]$.

Accordingly, you should choose the structure (St) with minimal costs:

$$St' \in Argmin_{St \in Os} f(s). \quad (1)$$

An important characteristic of the hierarchical structure, which determines optimality according to the cost criterion of team formation, is the absence of duplication, in which two managers $M1$, $M2$ manage one group of team members Pj, $j=1,\ldots,n$:

$$\left(\{P1,P2,\ldots,Pn\}M1\right)\left(\{P2.1,P2.2,\ldots,Pn\}M2\right)=\varnothing \quad (2)$$

To determine the qualitative characteristics of the optimization criteria of hierarchical structures, the approach of evaluating the topological properties of the organizational structure (stability, controllability, compactness) using graph theory is used.

To increase the accuracy of the quantitative assessment of the applicants' qualitative indicators, it is advisable to formalize the criteria and their weighting factors using the theory of qualimetry. The formalization of these indicators will reduce subjectivism. Qualimetry is a scientific direction that studies the methodology and problems of complex quantitative assessment of the quality of any objects – subjects, phenomena or processes.

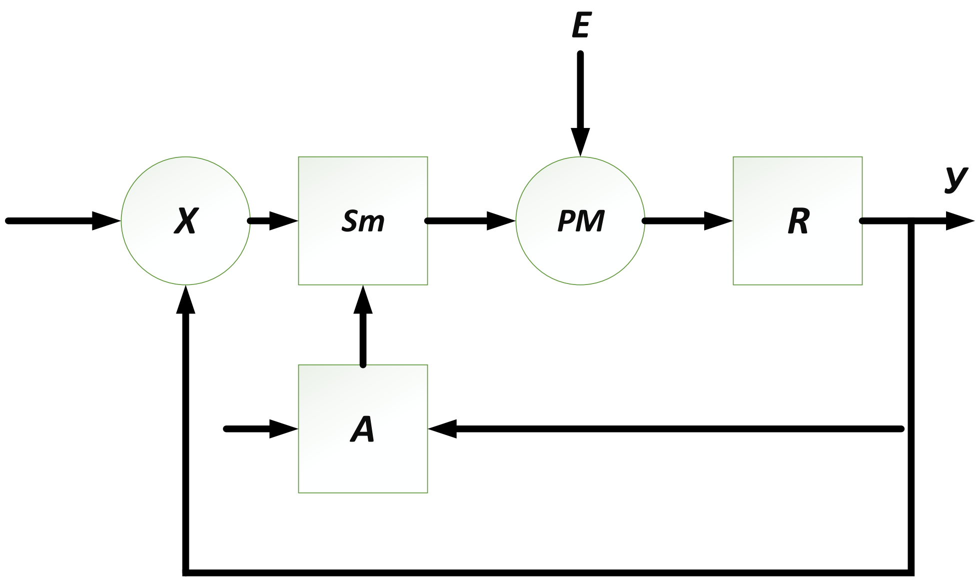

Fig. 3. Structural scheme adaptive Agile
Source: own elaboration [16]

X – is an input signal. For the project, these are signals of the external environment and its stakeholders;
Sm – is a management system for the HR project;
PM – entrance of the object (HR project);
E (environment) – external environment and project risks;
R – project implementation (transfer function);
Y – output of the object (result of the life cycle of adaptation of the project team);
A – is an adaptation block that changes the type of team development life cycle depending on external requirements.

The life cycle of team building should be flexible and adaptable to external factors and influences. From the point of view of the system approach, adaptation is the process of changing the parameters and structure of the system, in particular, controlling influences, based on current information in order to achieve a certain, usually optimal, state of the system in the face of initial uncertainty in the operating conditions.

A system that can adapt to changes in internal and external conditions is considered adaptive. Adaptive control is control in a system with incomplete information about the controlled process, which changes as information accumulates and is used to improve the quality of the system.

An adaptive model of the object management system is considered to be a model in which, as a result of changes in the characteristics of the internal and external properties of the object, corresponding changes in the structure and parameters of the control regulator occur in order to ensure the stability of the object's functioning.

Acknowledgment

In this work, we analyzed information systems of human resources management and selection criteria for complex socio-technical systems. A model of information system formation «scheme of Agile formation of project teams in the field of civil protection» has been developed for its implementation in security-oriented systems for automation and optimization of human resource management personnel processes. A module for the selection of candidates for project teams of safety-oriented systems based on the index method for further formation of the project team was introduced into the information system. A model is proposed for testing new information systems, as well as system integration with databases, which improve the efficiency of process management at all levels of the life cycles of employees and the organization.

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MODELS OF HR MANAGEMENT IN SECURITY-ORIENTED SYSTEMS (ON THE EXAMPLE OF CIVIL DEFENSE)

Matkivska H., Zachko O.

Human resource management is one of the management areas that has undergone significant changes in project-oriented organizations. Project organizations have to plan and develop alternative methods of human resource management, find modern strategies of how to manage employees or how they should be managed. Like all other strategies of organizations, the HR management strategy of civil protection is aimed at helping the organization to increase productivity. Project human resource management in civil protection intends to define the main objectives and determine the leadership of the project team to successfully achieve these objectives and successfully complete the project. The paper presents processes of components and interactions between project team members that will allow team members to stay focused and motivated. To this end, the paper describes the processes of human resource management planning, obtaining a project team, and developing and managing a project team.

Project human resource management in civilian protection is the main element of project management related to the organization, management and leadership of the project team. The team includes everyone who has been assigned roles and responsibilities to complete the project. Project human resource management in civilian protection can help every team achieve better results. Project management includes the processes that organize, direct, and manage a project team. The project team consists of people who are assigned roles and responsibilities for the execution of the project. Project team members can have different skill sets, can be assigned full-time or on a daily rotation, and can be added or removed from the team as the project progresses. Project team members can also be referred to as project staff. Although project team members have specific roles and responsibilities, it is beneficial to involve all team members in project planning and decision-making. The participation of team members during planning adds their expertise to the process and strengthens their commitment to the project. Linking HR management to project management (fig. 1), we see that this function plays a strategic role. It turns out that HR management focuses on the people who lead a particular project, managing and organizing them. The potential value created is related to project success and project achievements. This area of knowledge includes the processes required to organize, manage, and lead a project team. Team members' commitment to the project can be strengthened if they are involved and participate in the project planning process. The project management team is a subset of the project team and is responsible for initiating, planning, executing, monitoring, controlling, and closing the project phases.

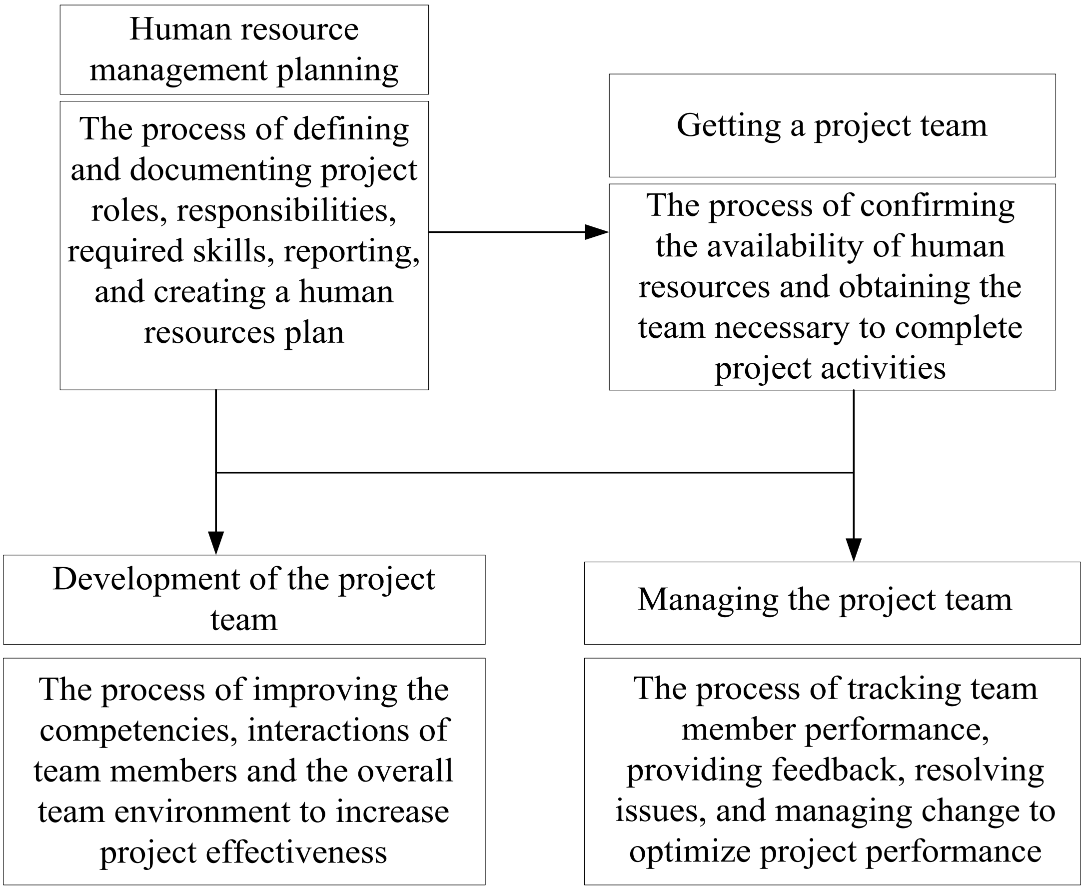

Fig. 1. Shows the processes of components and interactions between team members

Human resource management planning. Before starting any project, you need to define the project team. A major part of this initial planning phase involves determining the number of people needed and writing their job descriptions (fig. 2). In addition, the project's human resource management plan, part of the overall project management plan, contains human resource issues, such as how performance will be measured, where the project team will work, how conflicts will be resolved, and so on.

Getting a project team. Hiring employees is often time-consuming. Tasks related to posting job openings, interviewing candidates, and making hiring decisions fall under this process in the project execution process group, regardless of whether the project team member is internal or external (fig. 3). After hiring, a resource calendar is developed for each new project team member, which indicates the time available to work on the project or specific project tasks. Also, the project manager (human resource manager) assigns roles and responsibilities to employees who must successfully complete the project.

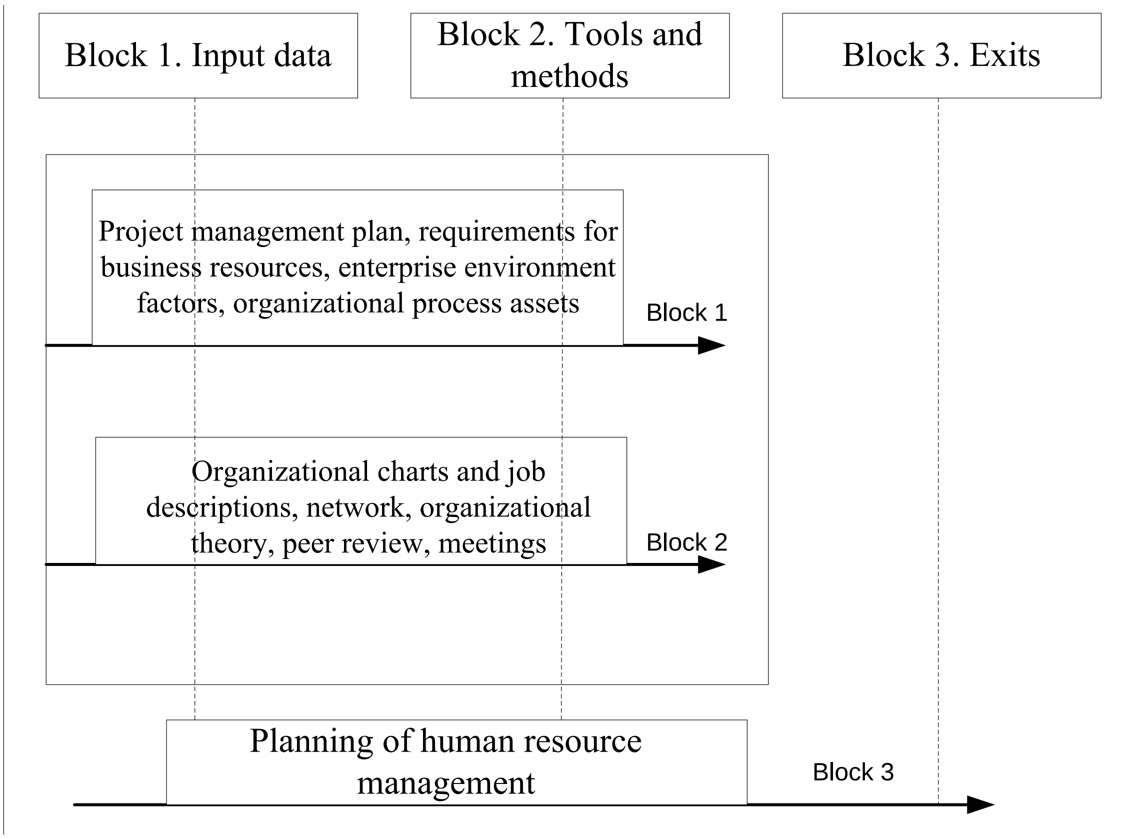

Fig. 2. The process of planning the human resource management of a project in civil protection

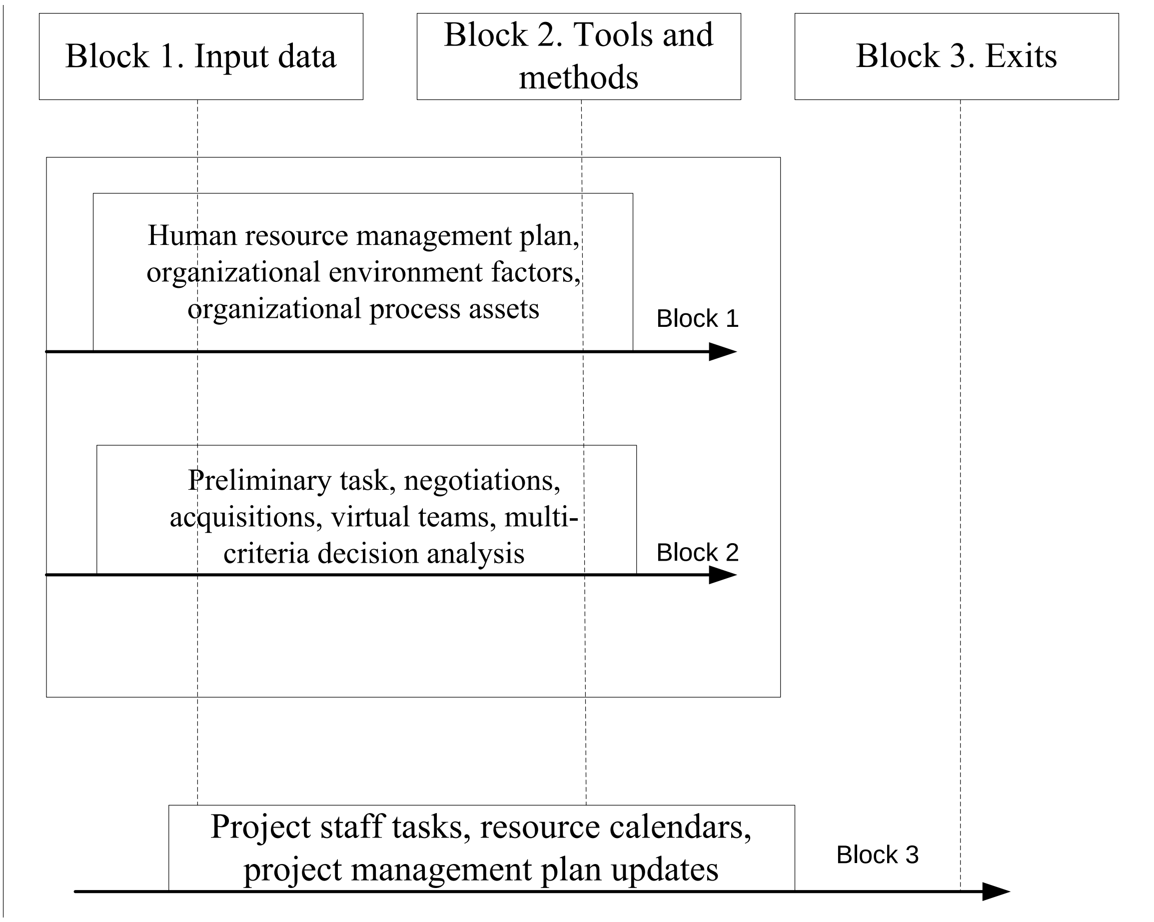

Fig. 3. The process of getting a project team

Developing the project team. It's not enough to hire a project team and expect them to know everything they need to know to execute a project to perfection. Developing a project team includes performance reviews, team building activities, recognition, and rewards (fig. 4). Every manager realizes the importance of additional training and coaching to improve the quality of the team's work on a project. So, this process is about understanding what the team needs and maintaining good cooperation between colleagues while working on the project. Team development activities may include:

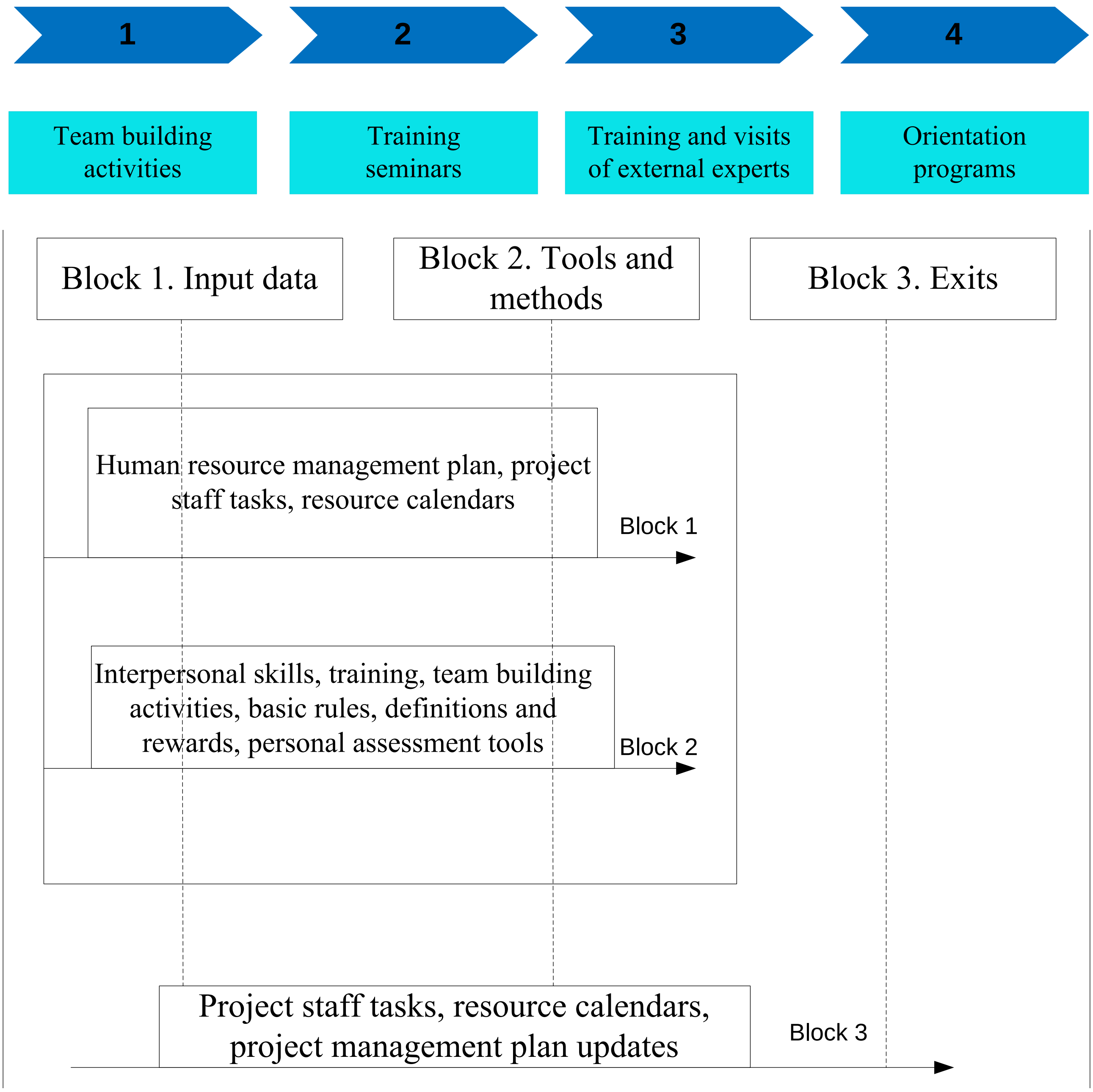

Fig. 4. The process of project team development

Project team management. Many books have been written on the topic of managing project teams. But it's clear that project success depends heavily on managing the changing roles, responsibilities, and performance criteria of the team (fig. 5). Project problems test the competence of the project manager and the project team and threaten to undermine project success. The project manager and project team's response to these issues is essential to ensuring the completion of a successful project.

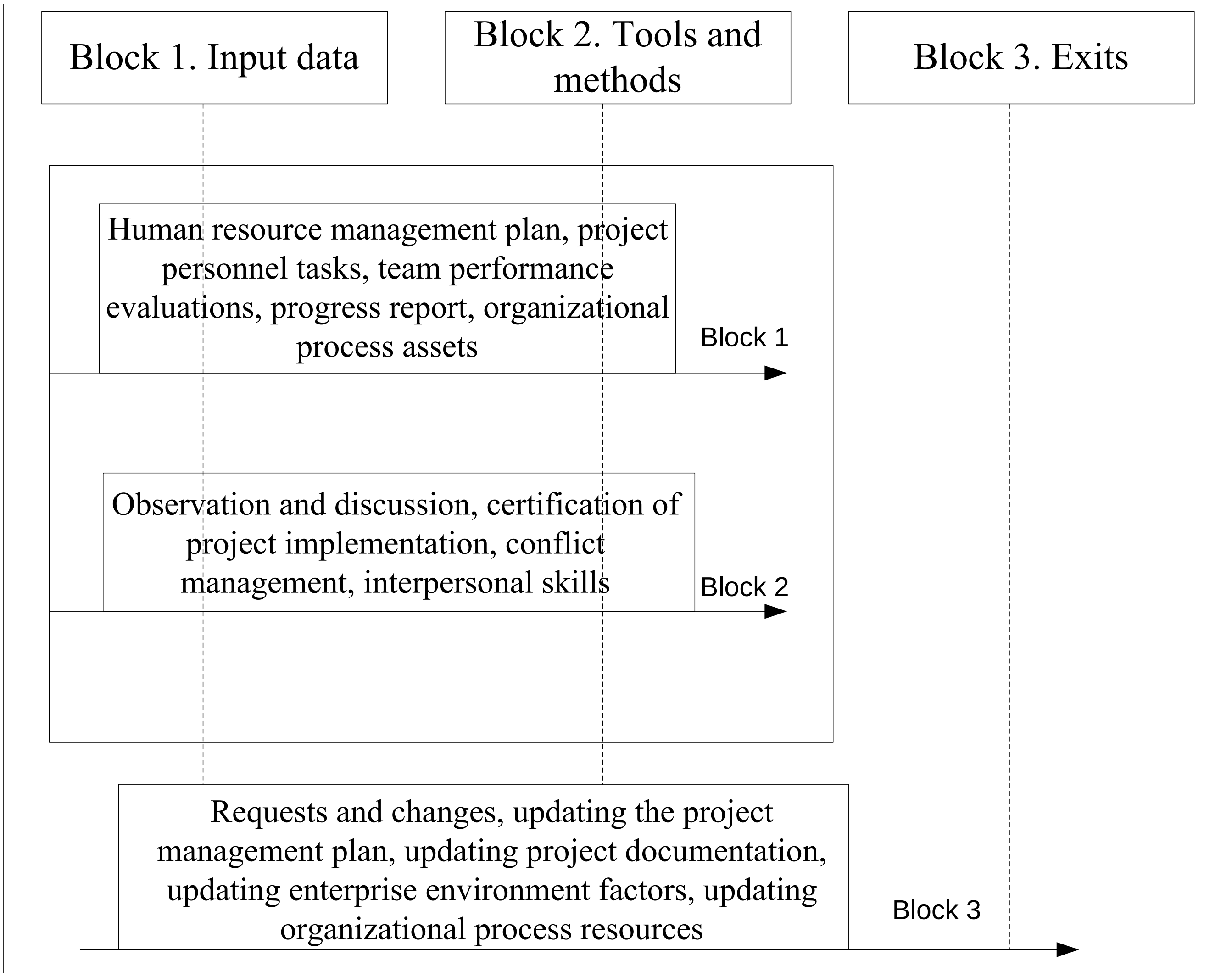

Fig. 5. Shows the process of managing a project team in civilian defense

Information technology has expanded the methods of communication available to the project team. Analyzing social media and mobile applications allows you to make communications within the team visible. You can see who is working with whom, the strength of the ties between team members, who the key players in the project are, and how information flows within the team (fig. 6). Teams can be analyzed in two ways: centered on one key project team member, where you can analyze the connections of this key player with other team members and establish the range of influence between them, or you can view the entire communication network and identify several key project participants.

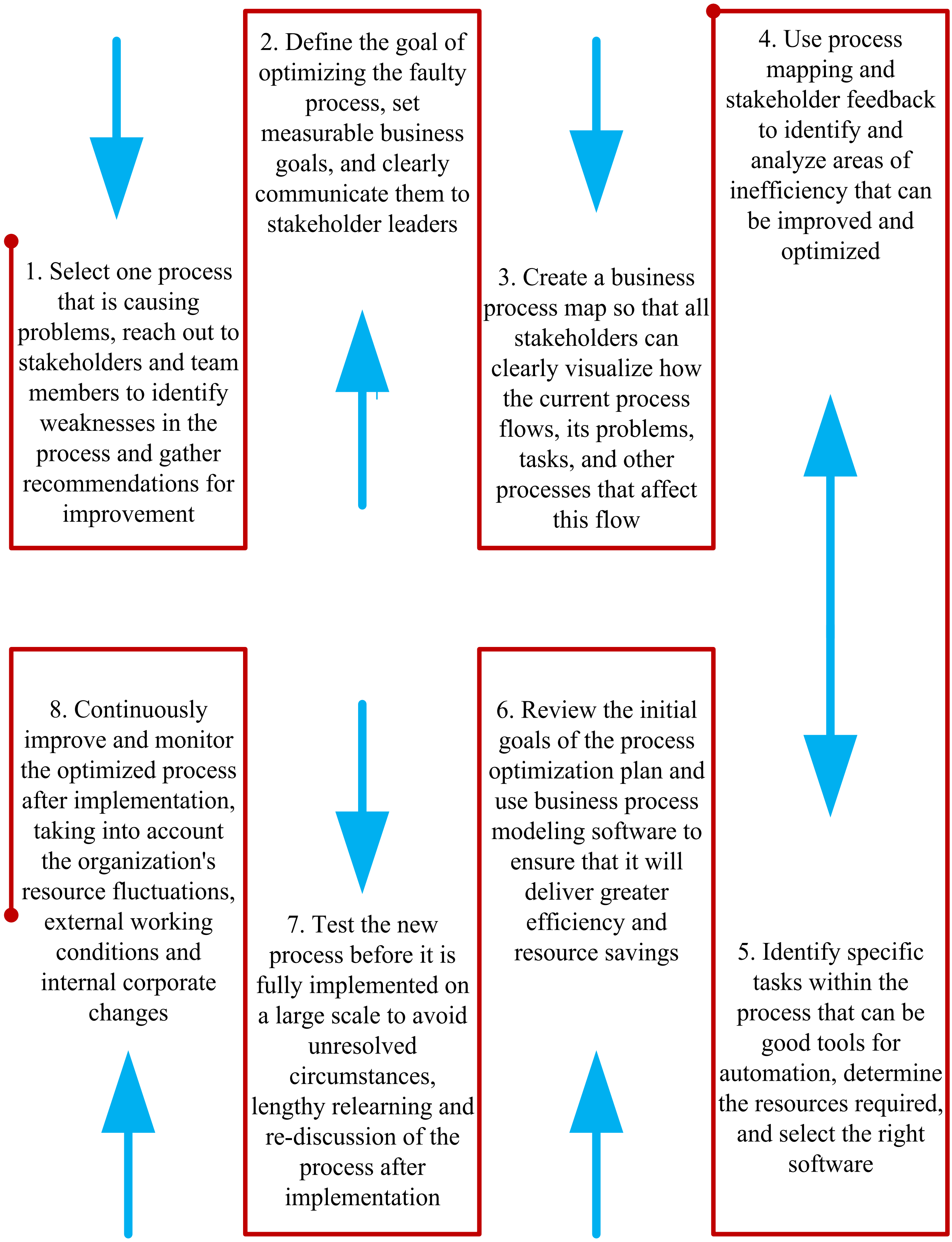

Fig. 6. Shows a map of optimization of project human resource management in civil protection

To ensure successful project management in civilian protection, the team must regularly provide and receive updates on progress at various stages of the project.

Just one dysfunctional process among hundreds of project processes in civil defense can create bottlenecks and impede the company's agility. This is where a well-thought-out step-by-step optimization plan can eliminate weak links and improve the flow of processes.

Conclusions

Project human resource management in civilian protection provides a clear overview of the project and its objectives, enabling you to prioritize where and when you invest limited resources, including time and money. This helps human resources teams stay on schedule and on budget and utilize resources in the most efficient way. Project management will also have a positive impact on hiring and onboarding new employees. Agile project management principles can help create inspired hiring programs and increase the number and quality of candidates, with new employees starting their roles after proper training and better equipped for the job. Having a clear understanding of timelines and progress allows HR to keep management informed about projects and gain valuable insight into team priorities when dealing with conflicts or limited resources. HR professionals can see how project goals align with the broader goals of the organization and communicate this to management.

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EFFECTIVE COMMUNICATIONS AS A MEANS OF CREATING VALUE IN EDUCATIONAL PROJECTS

Molokanova V.

The article considers issues related to the implementation of value-oriented methodology in the context of the educational projects. On the basis of the introduction of modern project-based learning, the model of value creation in educational projects has been further developed. The article examines how value is created in project teams by looking at two educational projects. The article discusses recent theoretical developments that propose to link value creation and project communities. It identifies the need to further improve the level of project competencies of individuals involved in the project development and target documents in communities. The article also considers the use of case-based learning in the field of project management, which allows gaining new knowledge and developing a culture of collegial decision-making. This approach will contribute to the development of initiative, higher-level subconscious thinking skills necessary to solve systemic problems in regional communities. The conclusions focus on how values are created; how this is done by identifying four key value of creation processes: mindset change, project management processes, structure development, and knowledge creation.

Introduction

Problem formulation. In modern project management, it is widely recognised that the main goal of projects is not only generation of financial profit, but to create new human values [1]. While in the last century, project management standards were mainly based on the commercial aspect of projects: making a profit. Nowadays, a project is increasingly seen as a commitment to create human values [2]. However, the general principles and tools of value-based project management are not well developed yet.

Analysis of recent researches and publications. The systems approach and systems analysis is a fairly broad separate field of knowledge that is widely used in project management, while the project approach to implementing development strategies is increasingly used at the tactical level. For a long time, the resource-based approach remained the most popular in system development [3–5]. However, over time, experts have come to the conclusion that enterprises that pay less attention to financial approaches and focus more on creating organisational value get better results [6, 7]. In recent years, the category of "value" has been increasingly used as a criterion for the effectiveness of enterprise development through projects, while the concept of "value" itself is changing with the development of human civilisation.

A number of studies consider the "value of project management" from an organizational point of view [8, 9]. However, the project portfolio management literature pays little attention to value management concepts. More and more often expressed the opinion about the need to expand the concept of portfolio value [10]. To form and plan a strategic development portfolio based on the value approach, a special project structure is needed that tracks the implementation of corporate strategy through project portfolios. Such functions in portfolio management can be performed by a special organizational platform that supports the project management environment in order to maximize the company's values. Studies have shown that in the context of the development of commercial products and services, a strong or exclusive focus on financial performance is associated with a weaker development strategy of the organization [11].

A significant step in the process of value-oriented development of the system based on the P2M standard [2] is the description of the mission, which defines the vision of the dominant organizational value, on the basis of which an appropriate strategy is developed. Over time, the evaluation of the intangible components of projects has become increasingly important, especially for educational projects.

While scientific publications focus most often on commercial value, research points to a growing need to include non-profits value issues that can be measured at a time.

The article is aimed at studying the manifestations of value-oriented project management in the sphere of education, methods of effective communication and ways to improve the practice of project management.

Methodical materials of the study

Presentation of methodology. In the 60s of the XX century, the development of systems theory led to its division into a "hard" and "soft" system approach [12]. The "hard" methodology allows for a single interpretation of the objective system essence and is effective in modelling technical systems, technological subsystems and certain aspects of organisational functioning. "The soft methodology allows for a multiplicity of reality interpretations, in which individuals and project teams with their own goals act largely independently. In particular, according to the soft modelling methodology, an organisational system model is a set of explicit and implicit models of its management [5]. Thus, the soft system approach deals with uncertain requirements of the future system transformation, important subjective factors, and the free use of tools to solve problems.

Hard and soft system approaches are most often distinguished by the nature of the presence of a person in the system. The main difference between "soft" systems and "hard" is determined by the fact that "soft" systems include a person as the most important fuzzy element of the system [12]. If all the factors of the task are rigidly formalized, determined, then in this case the situation is presented as "hard". At the same time, everything that is not formalized is not taken into account. The soft systems approach associated with intangible categories concerns such poorly formalized concepts as motivation, dynamic leadership, hierarchy of values, dedication to organizational values. Such poorly understood factors associated with human behaviour, as a rule, are not taken into account in the rigid formulation of management tasks. But these factors are often the only cause of failure in project management, which requires the efforts integration of all stakeholders [12]. The area of most effective application of the soft systems approach is the development of decision-making methods, solving organisational design problems and designing changes in the system. However, the "hardness" or "softness" of a systems approach is not a property of the problem situation to which it is applied, but rather a way of thinking and methods. Neither approach is right or wrong, but rather different ways of thinking. The main differences between the hard and soft systems approaches are presented in Table 1.

Table 1

Main differences between hard and soft systems approach

Hard systems approach	Soft systems approach
The problem has a definite solution	Too many problems need to be solved
The problem has a number of achievable goals	Achievement of goals is difficult to measure
The problem answers the question "How?"	The focus of the problem focuses not only on the question "How?", but on the question "Why?"
The problem has deterministic complexity	The problem has unforeseen, non-deterministic complexity
It is likely possible to determine the parameters of failure	The problem is very difficult to deal with
The solution to the problem does not depend on the values of system	The decision depends on the system values and mentality of the staff
Logical sequential connections	Intuitive metaphorical connections

Since any system develops according to certain laws, the implementation of the development strategy of any organization requires consideration of these laws, namely determining the current state of the system, the level of its dominant values and its ability to create new values structures through the use of project management. The logical-structural approach to the development of the system allows us to analyse the spatial-temporal and morphological properties of systems taking into account the main components as follows (Figure 1).

The expansion of the project approach to the intangible sphere of social activity has led to the emergence of value-oriented management. In the new standards for project management, more and more attention is paid to the fuzzy relationships of the basic project concepts and the values they create. At the same time, the constant increase in complexity changes the perception of the activities of organizations and shifts the focus of attention from rigid material concepts to soft fuzzy categories. Today, the scientific literature on project management continues to form a unified methodology for value-oriented management of the organizations' development. This methodology is based on the concept of spiral dynamics of the development of organizations and takes into account the dominant organizational values in the system [13].

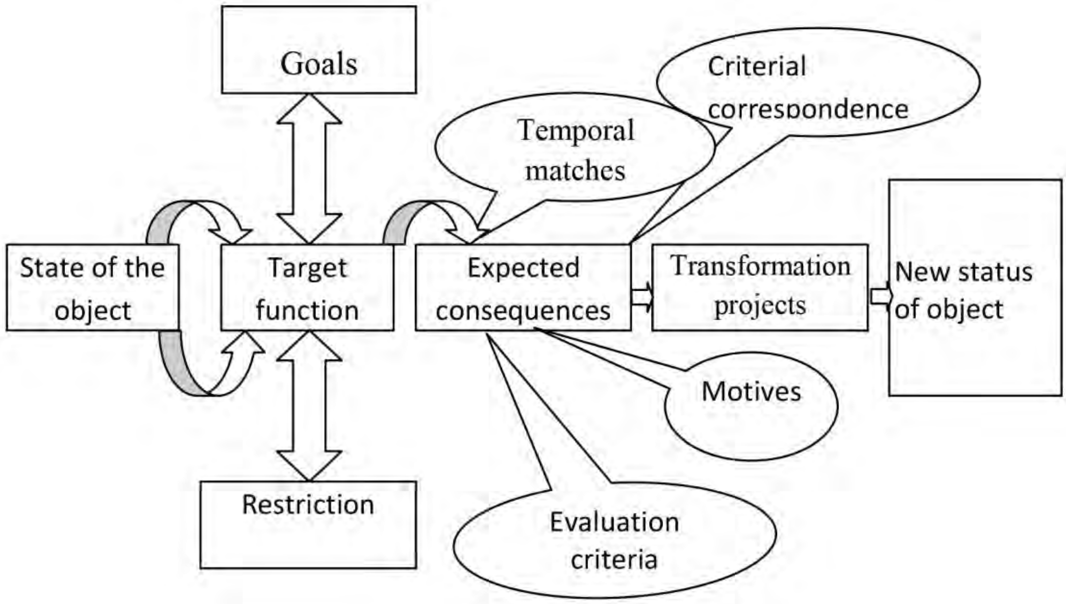

Fig. 1. Logical-structural approach to managing system development

In the practice of value management, the following three functions are considered: discovering value, creating value, evaluating value [14]. Identifying the value of a project's product or outcome often means simply copying the others organizational values. Imitation and copying of a valuable product is a path that many well-known companies have taken [15]. Organizations that use a system methodology to achieve certain goals are considered as organizational and technical systems with the following common features:

− objectives reflecting their mission, the types of products and services they produce to meet the needs of society;

– division of labour, which takes place in accordance with the professional qualification characteristics of each specialist and ensures rational structuring of relevant works;

– communications, or different types of connections, formal rules of actions are also necessary for employees in the course of performing joint work.

Results of the study

Presentation of results. The next section presents an overview of two educational projects: one project of DOBRE program for community training and the Caser Competition project. We present the activities in these projects that create certain values, and their implications. The Decentralization Offering Better Results and Efficiency (DOBRE) Programme had as its main goal the professional development of civil servants within the framework of the project "Management of Amalgamated Hromadas for Managers", based on the Cooperation Agreement with the Krakow University of Economics [16].

The DOBRE program began working in Ukraine in 2016, and 75 communities from seven regions of Ukraine were selected to participate in it. The main goal was to help the communities take advantage of the Decentralization opportunities and cope with the tasks set before them by the reforms. After five years of this activity, the donors noted the great success of the initiated project and it was decided to increase the assistance. Therefore, the DOBRE Program expanded to 25 communities from more three regions, and in total, before the beginning of the Russian invasion, covered 100 communities from 10 regions of Ukraine. And even with these new communities, despite the difficult challenges, they managed to complete all the projects [16].

The second project concerns one of the largest Ukrainian caser platforms for holding a case championship for the development of territorial communities, which was attended by a team of students of NTU "Dnipro Polytechnic", which reached the finals with the "Project of the freelance school creation in the territory of the Bilozirska' community". The project clearly highlighted the advantages and possibilities of using the Case-study for teaching students by solving specific tasks (cases) and developing specific projects based on them.

These two projects have been successfully implemented, and in the next section, we show the four value-creating activities identified in our analysis: mindset change, project management processes, structure development, and knowledge creation. Data analysis was based on feedback received during surveys and data collection from project participants. The bulk of the analysis took place after data collection, followed by a process of categorization and establishing the values of the results. The followed inductive approach of finding values formation processes and their definition shown in Table 2.

Table 2

Values formation processes and their definition

Value formation example	Category	Project DOBRE	Project Casers Championship
They worked alongside each other for many years, but there was no one who took the initiative to create shared knowledge.	Creating new knowledge	Implementation phase	Conceptual phase
When a scenario approach is applied in a project team, everyone can agree on the best and worst possible scenarios.	Rethinking habits	Conceptual phase	Conceptual phase
If you're just rethinking something you've done before, but just haven't thought about it, it's a process of the values rethinking.	Rethinking habits	Planning phase Implementation phase	Planning phase
For effective communication, it is necessary to discuss who makes decisions, how it will affect decisions, and whether they are majority decisions.	Rethinking habits	Implementation phase	Conceptual phase
For practical and logistical reasons, it is advisable to report the results of the project to other partners or other staff.	Communication in the media space	Completion phase	Completion phase
Teams are hired to do specific tasks, and if they want to do more tasks and we don't have the money for it, they do the work for free.	Change of mindset	Implementation phase	The entire project life cycle

Table 2 illustrates the relationship between situations data and examples of values creation. The table also includes structures and organizational principles served as input to determine the values created. Values creation tools are presented in the next section after a detailed review of the projects progress. Both projects are engaged in the search for new solutions; for the Dobre project, it is development projects for communities, and for the casers' championship, it is a presentation of their solution.

Scientific novelty. At the centre of both projects is a change in thinking, habits, and how people work and act. Public education and storytelling are some tools of communication used in both projects. DOBRE project is engaged in changing often familiar thinking among the regions of Ukraine, disseminating knowledge about project development to a wide public audience through open events for stakeholders.

The Caser Championship seeks to promote innovative thinking in community employees to encourage them to think about innovative development, and not just about survival. Consequently, all project participants are always updated and essentially expand their vision of development opportunities. Both projects focus differently on stakeholder values, but both are interested not only in achieving the project outcome but also in the post-project development of the values obtained. Changes, new values knowledge for each of the communities were the focus throughout the duration of the project, building trust and allowing the resources and commitments of the parties to be discussed upon completion of projects, which is the determination of who will receive these values. We summarized the value-creating activities in Table 3.

Table 3

Four key values created in projects processes

Four key values of processes	Project DOBRE	Casers Championship
Mindset change to…	Strategic thinking	Consensus thinking
Project management	Classical project processes	Agile project processes
Management structures	Matrix, delegating	Horizontal, levelling
Collaborative intelligence	Creative innovative projects	Environmental, socially oriented projects

After conducting additional research, we determined that in project DOBRE, the participants relied on the values of the 5th level, and in the Caser Championship project, the values of the sixth level on a scale of spiral dynamics dominated [13]. Both projects create new knowledge by demonstrating how changes can be implemented in the external environment. Because both projects explore community development and serve two purposes: training partners in project management and collaboration based on effective communication. Collaboration between representatives of different external organizations serves as a way to integrate professional competencies that can promote creativity and lead to new, unexpected solutions. We suggest that the two presented projects are implementing with the values of different levels could be examples of educational projects. We summarize the four phases of values creation with project life cycle, which are considered in the figure 2.

The model is related to the existing understanding of values creation, in the process of implementing projects. Managing development through projects has been a major source of inspiration in the DOBRE project. After receiving the results of the project, communities understood that changes should be actively managed, measured and implemented. One at the time our research shows that the value of learning and competencies is a source of values creation, meaning it benefits for stakeholders. The collaboration and created project team allow us to create future value both during the project and after the completion of the project.

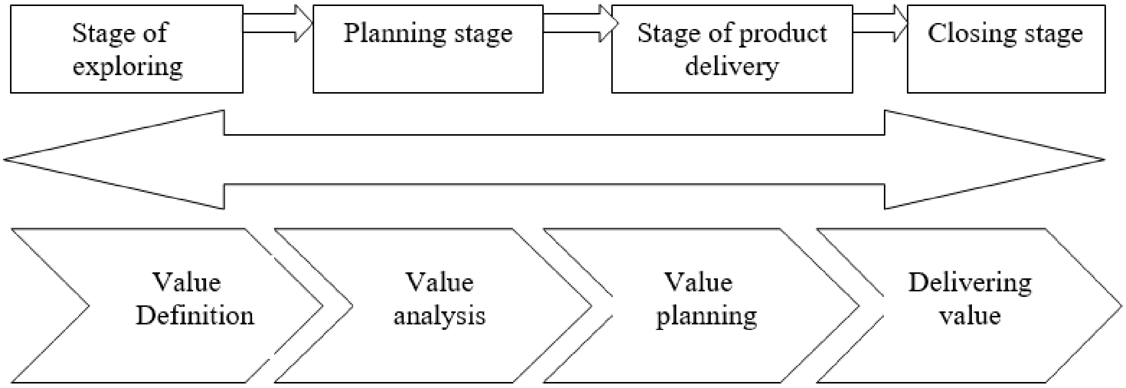

Fig. 2. The relation between the projects' life cycle and values management

In addition to the implications of the model for theory, our research has implications for project values creation practice: for the DOBRE project, the management group has secured a commitment to the steering committee to continue managing the development after project implementation. As for the second project, students intend to expand their participation in the Caser Competition. This is a strong approach to engaging students to gain specific experience in projects. Our main assumption about this activity is that it can lead to better and innovative values propositions.

Conclusions and perspectives of further research

Conclusions. This article presents the results of a study that explores design tools for values creation. The projects we studied were drivers for creating new organizational values through the collaboration of participants that combine their competencies in projects. Thus, if two systems want to start collaborating, they can start with mutual project. Our contribution to project management research presents there are four processes that create values. The article presents a model of project values creation, which focuses on the stages of the project life cycle and outlines the types of created values.

Future Research. Since the two presented projects may not be very revealing, we suggest further exploration of value creation in other types of educational projects. When value is created in different types of projects, it would be interesting to explore its further transformations, as this may affect the definition of the project success and, in turn, can change the picture of determining failure rates for projects. We also propose to investigate how public perception of values effects publicly funded projects or sponsors.

Further research is needed on the methodological basis for cooperation between public organizations and the tools for initiating such collaboration, and obstacles along the way.

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STUDY OF THE METHODS AND MEANS OF DATA MIGRATION BETWEEN RELATIVE AND NON-RELATIVE DATABASES

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Nowadays, all information and information-analytical systems require the use of databases (DBs). Databases are an integral part of the information infrastructure of modern enterprises and organizations. These systems have to process, read, and record certain data sets that need to be organized, structured, and stored. The need to solve these problems has given rise to a number of new platforms and tools for large volumes of diverse and unstructured data. In this case, non-relational data warehouses appear in contrast to the well-known relational ones. NoSQL offers a certain concept in contrast to the SQL paradigm that has dominated for a long time. Therefore, the transition from a relational to a non-relational storage implies not only data migration, but also a revision of the concept of data processing and its model.

Introduction

Developers are increasingly choosing MongoDB for their projects. MongoDB is an open source document-oriented database management system (DBMS) that does not require a table schema description. MongoDB is not a replacement for relational databases, but rather an alternative, but for some projects where data can be presented in the form of documents, such as blog pages, it is rational to use it.

However, if existing projects written using relational SQL databases are migrated to MongoDB, the problem of optimizing the relational data structure arises.

Currently, there are several software solutions for converting SQL queries to JSON queries for the new DBMS. All of them use a simple query conversion with the preservation of the relational structure, which is in line with the MongoDB philosophy.

According to the theory of relational databases, they should be given a third normal form. The purpose of normalizing a relational database is to eliminate the flaws in its structure that lead to redundancy, which, in turn, potentially causes various anomalies and data integrity violations. Data can be stored in the third normal form of MongoDB, but this storage method does not provide all the advantages of MongoDB.

MongoDB operates with the concepts of database (db), collection, documents, and fields, which in relational DB terms are a database, table, and table element, respectively. A database can have zero or more collections. Collections consist of zero or more "documents". A document has one or more "fields", which, as you might guess, are similar to "columns". MongoDB supports nested arrays and collections.

The proposed solution will make it easier for developers to switch to a document-oriented database and migrate data and offer a new, MongoDB-optimized structure. In addition, there will be a choice between several options for a new data structure focused on the new database, as well as the possibility of corrections in the DB structure and fields.

The main direction of the work should be the regularities that arise in the process of transition from a relational to a non-relational data structure, as well as the optimization of this structure in accordance with the concepts of MongoDB.

Analysis of existing ways to represent DBs

The literature offers many definitions of the concept of "database", reflecting rather the subjective opinion of certain authors, but there is no single universally recognized formulation.

The author of the article believes that the following definition of databases is the most successful: "A database is a collection of data organized in accordance with certain rules and maintained in a computer's memory that characterizes the current state of a certain subject area and is used to meet the information needs of users" [1].

Currently, there is no single approach to data migrations, so a large number of software products use outdated versions of DBMSs that are limitedly or not supported by developers. Also, one of the reasons for the stupor on one version of the DBMS is that migrations lead to numerous risks in the form of data loss and incompatibility of the existing program code with the modernized DBMS [2]. All of the above factors discourage software product owners from migrations of this kind.

An unsuccessful migration can result in data degradation or loss of data altogether. This can happen even when the data in the source DBMS looks perfectly adequate and usable. In addition, any problems that existed in the data may be amplified after it is transferred to the new storage [3].

Typically, data migration strategies prevent the use of auxiliary software packages [4], which end up creating more problems than they solve. When planning and developing a work strategy, developers need to pay full attention to such migrations, without diminishing their importance and scope.

There are many types of databases that differ by different criteria. The main classifications are listed below.

Classification by data model: hierarchical, object and object-oriented, object-relational, relational, network, functional [5].

Classification by the level of distribution: centralized, or concentrated (a database fully supported on one computer), distributed (a database whose components are located in different nodes of a computer network in accordance with any criteria).

Distributed databases, in turn, are divided into: heterogeneous, homogeneous, fragmented, or sectioned, replicated [6].

A database management system is a set of software and linguistic tools for general or special purposes that manage the creation and use of databases [7].

Relational DBMS is a relational database management system. The relational data model is aimed at organizing data as a relationship [8].

Let's consider some of the most popular RDBMSs.

MySQL is a free relational database management system developed and maintained by Oracle Corporation. MySQL is a solution for small and medium-sized applications and is ranked second in the DBMS rating according to the results of research from the DB Engines website.

Microsoft SQL Server is a RDBMS developed by Microsoft. The main query language is Transact-SQL, created jointly by Microsoft and Sybase. Transact-SQL is an implementation of the ANSI/ISO standard for structured query language (SQL) with extensions. It is used to work with databases ranging in size from personal to large enterprise-scale databases; it competes with other DBMSs in this market segment. It is ranked third in the DB Engines rating [9].

PostgreSQL is the most advanced of the three DBMSs we have considered. It is freely distributed and complies with SQL standards to the maximum extent possible. PostgreSQL or Postgres tries to fully implement ANSI/ISO SQL standards simultaneously with the release of new versions [10].

PostgreSQL differs from other DBMSs by supporting the popular object-oriented and/or relational approach to databases. Thanks to powerful technologies, Postgre is very productive. PostgreSQL is easy to extend with procedures called stored procedures. These features simplify the use of constantly repeated operations.

Couchbase is a document-oriented database that is interesting for its relative simplicity, exceptional ease of setup and support, high query execution speed due to in-memory data storage, scalability, and automatic cluster recovery in case of machine crashes and other factors. It provides tools similar to Apache CouchDB for creating document-oriented databases in combination with Membase-like storages in the key-value format.

Thanks to support for the standard memcached protocol, the system remains compatible with a large number of legacy applications and can transparently replace a number of other NoSQL systems.

Couchbase documents are in JSON, a self-describing format capable of representing voluminous structures and relationships. Unlike a traditional DBMS, a schema on Couchbase Server is a logical construct fully defined in the program code and fixed in the structure of the stored documents. Because there is no explicit schema support, developers can add new objects and properties at any time by simply clicking on the new application code that stores the new JSON, without having to make the same changes to the schemas. This facilitates fast and easy program development.

Couchbase's architecture ensures that workloads are evenly distributed among cluster nodes, reducing bottlenecks and allowing users to fully utilize available hardware.

MongoDB is an open source document-oriented database management system (DBMS) that does not require a table schema description. It is written in C++ [11].

The DBMS architecture manages sets of JSON-like documents stored in binary form in BSON format. Saving and searching files in MongoDB is done by calling the GridFS protocol. Like other document-oriented DBMSs (CouchDB, etc.), MongoDB is not a relational DBMS.

MongoDB implements asynchronous replication in a master-slave configuration based on the transfer of the change log from the master node to the slaves. Automatic recovery is supported in the event of a master node failure. The servers running the mongod process must form a quorum for the new master to be automatically determined. Therefore, unless a special arbitrator process is used (a mongod process that only participates in quorum establishment but does not store any data), the number of running replicas must be odd.

To summarize. MongoDB contains databases that consist of collections. "Collections" consist of "documents". Each "document" contains "fields". "Collections" can be indexed, which improves the performance of selecting and sorting. And finally, retrieving data from MongoDB is reduced to retrieving a "cursor" that gives that data as needed. These terms, while close to their relational counterparts, are not completely identical. The main difference is that relational databases define "columns" only at the "table" level, while document-oriented databases define "fields" only at the "document" level. This means that any "document" within a "collection" can have its own unique set of "fields". In this sense, a collection is "dumber" than a table, while a document has much more information than a string.

So, according to the author of the article, MongoDB can be considered as a direct alternative to relational databases. MongoDB cannot be called a replacement for a RDBMS, but rather an alternative.

Purpose of the study

The aim of the study is to develop a subsystem for migrating from a relational to a document-oriented DBMS, as well as to study patterns and investigate dependencies between SQL and MongoDB queries that describe the same data but in different representations of the data model.

To solve this problem, you need to develop several relational data models with different structures and subject areas. For each model, create SQL queries in different DBMSs, because each DBMS has a different syntax. Next, for each relational data model, you need to create a hierarchical data model that describes the same fields and their attributes. In the process of model conversion, it is necessary to maintain data integrity and optimize its structure for the purposes of a document-oriented DBMS. Based on the hierarchical model (hierarchical data structure) of the document, create MongoDB queries that describe and create a document corresponding to this model.

After analyzing these parameters and identifying patterns of transitions between data models, an algorithm for translating queries and an algorithm for optimizing the document structure in accordance with MongoDB requirements were developed.

Description of the work results

A comparative analysis of the performance of MongoDB and MySql was conducted. The simplest database containing words and their lengths is used as a test database. The test results are shown in the following figures (the lower the execution time, the better).

Fig. 1 shows a comparison of the execution time of the insert operation in MongoDB and MySQL.

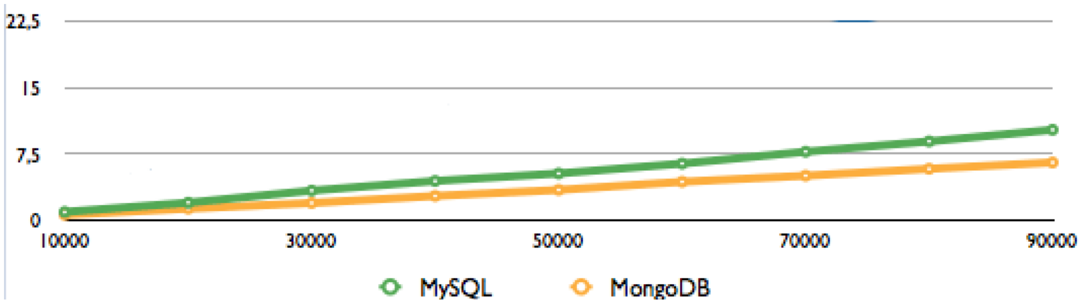

Fig. 1. Insertion execution time

Figs. 2–3 show diagrams of the dependence of query execution time on the sample size.

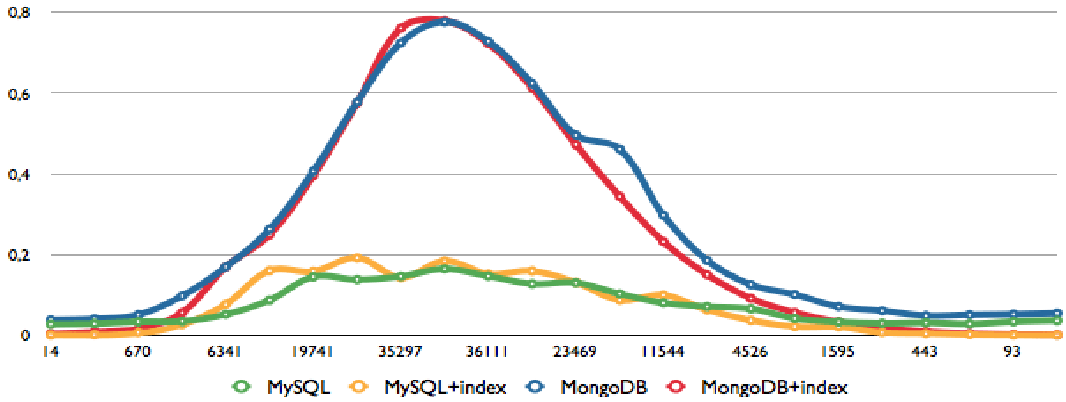

Fig. 2. Full sample of data by word length ranges with and without additional indexes

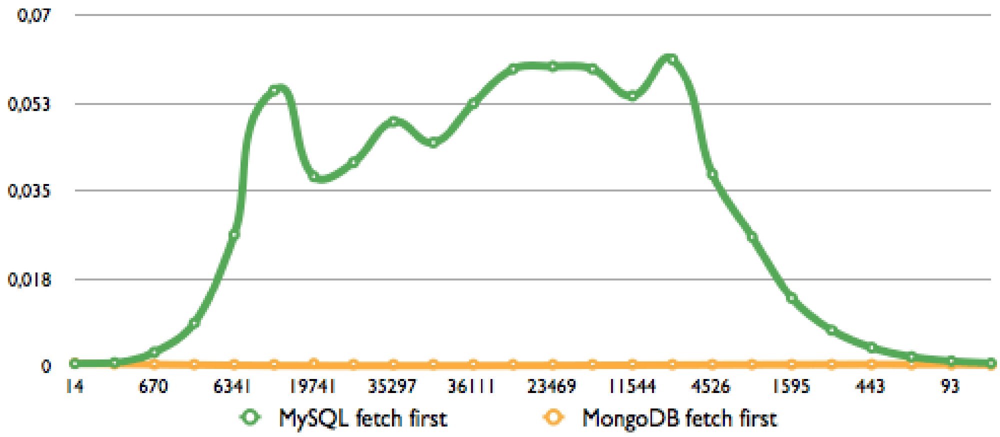

Fig. 3. Processing a request to select only the first result by word length range

Figs. 4–5 show the diagrams of the update and retrieval rates for each 10/100/1000 row.

	MySQL	*MongoDB*
10	0,695042	0,269425
100	0,055984	0,027250
1000	0,005612	0,002600

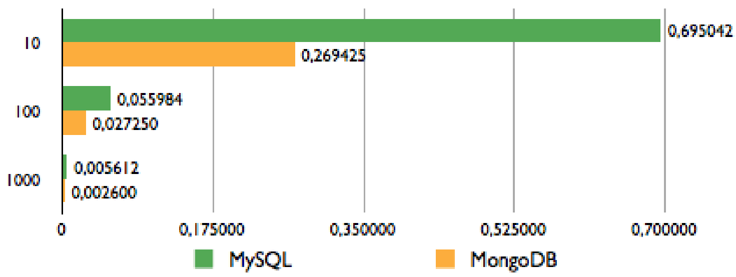

Fig. 4. Updating every 10/100/1000 records

	MySQL	MongoDB
10	0,804231	0,247743
100	0,082997	0,023055
1000	0,008276	0,002383

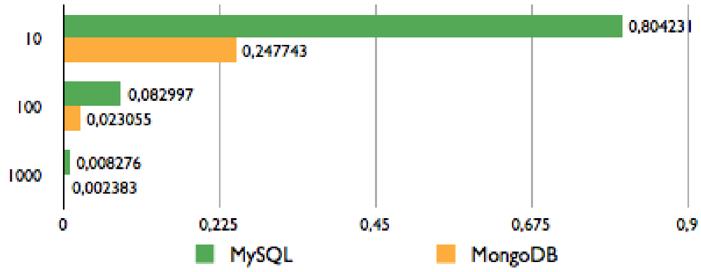

Fig. 5. Extracting every 10/100/1000 records

Development of a method for transition from a relational model to a document-oriented one

When it comes to data modeling, document-oriented databases are not as different from relational databases as other NoSQL solutions. The differences are not that significant, but that does not diminish their importance.

The first and most fundamental difference is that MongoDB does not have an analog of the JOIN construct. JOIN is not scalable. This means that if you start splitting data horizontally, you will still have to perform JOINs on the client (which is the application server). In the worst case, the lack of JOINs in MongoDB will often require an additional query.

Arrays of values are much more convenient to use than many-to-many tables and provide a significant number of options for implementing multiple inheritance.

In addition to arrays, MongoDB also supports nested documents. They can be queried using dot notation:

MongoDB supports DBRefs. When a driver sees a DBRef, it can automatically retrieve the associated document. A DBRef contains the collection and _id of the document it refers to. This means that documents from one collection can refer to other documents from different collections.

In the process of moving from a relational data model with many tables, relationships, and keys to MongoDB documents, the question arises of the number of collections needed to reproduce all the data from the relational model without losing data. In other words, is it worth following the structure and creating a separate collection in MongoDB for what would be a table in a relational database (many-to-many tables are an important exception). Given that collections do not tie us to a specific schema, you can get by with a single collection that has documents of different structures.

Let's create a MongoDB collection based on the SQL queries from the previous section (Fig. 6).

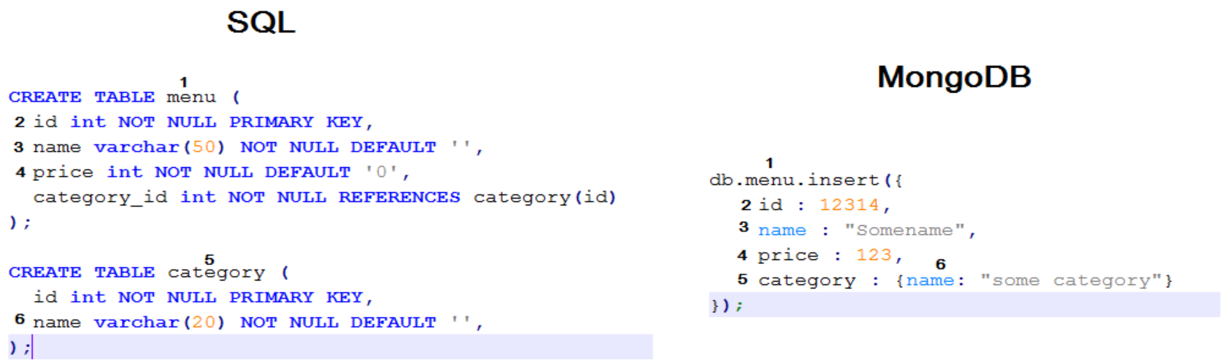

Fig. 6. Creation requests

As you can see, MongoDB uses the names of the tables and fields from the SQL query (they are marked with numbers), and there is no foreign key in the query, it has turned into a field with a nested document.

Based on the analysis results and conclusions, let's describe the algorithm verbally.

Step 1. Find the "main" table (with the maximum number of foreign keys).

Step 2. Go through each field of the table.

Step 3. Check the field type.

Detailed algorithm of the method of transition from a relational data model to a document-oriented one:

Step 1. Read the original SQL query one by one (get a container of strings).

Step 2. Determine the number of tables (search for the line with the CREATE TABLE statements).

Step 3. For each row container for tables, determine the number of foreign keys (by REFERENCES). The container with the maximum number of foreign keys is passed to step 4. If two or more tables have the same number of foreign keys, then we pass the container with the larger number of rows (fields) to step 4.

Step 4. Get the field name, type, and additional attributes (foreign, primary, etc.) from each row. The type leads to a related data type from MongoDB with the default values set.

Step 5. Validate the fields.

Unlike the relational database model, the MongoDB schema is focused on the application and its interaction with the database. To optimize the model, many factors must be taken into account:

a) access to the field;

b) the frequency of access to a particular field;

c) response time for a particular field, etc.

So, shifting from a relational data model to a document-oriented one does not guarantee faster query processing. Sometimes it is advisable to leave the (model) database schema in its relational form to maintain integrity and logic.

In our opinion, there is no need to use only one collection:

a) when the structure becomes too complicated to understand (more than 3 levels of nesting are more difficult to perceive both by the programmer and the application);

b) when database queries become cumbersome (searching for massive objects in a nested collection within a collection will not speed up the application);

c) when the document exceeds the 16 MB limit on the size of the document (if you exceeded this limit, you probably didn't think about it when you created it).

All these factors directly or indirectly affect the performance of the application. The developed application takes these factors into account and does not greatly complicate the structure of the document, and if the structure becomes more complex or the number of fields in the table increases above the specified one, it partially preserves the relational structure.

The user is free to perform several actions to improve performance: indexing, sharding, and replication. Indexes in MongoDB work in the same way as indexes in relational databases: they speed up data selection and sorting. MongoDB supports auto-sharding. Sharding is an approach to scalability when separate parts of data are stored on different servers. A simple example: store data of users whose name begins with the letters A-M on one server, and H-Z on another.

Replication in MongoDB works in a similar way to replication in relational databases. Records are sent to one server, the master, which then synchronizes its state with other servers, the slaves. The user can allow or disallow reading from the managed servers, depending on whether their system allows reading inconsistent data. If the master server goes down, one of the slaves can take over the role of the main server.

The results of the tests show that MongoDB is much faster at inserting, updating, and deleting records from the database. The data may differ for different data types and structures, but it is safe to say that MongoDB does not lose to MySQL in terms of query execution speed and is a high-performance system that is great for projects with high database update dynamics.

We created an application that implements the developed algorithm for transitioning from the relational to the document-oriented MongoDB data model.

This program generates MongoDB statements to create a document based on SQL queries entered by the user to create tables. The application accepts and correctly processes SQL queries from the DBMS: MySQL, MS SQL, PostgreSQL.

The test results are shown in Figs. 7 i 8. They allow us to talk about the exact operation of the algorithm. Based on the analysis of the test results, it is recommended to:

a) create a field for entering the number of tables;

b) create a separate text field for each SQL query to create a table.

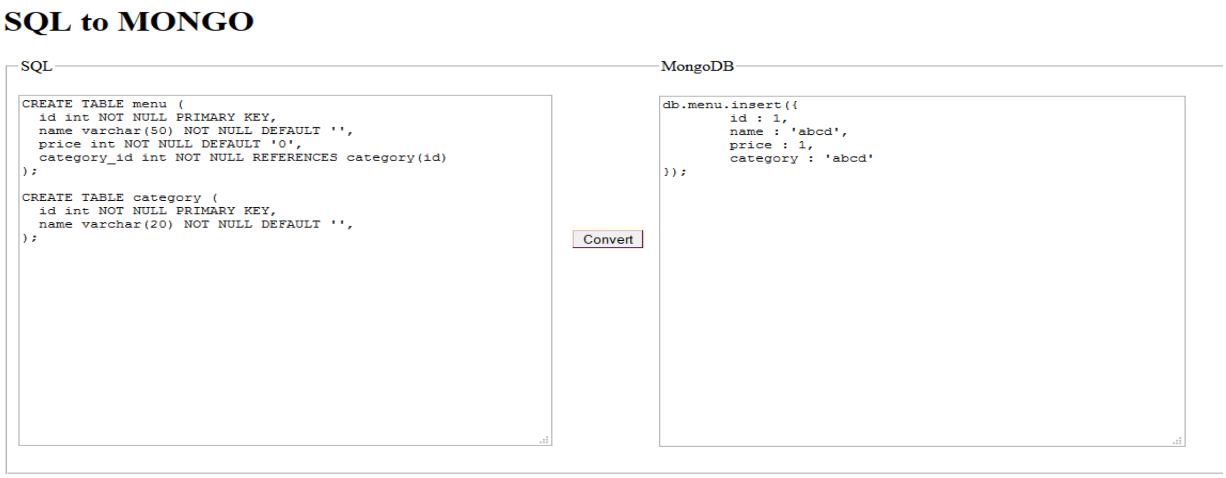

Fig. 7. The result of the program with two tables

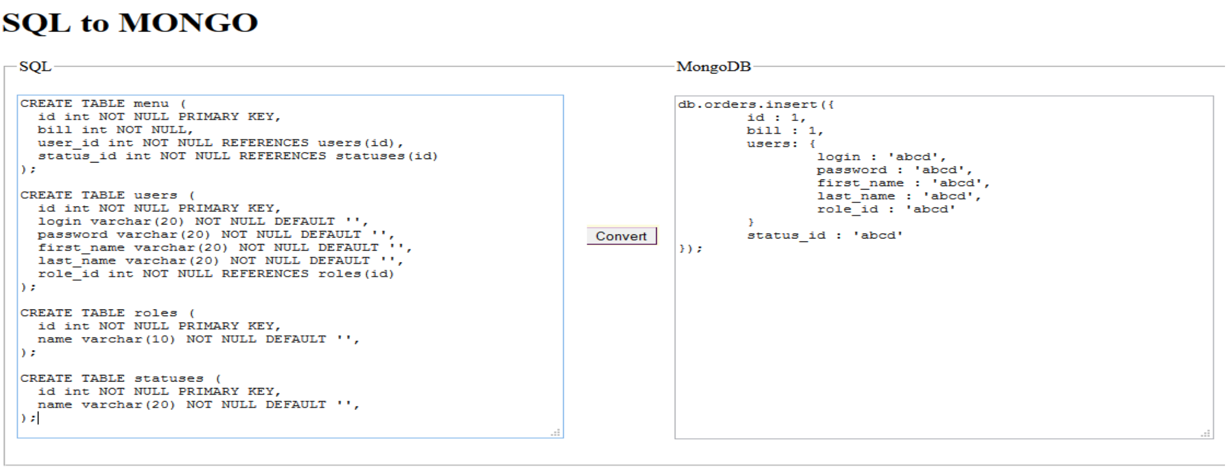

Fig. 8. The result of the program with four tables

Conclusions

The emergence of the new generation of non-relational DBMSs was driven by the need to create parallel distributed systems for highly scalable Internet applications such as search engines, blogs, etc. Document-oriented DBMSs are used to store hierarchical data structures and are used in content management systems, publishing, document retrieval, etc. Examples of DBMSs of this type: CouchDB, Couchbase, MarkLogic, MongoDB, eXist, Berkeley DB XML. Document-oriented DBMSs are based on document repositories that have a tree structure. The tree structure starts with the root node and can contain several internal and leaf nodes. Leaf nodes contain data that is entered into indexes during the process of adding a document, which makes it possible to find the location (path) of the data being searched even with a rather complex structure. The search API finds documents and parts of documents on request. Unlike key-value storages, a query selection for a document repository can contain parts of a large number of documents without loading them into RAM.

The main problem with using document-oriented databases is the complexity of designing a data model. When it comes to data modeling, document-oriented databases are not as different from relational databases as other NoSQL solutions, but there are several significant differences.

When switching from a relational data model to a document-oriented one, the wrong approach is to keep the structure with tables and relationships. MongoDB provides opportunities to build complex documents using nested collections and arrays, and if it is impossible to abandon the relational model, then it allows you to stick to it.

Increasingly, developers are choosing MongoDB for their projects, and the problem they face is a data model that differs from the relational one.

We analyzed the patterns between SQL and MongoDB queries describing the same data, compiled query mappings, and analyzed the problems that arise in the process of model transition. An algorithm for transitioning from a relational model to a document-oriented model based on SQL queries has also been developed.

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SOFTWARE IMPLEMENTATION OF THE CONVEYOR DIGITAL TWIN OF THE TECHNOLOGICAL LINE

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The paper describes the results of the analysis of methods for creating digital twins and the technology of designing software for virtual training models on the example of the laboratory stand from FESTO "Mechatronic module "Sorting Station". The structural diagram of the software is described. The scheme of interaction of the developed digital twin with real automation means is constructed. The algorithms of the digital twin are described. The program for controlling the digital twin of the conveyor of the technological line is described. The problem of remote monitoring of the state of the main nodes of the conveyor using the Codesys technological software development environment has been solved.

Introduction

A digital twin of an object is a means of accessing life cycle information and a single interface to it. Digital twins can be created for any entity of interest to an enterprise. All of these technologies are approaches to implementing the concept of the Fourth Industrial Revolution (Industry 4.0). Whereas traditional industry requires numerous field tests to obtain the required product characteristics, Industry 4.0 aims to conduct multiple tests using a digital twin, and pass the field tests the first time.

A digital twin of a product contains:

– geometric and structural model of the object;

– a set of design data for parts, assemblies and products in general;

– mathematical models that describe all physical processes occurring in the product;

– information on the manufacturing and assembly processes of individual elements and the product as a whole;

– a product life cycle management system.

In this paper, a digital twin of the FESTO laboratory model is being developed, which is intended for training students and specialists in the field of production automation. It allows you to reproduce the process of automatic sorting of parts, which ensures efficient and accurate operation of the production process.

The aim of the work is to develop a control program for the digital twin of the laboratory model from FESTO "Mechatronic module "Sorting Station"".

Design analysis of the mechatronic module "Sorting Station"

The FESTO Sorting Station training model is designed to train students and professionals in the field of production automation. It allows you to reproduce the process of automatic sorting of parts, which ensures efficient and accurate operation of the production process (Fig. 1).

Using this model, you can learn how to program an industrial controller that controls the operation of the station, as well as how to establish the interaction of various system components, such as a conveyor, work tables, and manipulators. Such a model is useful for reproducing production processes in an educational institution, which allows students to gain the necessary experience in solving practical problems in the field of production automation.

The mechatronic module "Sorting Station" from FESTO is a training model for studying the principles of automated product sorting. The module consists of various components, such as actuators, sensors, pneumatic valves, and others. All these components allow you to automatically sort products according to various parameters, such as size, color, or shape.

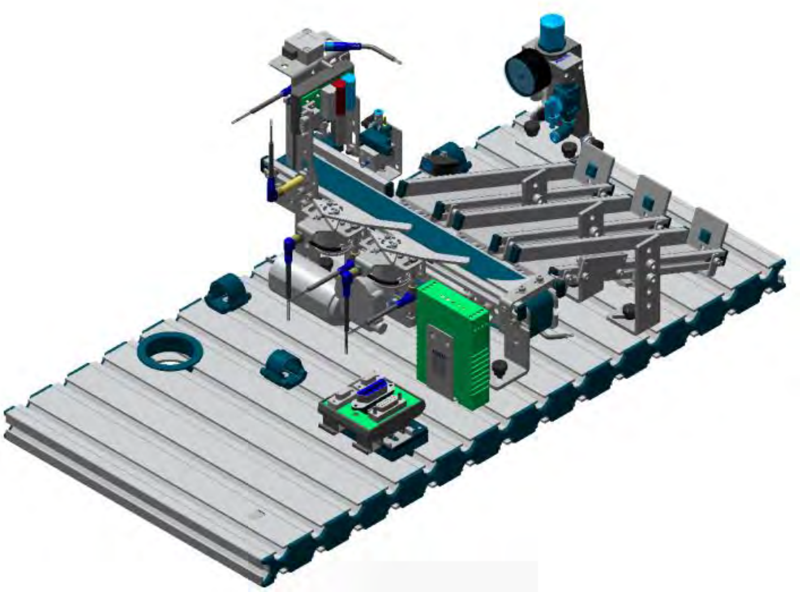


Fig. 1. Exterior of the mechatronic module "Sorting station"

The use of the mechatronic module "Sorting Station" allows not only to learn the basics of automation and sorting of products, but also to apply this knowledge in practical tasks, for example, in the field of logistics or manufacturing [1, 2].

The module simulates a section of a production line where metal and plastic parts are sorted from a store [1]. The parts are fed to the conveyor line using a vacuum transfer device.

This model can be used

– as a programming object for the SIEMENS SIMATIC S7-1200 controller, in accordance with the cyclogram for sorting parts by material type;

– to set up and calibrate sensors for recognizing the position of the part and the position of the stem of pneumatic actuators;

– installation of electrical and pneumatic equipment, signal elements, electrical and pneumatic cables, power supply, push-button control panel and terminal boxes.

The sorting station distributes the workpieces in three directions depending on the material properties or other specified conditions specified in the controller programming.

The training layout consists of a set of pneumatic mechatronic actuators fixed on a stationary base:

– conveyor belt

– pneumatic distributors;

– slopes;

– a set of sensors for detecting parts in different directions.

The following components are required for the sorting station to operate:

– compressor

– a laptop for programming the PLC;

– PLC programming software.

The incoming workpieces are detected by either a diffuse optical or inductive sensor installed at the beginning of the belt conveyor. Sensors in front of the barrier recognize the properties of the workpieces (black or red color, metal).

Figure 2 shows the assembly of the conveyor, pneumatic distributors and diffuse optical sensor.

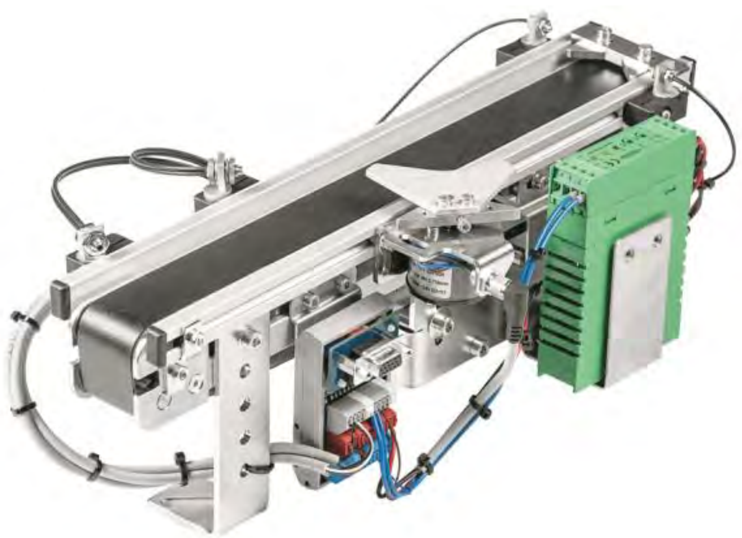


Fig. 2. Block of conveyor, pneumatic distributors and diffusion optical sensor

Pneumatic distributors driven by short-stroke cylinders with a directional change mechanism sort the workpieces into the appropriate slopes.

Development of the principle of interaction between the digital twin of the "Sorting Station" layout and the real world

The components of the digital twin are shown in Fig. 3 [3].

Information modeling. The main element of a digital twin is information related to different stages of the entity's life cycle.

Information content. Information for digital twins comes from various sources. Some may be contained within the twins themselves. For example, if an advanced analytics application uses the content of a digital twin as its input, the application can only store the results of the analysis in that twin.

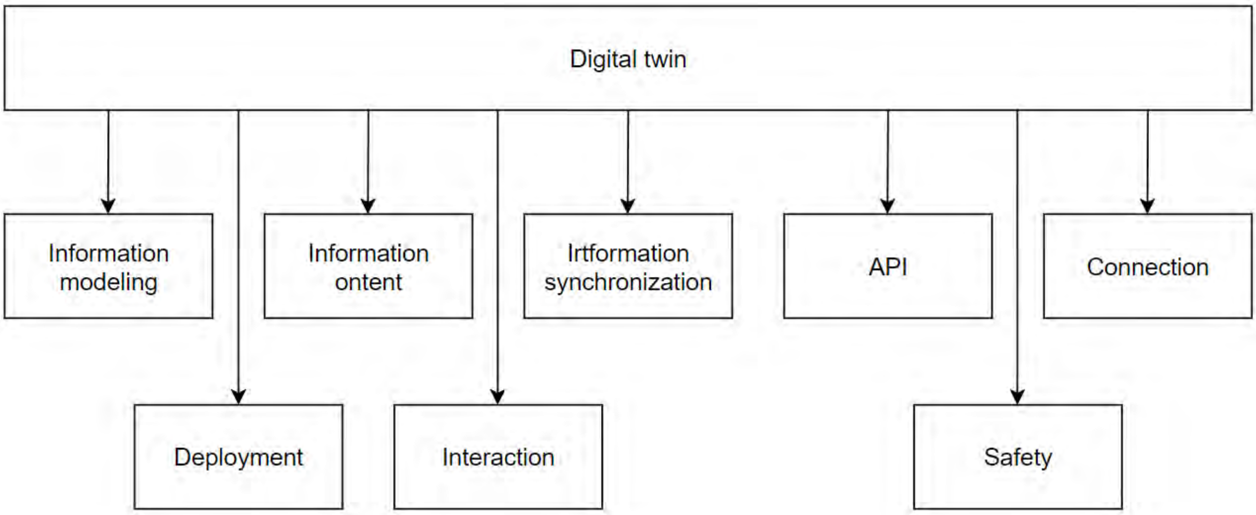


Fig. 3. Technical aspects of the digital twin

Synchronization of information:

– means of synchronizing information between a digital twin and relevant information sources in both directions – from sources to twin and vice versa;

– mechanisms for synchronizing information between multiple digital doubles that are part of different composite forms;

– policies (such as security and frequency of synchronization) for performing synchronization and standards and means for ensuring interoperability of digital twins and their information sources to facilitate synchronization.

API. Digital twins interact with other components.

Communication is a key factor in the interaction between digital twins. Various key decisions should address communication.

Deployment. Digital twins can be deployed anywhere from the edge device to the cloud, depending on the application requirements.

Security: The interaction of digital twins with different entities is based on different security considerations. A number of key decisions need to be made with respect to the deployment of digital twins.

Interoperability is "the ability of two or more systems or applications to exchange information and mutually use the information received." To ensure interoperability, international standards or generally accepted communication protocols are needed to define the syntax of information, its semantics, expected behavior, and rules for exchanging information [4].

According to the structure shown in Fig. 3, a digital twin must have one or more communication channels to interact with the real world. These channels are used to read information from sensors and execute commands from the control device. Figure 4 shows the scheme of interaction of the developed digital twin with real automation means.

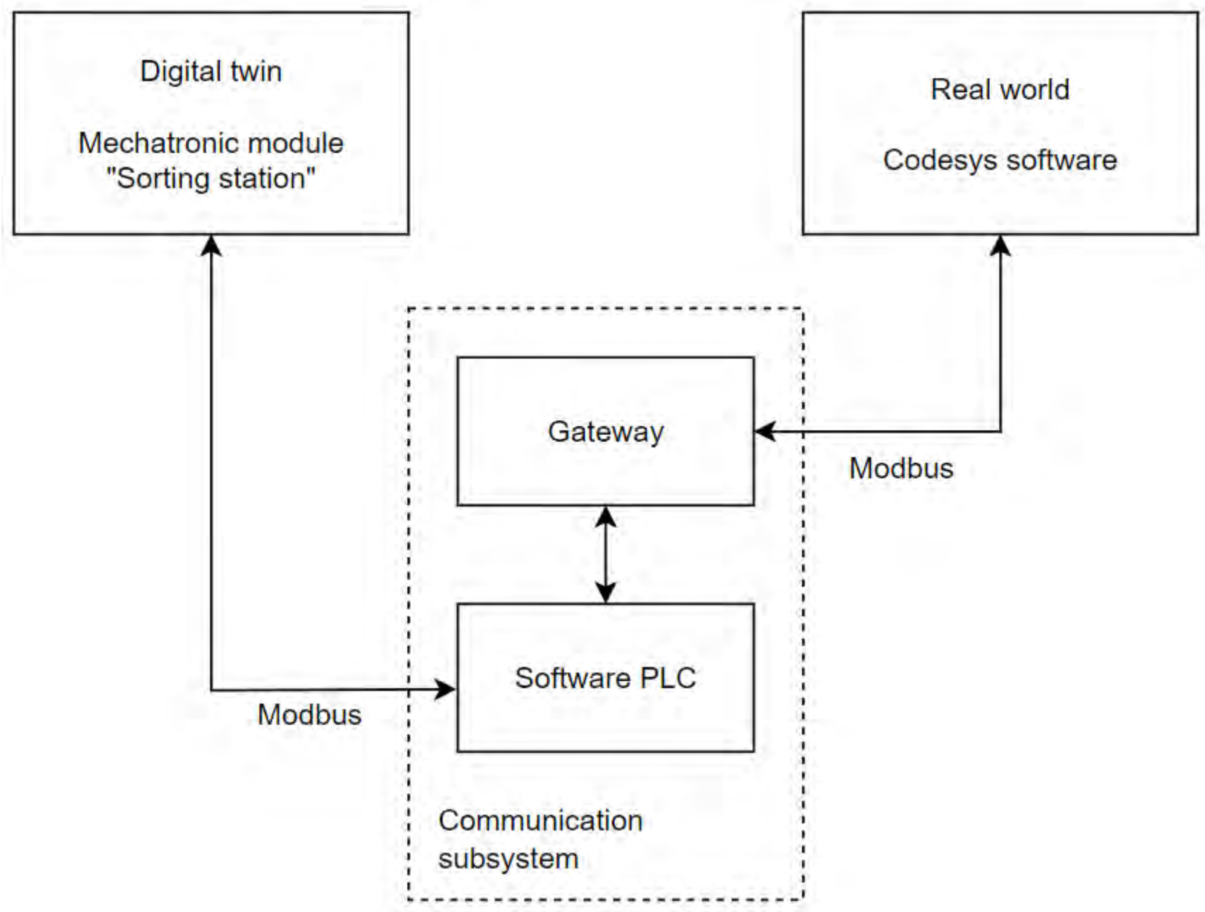


Fig. 4. Scheme of interaction of the developed digital twin with real automation means

The virtual layout "Mechatronic module "Sorting station" generates signals from virtual sensors depending on the location of the parts on the conveyor line and the position of the actuators.

The Codesys software receives this data through its own Software PLC tool, processes it, and, based on the algorithm embedded in the process program, controls the operation of the actuators.

Thus, the digital twin interacts with the real world through the industrial Modbus protocol. It is used to receive data packets with information about the state of the sensors, in accordance with the design of the real layout:

– sensor for the presence of parts at the entrance to the conveyor line;

– sensors for filling the drives in all directions of sorting.

Also, using the Modbus protocol, commands are received to control virtual automation tools:

– conveyor motor

– parts flow distributors;

– layout status indicators.

To combine the two main components of the system, auxiliary software components are used:

– PLC server;

– Gateway to the virtual device.

As a result, the structure of the software that implements the functions of the digital twin of the model "Mechatronic module "Sorting Station"" was built, which is shown in Figure 5.

As part of the software, we can distinguish [5]:

– a module for processing messages via the modbus protocol;

– a set of virtual modules that implement the functions of actuators;

– a set of virtual modules that implement the functions of sensors.

The set of virtual modules that implement the functions of actuators includes software emulators of such devices:

– conveyor belt motor;

– parts magazine rod that feeds the conveyor line;

– parts flow distributor;

– line status indicator.

The set of virtual modules that implement the functions of sensors includes software emulators of the following devices:

– layout control buttons;

– parts presence sensor at the conveyor inlet;

– parts presence sensor at the conveyor outlet;
– storage devices filling sensors.

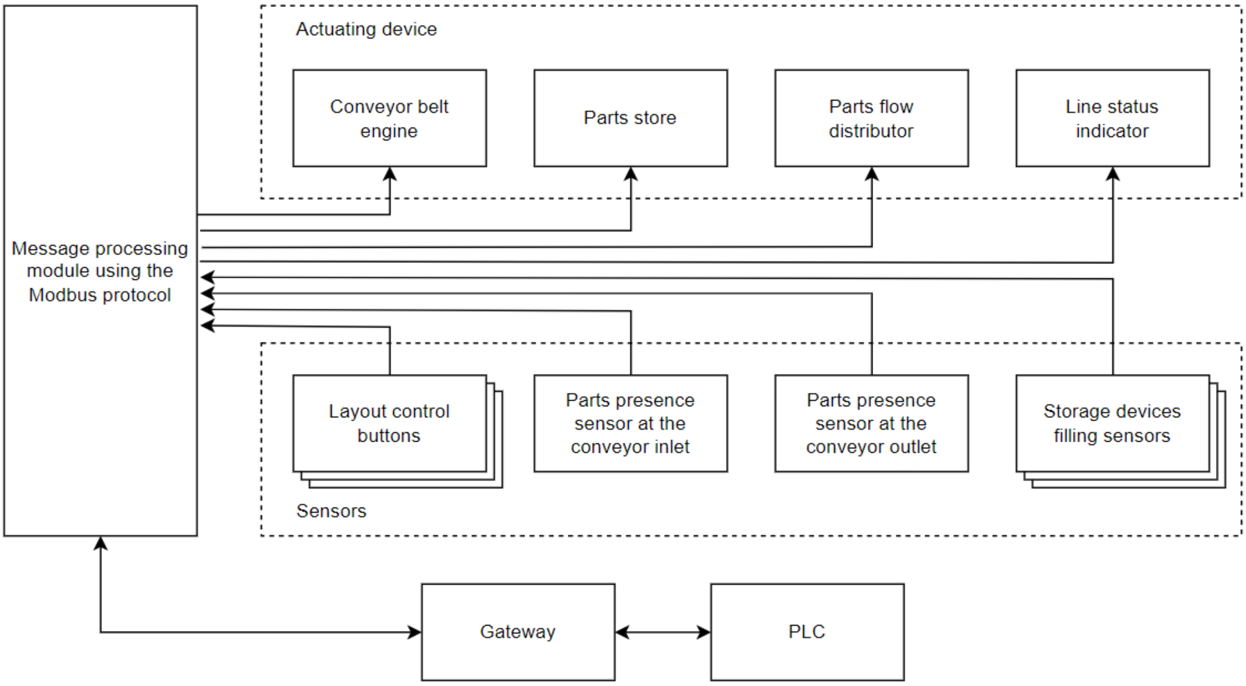


Fig. 5. The structure of the software that implements the functions of the digital twin of the model "Mechatronic module "Sorting Station"

Development of a digital twin operation algorithm

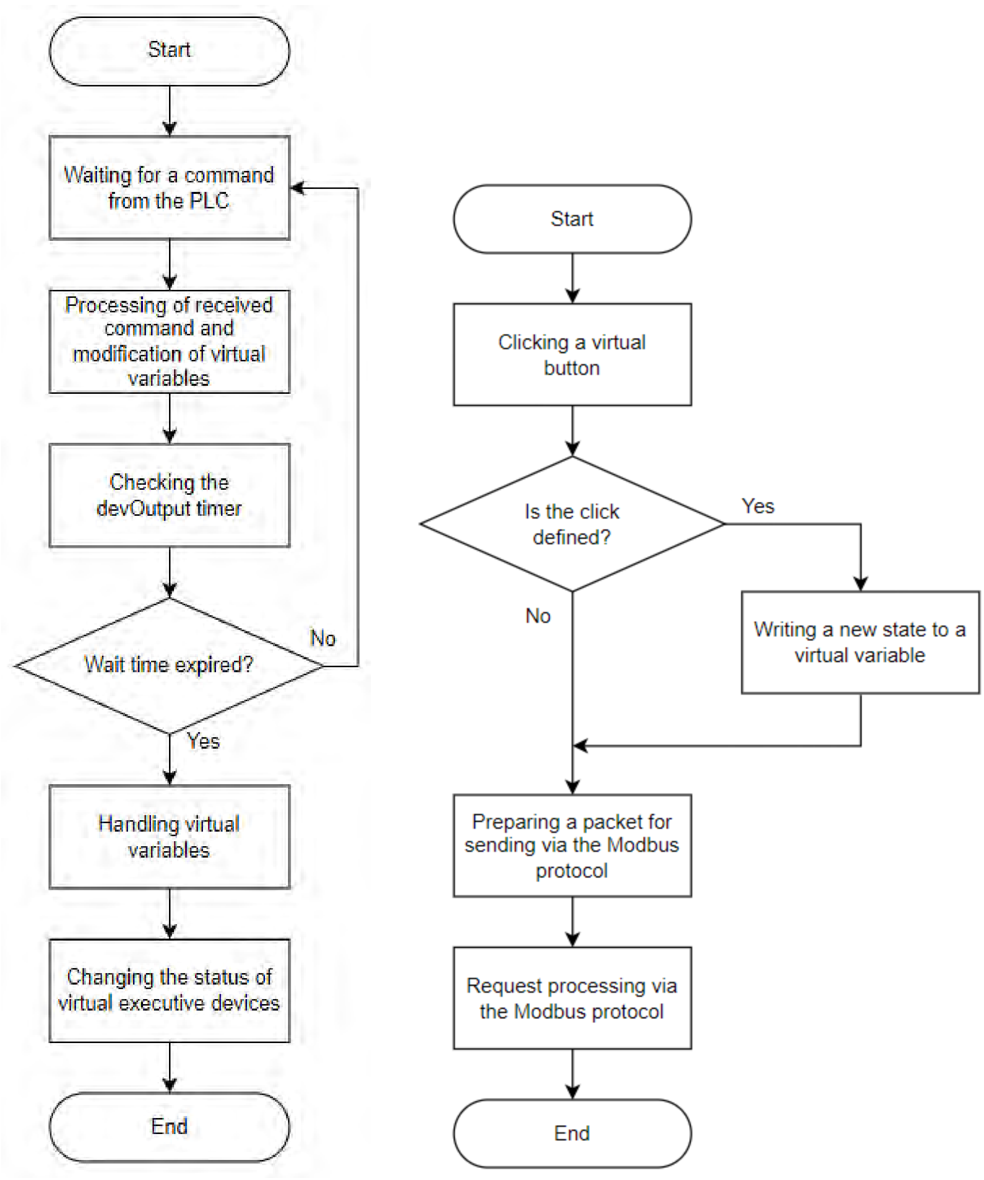
Let's consider the principle of operation of the decision-making subsystem, which is the basis of the digital twin of the Sorting Station layout. Thanks to the developed algorithm, the virtual layout behaves like a real device, responding to external influences through the GUI controls and through a network communication channel using the industrial Modbus protocol.

The algorithm for processing messages via the Modbus protocol and controlling actuators is shown in Figure 6, a.

Message processing module receives packets in the Modbus protocol format automatically and stores information in the appropriate registers specified in the message.

The system timer is set for a certain period of time. When it expires, the received data is processed. Depending on the information received, internal variables are modified. Each variable is assigned to a specific Modbus register address.

The algorithm for polling sensors and generating messages via the Modbus protocol is shown in Figure 6, b.



a) b)

Fig. 6. Algorithm for processing messages via Modbus protocol and controlling actuators

Description of the graphical layout interface

The software implementation of the digital twin allows you to perform the following functions:

– issuing parts to feed the conveyor line;

– moving them along the conveyor line;

– if necessary, distribution of the flow of parts depending on the characteristics of the parts, or according to another principle;

– control of the layout operation mode using an additional block of buttons;

– visualization of the current state of all layout elements.

Let's consider the purpose of the controls and visualization of the virtual layout state. The designation of the main elements of the virtual layout is shown in Figure 7.

Motor 1 moves the conveyor belt in only one direction – from left to right, so only one signal and the corresponding variable "YC_Moto" are used to turn on the motor.

The virtual layout has three sensors:

– a part counting sensor at the conveyor inlet (2);

– part counting sensor at the conveyor outlet (5);

– analog part color sensor (11), which is structurally combined with the part count sensor at the input (2).

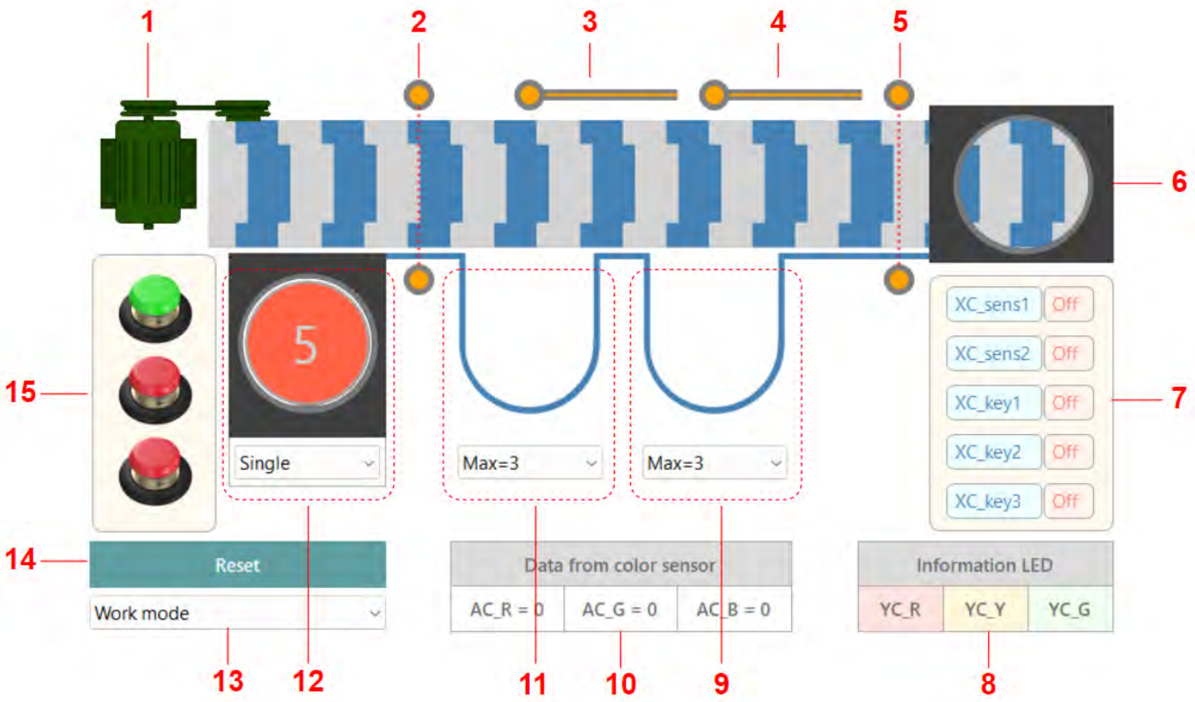


Fig. 7. Designation of the main elements of the virtual layout

Sensors 2 and 5 are discrete. The signal at their output can be one of two possible states: true and false (on and off).

The part counting sensor 2 emits a logical unit signal when a part crosses its beam and holds the same output signal for the entire time until the part goes beyond its boundaries. The variable "SC_sens1" is associated with this sensor. Sensor 5 works in a similar way and its state is associated with the variable "SC_sens2".

Analog sensor 11 is used to determine the color of the parts entering the conveyor line.

Figure 8 shows the binding of program variables to the resources of the Modbus channels.

Переменная	Соотнесение	Канал	Адрес	Тип	Единица	Описание
Application.PLC_PRG.YC_Magz		YC_Magz	~~%QB0~~	ARRAY [0..0] OF BYTE		Write Single Coil
Application.PLC_PRG.YC_Moto		YC_Moto	~~%QB1~~	ARRAY [0..0] OF BYTE		Write Single Coil
		Stor	%IW0	ARRAY [0..3] OF WORD		Read Holding Registers
Application.PLC_PRG.Stor_1		Stor[0]	~~%IW0~~	WORD		0x0064
Application.PLC_PRG.Stor_2		Stor[1]	~~%IW1~~	WORD		0x0065
Application.PLC_PRG.Stor_3		Stor[2]	~~%IW2~~	WORD		0x0066
Application.PLC_PRG.Stor_4		Stor[3]	~~%IW3~~	WORD		0x0067
Application.PLC_PRG.mon_YC_Moto		monMoto	~~%IB8~~	ARRAY [0..0] OF BYTE		Read Coils
Application.PLC_PRG.mon_YC_Sp1		monSp1	~~%IB9~~	ARRAY [0..0] OF BYTE		Read Coils
Application.PLC_PRG.XC_Sens1		XC_Sens1	~~%IB10~~	ARRAY [0..0] OF BYTE		Read Discrete Inputs
Application.PLC_PRG.YC_Sp1		YC_Sp1	~~%QB2~~	ARRAY [0..0] OF BYTE		Write Single Coil

Fig. 8. Binding program variables to Modbus channel resources

Using visual components, we will develop the graphical interface of the operator panel (Fig. 9).

Fig. 9. An example of the program interface
and virtual layout in the process of executing a technological program

There are four different colored panels on the operator's screen to display the remaining parts in the store and in the layout drives. You can see that the number display uses the format "%.2d", which, in accordance with the principle of text data formatting, means displaying two-digit numbers with a zero in front.

The graphical panel has a toggle switch to turn on or off the motor that moves the conveyor belt.

The "Issue part" button should be associated with a rod that pushes parts out of the magazine.

The interface also provides two LED indicators to monitor the operation status of the motor and the flow distributor, respectively.

Conclusions

The paper describes the results of the analysis of methods for creating digital twins and design technology for developing software for virtual training models on the example of a laboratory model from FESTO "Mechatronic module "Sorting Station".

A structural diagram of the software was developed. The principle of interaction of the digital twin of the "Sorting Station" model with the real world was developed. The scheme of interaction of the developed digital twin with real automation means is built. The algorithms of the digital twin's operation were developed.

A control program for a digital twin of an industrial conveyor has been developed. The peculiarity of this device implementation is the combination of the conveyor line with the module for supplying the conveyor line parts into a single production module.

The software implementation of the digital twin allows you to perform the following functions

– delivery of parts for feeding the conveyor line;

– moving them along the conveyor line;

– if necessary, distributing the flow of parts depending on the characteristics of the parts, or according to another principle;

– control of the layout operation mode using an additional block of buttons;

– visualization of the current state of all elements of the technological conveyor.

To test the performance of the developed layout, the task of remote monitoring of the state of the main conveyor components was solved using the Codesys process software development environment.

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FEATURES OF WAVE ALGORITHM APPLICATION IN WAREHOUSE LOGISTICS TRANSPORT SYSTEMS

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The relevance of research in the field of storage organization using automated transportation systems, including pallet transport technology using Radio Shuttle as part of Warehouse 4.0, is due to the rapid development of modern industry [1–3]. With the emergence of Warehouse 4.0 concept, warehouse systems have become an integral part of enterprises digital transformation within the framework of Industry 4.0 concept [4–6]. Automated transportation systems make it possible to significantly improve the productivity and efficiency of warehouse operations. This made it possible to improve the technologies of pallet storage and transportation moved to a new level became more flexible and adaptable thanks to Warehouse 4.0. This allows enterprises to cope with the growing volume of goods, meet the needs of customers and reduce costs. Robotic transportation systems using Radio Shuttle not only ensure pallets uninterrupted movement, but also integrate with other technologies, such as data analytics, artificial intelligence and the Internet of Things, enriching the warehouse system with valuable information data [7]. In addition, in the context of sustainable development, automated transportation systems based on Radio Shuttle allow to reduce energy consumption and reduce the impact on the environment, which corresponds to modern standards of responsible production and allows companies to implement environmentally sustainable practices.

But despite all the positive aspects of the implementation of automated transportation systems based on Radio Shuttle as part of Warehouse 4.0, these systems have a number of significant disadvantages. One of them is the limited flexibility when using the Radio Shuttle system, which refers to limitations in the ability to change or reorganize warehouse space without serious technical changes [8–10]. Here are some aspects that make the system less flexible:

– Radio Shuttle works inside certain rails and specially designed racks. These structural elements are specially designed to work together with the system. Because of this, it is impossible to simply change the configuration of the warehouse, move racks or rails. Changing the warehouse structure will require a complete restructuring of the system, which is difficult and expensive;

– due to fixed rails and racks, storage options are limited. The system does not allow quick adaptation to new types of goods or changes in demand. New products may not meet the system parameters, this creates difficulties in their effective storage and use;

– because the system works within a limited space, products that require turning or flipping for optimal storage can cause complications. In some cases, this can lead to inefficient use of warehouse space;

– difficulties with manual access. If manual access to the goods is necessary (for example, for inventory or processing of defective goods), the Radio Shuttle system could become an obstacle due to its fixed elements. It will be necessary to disrupt the normal operation of the system to carry out such operations.

So, the limited flexibility of the Radio Shuttle system means that warehouse operations become less adaptable to changes, which can lead to inefficient use of resources and hinder the company's ability to adapt to changing market requirements [11–13]. As a result, there is a task of developing a new or upgrading existing robotic systems based on Radio Shuttle, which will reduce the impact of limited flexibility and achieve a more additive approach to the storage of goods within the framework of Warehouse 4.0 [14].

Radio Shuttle systems, like many other automated storage systems within the framework of Warehouse 4.0 [15], can interact with various storage methods, such as LIFO (Last-In-First-Out) and FIFO (First-In-First-Out). We will compare the main disadvantages of these methods and present them in Table 1.

Table 1

The LIFO and FIFO Storage Methods Main Disadvantages Comparison

Disadvantages	Radio Shuttle Method	
	LIFO	FIFO
Goods management	1. Difficulties in handling the goods last taken. 2. Difficulties with distribution of goods due to different sizes and characteristics of goods new batches	1. Difficulties in managing the order of movement of goods. 2. Difficulty in managing the use of space due to the need to store old goods closer to the exit
Accessibility	Limited access to old products due to their remoteness within the system	Difficulties in changing the order, especially if it is necessary to take the old goods first.
Space	Restrictions in the effective use of space due to the location of the last goods closer to the exit.	Difficulties in optimizing the use of space due to the need to store old products closer to the exit
Flexibility	Difficulties in changing the configuration of the system due to fixed rails and racks	Difficulties in managing the goods movement order and making changes due to the non-optimal structure of the system.
Interference	Difficulty in reordering in the occasion of an intervention requiring old items to be taken first	Difficulties in intervening in order due to the need to maintain order when issuing goods

As can be seen, the existing disadvantages of LIFO and FIFO storage methods are influenced by Radio Shuttle design features, such as:

– limited flexibility of Radio Shuttle design: The disadvantages of LIFO and FIFO methods reinforce the limited flexibility of Radio Shuttle design. For example, if the system is LIFO, it is more difficult to distribute new goods and rearrange the storage of old goods due to fixed rails and racks. Such restrictions can make it difficult to optimize warehouse space and manage the movement of goods;

– difficulties in managing access to goods: If the system uses the LIFO method and the latest goods are stored closer to the exit, this may create restrictions on access to old goods, especially if there is a need for manual access to them. Similarly, in the case of FIFO, it is more difficult to organize quick access to new goods, since old goods may take up more accessible space within the system;

– optimizing space usage: Disadvantages in storage methods can increase the challenges of optimizing space usage within Radio Shuttle structures. Difficulties in efficient space using may arise due to the system's inability to adapt to different sizes and goods characteristics that require storage using certain methods (LIFO or FIFO);

– difficulties in configuration changes: If LIFO and FIFO methods require changes in goods distribution, this may require major changes in the configuration of the Radio Shuttle system. This, in turn, can be a labor-intensive and costly process, which creates difficulties in System control [16].

Thus, the disadvantages of LIFO and FIFO storage methods may exacerbate limitations and weaknesses in Radio Shuttle design, creating additional challenges in optimizing and cotrolling warehouse operations. The optimal solution in this situation requires a careful analysis of warehouse requirements and selection of a storage method that best meets the characteristics of the goods and warehouse operations[17, 18]. The main types of Radio Shuttle that are used within Warehouse 4.0 are presented in Figure 1 [19].

a) b) c) d)

Fig. 1. Main Radio Shuttle Types That Are Used within Warehouse 4.0
a) Radio Shuttle; b) Multi-deck Shuttle carrier;
c) Four-way Shuttle system; d) Shuttle Carrier

Based on the design features of the above Radio Shuttle, we will conduct a study and compare the permissible movement trajectories, which are presented in Table 2.

From the presented table it can be seen that each of the systems has its own advantages and limitations regarding permissible movement trajectories. The use of Mecanum wheels can significantly improve the efficiency and flexibility of these designs.

Table 2

Acceptable Radio Shuttle Movement Trajectories Comparison

Parameters/ Systems	Radio Shuttle [19]	Multi-deck Shuttle carrier [19]	Four-way Shuttle system [19]	Shuttle Carrier [19]
Trajectory Limitation	Restricted to rails and racks	Multi-link system with different levels	Multi-tasking system with four-way movement capability	Limited to a specific trajectory in the warehouse
Space Efficiency	Limited due to fixed rails and shelving.	Effective use of many levels	Efficient use of space due to flexible trajectories	Limited due to fixed trajectories
Flexibility and Customizability	Limited flexibility due to fixed trajectories	More flexibility due to the ability to move at different levels	High flexibility due to four-way movement	Limited flexibility due to fixed trajectories
Difficulties in Control	May require complex setup and control due to limited trajectories.	May require additional control when moving to different levels	Requires careful control to avoid collisions when driving in different directions	Requires precise control to avoid collisions on fixed trajectories

Here are the conclusions that can be drawn to justify the improvement of these structures through the use of Mecanum wheels:

– good flexibility and maneuverability, Mecanum wheels have the ability to move in any direction without the need to turn the entire structure. This adds high agility and flexibility when moving goods in tight spaces. This is a key advantage when working in warehouse environments;

– easy access to goods, thanks to the ability to move sideways and diagonally, Mecanum wheels provide easy access to goods located at various levels and angles, reducing the complexity of moving goods in systems with many levels and complex configurations;

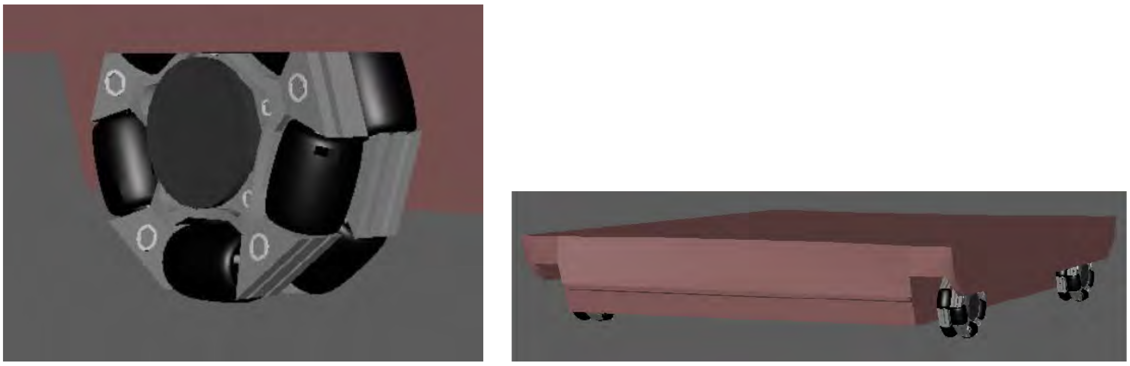
– efficient space using, Mecanum wheels allow optimal space using in the warehouse, as they allow movement in different directions without the need to rebuild the entire system, which is especially useful in systems with limited space;

– simplified control, moving in any direction without turning, systems with Mecanum wheels can be controlled more efficiently and accurately. This allows you to avoid collisions and optimize the planning of goods movements;

– easy implementation and integration, Mecanum wheels are easy to install and integrate, making it easy to upgrade existing designs without having to completely replace the system.

Thus, the use of Mecanum wheels improves the flexibility, maneuverability, accessibility and controllability of existing structures, making them more efficient and adaptable to different working conditions in the warehouse. These advantages justify the decision to improve systems using Mecanum wheels [20].

Using 3D modeling, let us design a Radio Shuttle robotic platform with built-in Mecanum wheels; an example of implementation is shown in Figure 2.



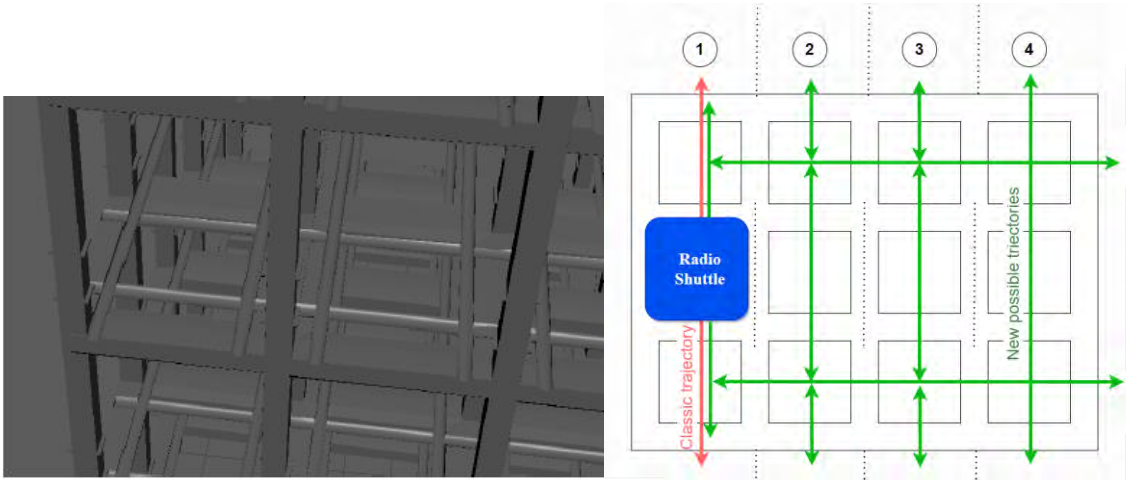
a) b)

Fig. 2. Mecanum Wheels 3D Model on 3D Radio Shuttle Robotic Platform
a) Mecanum Wheels 3D Model;
b) Radio Shuttle Robotic Platform 3D Model General View

So, it is necessary to improve the supporting structure of the racks in order to realize the benefits of Mecanum wheels on the Radio Shuttle platform. A 3D model of rack structure and a schematic representation of permissible movement trajectories are presented in Figure 3.

Let's improve the wave algorithm in accordance with the schematic representation of the permissible trajectories of Radio Shuttle movement when using Mecanum wheels.

Let W – wavefront matrix of size $M \times N$, where M – number of lines, N – number of columns. We denote the initial position of the robot by (x_{start}, y_{start}), since the route is arranged in two-dimensional space, therefore the final position where the robot should deliver/pick up the cargo will be denoted by (x_{end}, y_{end}). Let us fill in the wavefront matrix $M \times N$ by values -1. This will indicate that a given cell in the matrix W, Radio Shuttle was not visited. Let us set $W(x_{start}, y_{start}) = 0$, this entry will make it possible to indicate that Radio Shuttle is in this position. Now we can move on to a description of wave propagation. Wave propagation is a key step in the wave propagation algorithm. In this step, the wave propagates from the starting position of the Radio Shuttle to the remaining cells in the work area. In each iteration of this step, the wave propagates one cell further from the starting position. The robot uses this wave to determine the shortest path to each cell in the warehouse. Based on this, we can say that the first cell in the wave front will be $W(x_{start}, y_{start}) = 0$. From this we can conclude that every cell that has a value of 0 in the wavefront matrix is the first wave.



a) b)

Fig. 3. Rack Design 3D Model and Acceptable Radio Shuttle Moving Trajectory Schematic Representation: a) Rack Design 3D Model
b) Acceptable Radio Shuttle Moving Trajectory Schematic Representation

For each cell that is part of the current wave $W(x_i, y_i) = current\_wave\_value$, all its admissible neighbors are considered. If the neighboring cell has a value -1, then we set the value of the wavefront in this cell equal to the current value of the wavefront $+1$. This means that the wave propagates to this cell from the previous wave to a distance 1.

Formally, this can be written as follows for the cell (x, y) and its neighbor (x', y').

$$W(x, y) = current\_wave\_value$$
$$W(x', y') = -1 \quad (1)$$
$$W(x', y') = current\_wave\_value + 1$$

This part means that if the current cell (x, y) has a wavefront value equal to $current\_wave\_value$, and its neighboring cell (x', y') hasn't been visited yet. That is, its value in the matrix $M \times N$ is equal to –1, then, accordingly, the new value of the wave front for the cell (x', y') will be $W(x', y') = current\_wave\_value + 1$. This update occurs when a wave propagates to a new cell, through the current cell.

$$W(x', y') \neq -1 \quad (2)$$

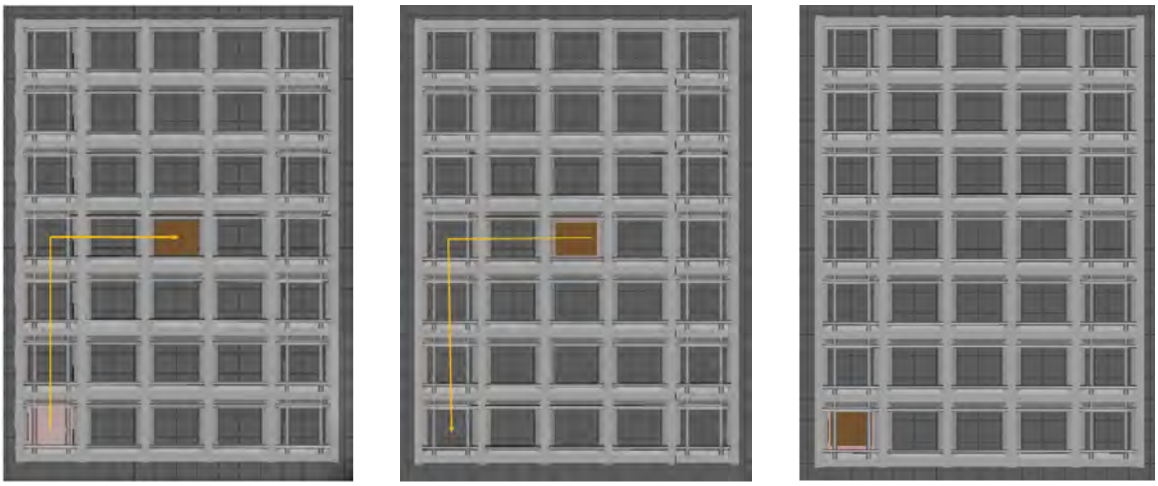
Means that if an neighboring cell (x', y') already has a wavefront value (i.e., its value is not –1), then this value is retained. There is no wavefront update because the wave does not propagate to cells that have already been visited. Thus, it is determined how to update the value of the wavefront during wave propagation, taking into account the current value of the wavefront in the cells (x, y) and neighboring cell (x', y') state.

The next step in finding the shortest path in the wave propagation algorithm occurs after the wave has been successfully propagated from the initial position to all other cells in the working area. The process of finding the shortest path consists of going back from the final position to the starting position, choosing a path through cells with decreasing wavefront values. This process ensures that the path found using wave propagation is the shortest path as it follows cells of decreasing wavefront values from the final position to the starting position. Let's describe it like this: let (x, y) be the current position, we look for neighboring cells (x', y') that satisfy the following condition

$$W(x', y') = W(x', y') - 1 \ . \tag{3}$$

In expression 3, $W(x, y)$ is the value of the wavefront in the cell (x, y). After finding such a cell, we add it to the path and set $(x, y) = (x', y')$. The process is repeated until we reach the starting position. The resulting path will be the shortest path from the end position to the start position.

To check the correctness of decision-making, let us conduct several experiments to simulate the movements of the Radio Shuttle. Let the Radio Shuttle be in the lower left part of the storage system, and the cargo that needs to be retrieved be in the center of the storage system. Using the improved wave algorithm (1–3), we will simulate route construction in the developed 3D model of the storage system. The simulation results are presented in Figure 4.



a) b) c)

Fig. 4. Results of the First Experiment in Modeling the Route Construction of an Improved Radio Shuttle: a) starting point (with a constructed route); b) end point (route back); c) Radio Shuttle delivered the cargo

Let's complicate the experiment, install 2 cargoes, among which we need to pick up only the green one, and build a route based on the improved wave algorithm, the starting point will be the same as in Figure 4, a. The simulation results are presented in Figure 5.

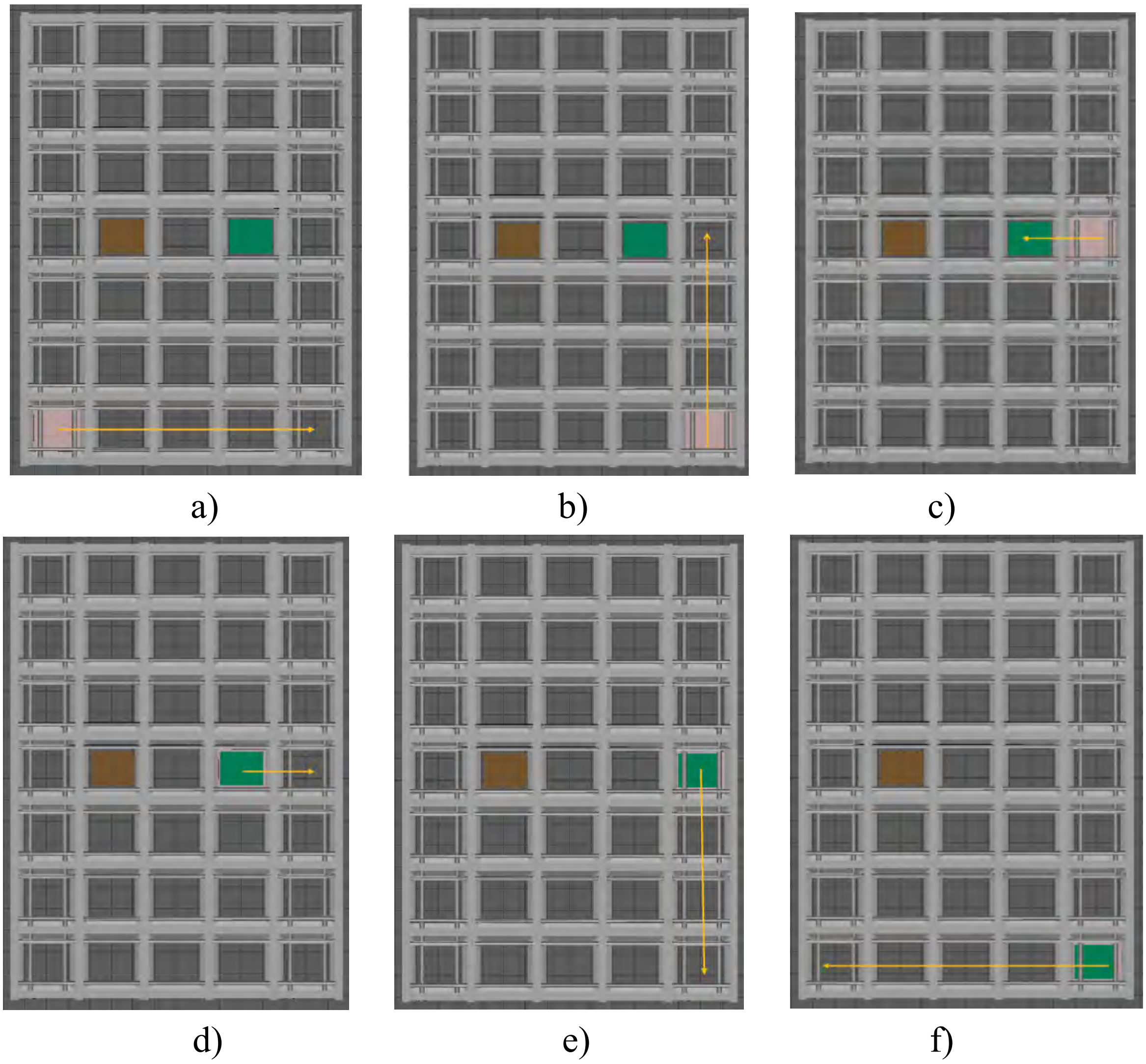


Fig. 5. Results of the Second Experiment of Modeling the Route Construction of an Improved Radio Shuttle

Let's carry out the third experiment, install 4 cargoes, among which we need to pick up the yellow one, and take it to the starting point, the starting point will be the same as in Figure 4, a. The simulation results are presented in Figure 6.

Based on the results obtained during the experiments (Fig. 4–6), a graph was constructed that shows the effectiveness of the improved wave route search method for Radio Shuttle. Graph of the number of sections passed versus the amount of interference is presented in Figure 7.

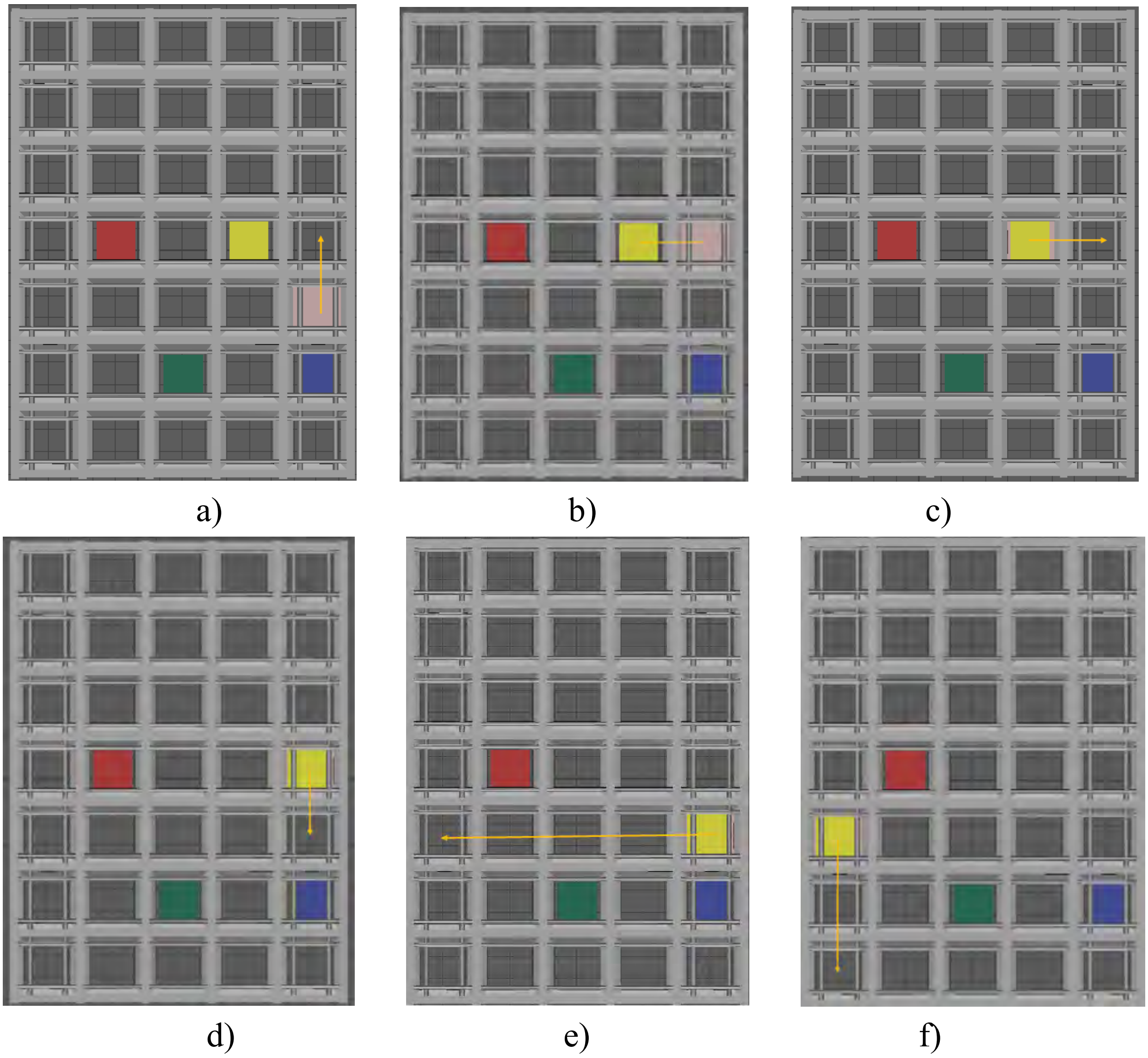


Fig. 6. Results of the Third Experiment
in Modeling the Route Construction of an Improved Radio Shuttle

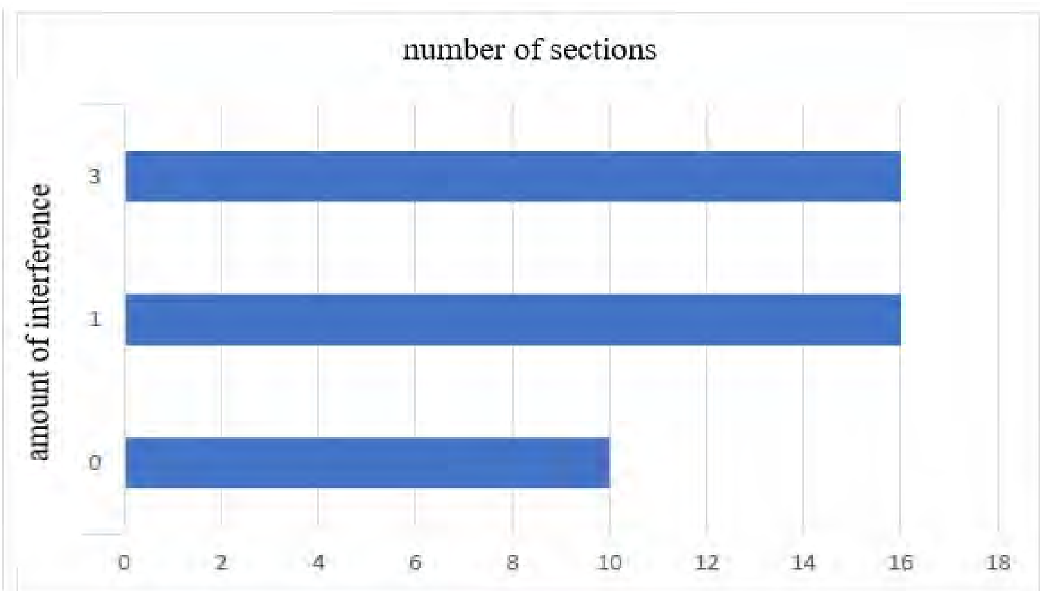


Fig. 7. Graph of the Number of Sections Passed Versus the Amount of Interference

Conclusions

In the proposed section of the collective monograph, the authors present an innovative approach to improving the Radio Shuttle design using Mecanum wheels. This improvement significantly increases the system functionality and mobility, allowing the Radio Shuttle to move freely horizontally and vertically in any plane. The main result of the study is the development and implementation of an improved wave algorithm for constructing Radio Shuttle moving routes in new conditions.

The integration of Mecanum wheels into the Radio Shuttle design has led to significant changes in the design of product storage racks. These changes created a more flexible and efficient storage system capable of moving in any direction and vertically, which was not previously possible with the Radio Shuttle system.

To confirm the effectiveness of the proposed solution and the correctness of the decisions made, the researchers developed a 3D model of the Radio Shuttle and the racks. After this, a series of simulations were carried out, which demonstrated the successful operation and high efficiency of the new system. Simulation results confirmed the improved performance, mobility and accuracy of the Radio Shuttle, making this improvement highly promising for practical implementation in warehouse systems and improving the efficiency of logistics processes. The findings highlight the significance of the proposed changes and their potential to optimize warehouse operations and improve overall performance in the logistics and storage of goods within Warehouse 4.0.

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PRACTICAL RESULTS OF THE STUDY OF PHOTOPOLYMER EXPOSURE OF PRINTED CIRCUIT BOARD TOPOLOGY

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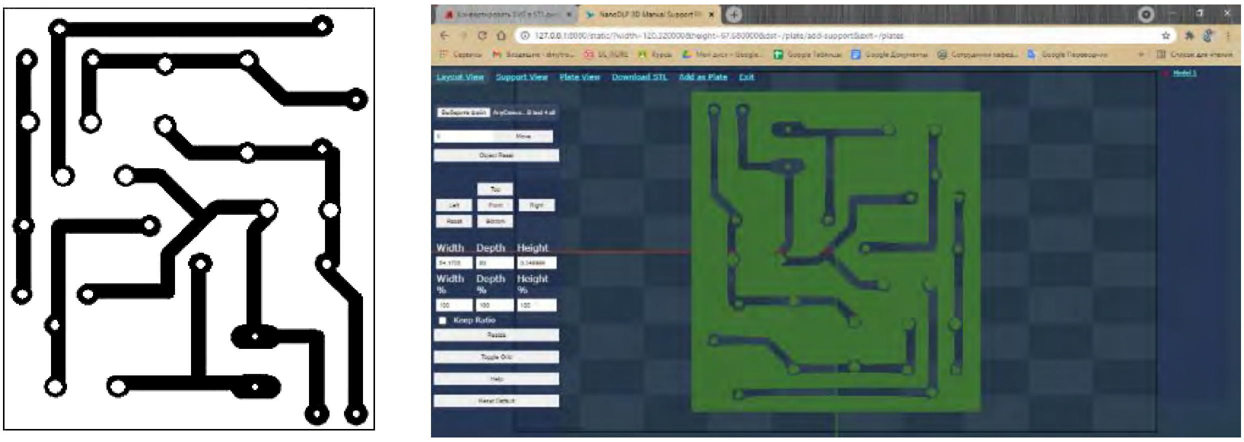
Practical results of studies of deviations of geometric dimensions of the topological structure of printed circuit boards during photopolymer 3D exposure are presented. A series of experiments of topology exposure under different process parameters was carried out. The results of 112 samples were checked using statistical analysis and a regression model of the influence of parameters on the deviation of the geometric dimensions of conductors was built.

Introduction

The modern development of technologies in the field of instrumentation is primarily focused on reducing the size of devices and integrating a large number of modules in one device [1–3]. This leads to the need to reduce the size of both products as a whole and their individual components, assemblies and printed circuit boards. The process of miniaturisation involves not only reducing the size of electronic elements, but also the size of printed circuit boards (PCBs). Photolithography technology is the most suitable for PCB production, but this process is labour-intensive and requires additional costs for creating stencils [4]. The use of stencils limits the flexibility of production, as it takes time to switch to creating new products. In today's automated production environment, this lack of flexibility is a serious limitation. However, one of the possible ways to solve these problems is to develop methods for adapting and optimising the technological parameters of PCB topology exposure using additive 3D printing technologies [5–6]. This topic is relevant because it can solve not only problems with production flexibility but also ensure the required product parameters.

Preparing for the experiment

To conduct the research, a stencil of the PCB topology with dimensions of 80×72 mm was created in the format of a vector image (svg.), which was then converted to a format for 3D printing (stl.) [7–8]. Such an approach to processing and converting a 2D image into a 3D object is necessary to work with the mask in the NanoDLP program, in which it is possible to generate a machine code for sequential execution of commands (G-code) for a DLP/LCD printer, in which the necessary printing parameters will be set, (fig. 1).



a) b)

Fig. 1. Vector image processing for 3D-exponuvannya:
a) vector image; b) 3D-mask

The samples were made using Plexiwire Resin Basic Orange Transparent photopolymer resin, which was chosen because of its high mechanical and technological parameters (short exposure time, minimum possible layer thickness and no harmful effects on personnel), low shrinkage during polymerisation, and high resistance to chemicals, which has a positive effect on the etching process [9–10].

To verify these assumptions, 112 measurements of the deviation of the obtained dimensions from the original geometric ones were carried out. A linear regression model was built taking into account the following parameters:

– resin illumination duration from 7 seconds to 20 seconds;

– radiation intensity maximum 2800 Lm and minimum 1600 Lm;

– emission wavelength 405–435 nm;

– base layer thickness 20 μm and 50 μm.

The created 3D topology of 80×72 mm DP conductors was transferred to foil fiberglass (SF grade DSTU 10316-78) and etched in ferric chloride solution ($FeCl_3$).

In the first experiment, the adhesion of the photopolymer resin to the foil billet was tested. The result confirms the resistance of the photopolymer resin to ferric chloride and high-quality adhesion to the surface, but there is a deviation in the geometric dimensions of the conductor structure by ±0,00847 mm (minimum deviation) with a base conductor size of 2 mm [11–12].

For greater clarity and a better understanding of the influence of parameters on the manufacturing process, the abbreviated results in the range of exposure times from 7 seconds to 11 seconds are shown in table 1.

A graphical description of the dependence of deviations at different parameter values is shown in (fig. 2).

Table 1

Average values of deviations of conductor sizes at different values of parameters in the range from 7 to 11 seconds at different values of exposure parameters

Emission wavelength 405 nm			
Radiation intensity 1600 Lm		Radiation intensity 2800 Lm	
Exposure time, s	Deviation, mm	Exposure time, s	Deviation, mm
7	+0,00847	7	+0,01025
8	+0,01074	8	+0,012925
9	+0,0125	9	+0,0135
10	+0,01375	10	+0,0165
11	+0,01575	11	+0,017
Layer thickness 20 µm		Layer thickness 50 µm	
Exposure time, s	Deviation, mm	Exposure time, s	Deviation, mm
7	+0,0092	7	+0,0102
8	+0,0111	8	+0,01287
9	+0,01225	9	+0,01482
10	+0,0142	10	+0,01625
11	+0,01527	11	+0,018775
Average deviation at 1600 lm radiation intensity and 20 µm layer thickness		Average deviation at 2800 lm radiation intensity and 50 µm layer thickness	
Exposure time, s	Deviation, mm	Exposure time, s	Deviation, mm
7	**+0,008835**	7	**+0,01022**
8	**+0,01092**	8	**+0,01289**
9	**+0,012375**	9	**+0,01416**
10	**+0,013975**	10	**+0,01637**
11	**+0,01551**	11	**+0,01788**

These deviations may be due to the long duration of the photopolymer illumination. This result allowed us to make the following assumptions:

1. There is a linear dependence of the illumination duration on the geometric size of the conductor. The longer the illumination time, the greater the upward deviation of the size, respectively, with a shorter illumination time, the deviation is smaller.

2. At low luminous flux intensity, the photopolymer resin may not be completely polymerised due to the incomplete transparency of the mask screen, which absorbs part of the radiation, which reduces the effect of UV on the resin and shortens the service life of the screen. Thus, the lack of UV radiation can lead to poor

adhesion to the workpiece, resulting in the transfer of the topology to the workpiece leaving the polymer in a semi-polymerised state on the film, which will reduce the service life of the film. Lack of light intensity with poor adhesion of the layer to the workpiece can lead to etching of the conductors and deviation of the dimensions downward from the original.

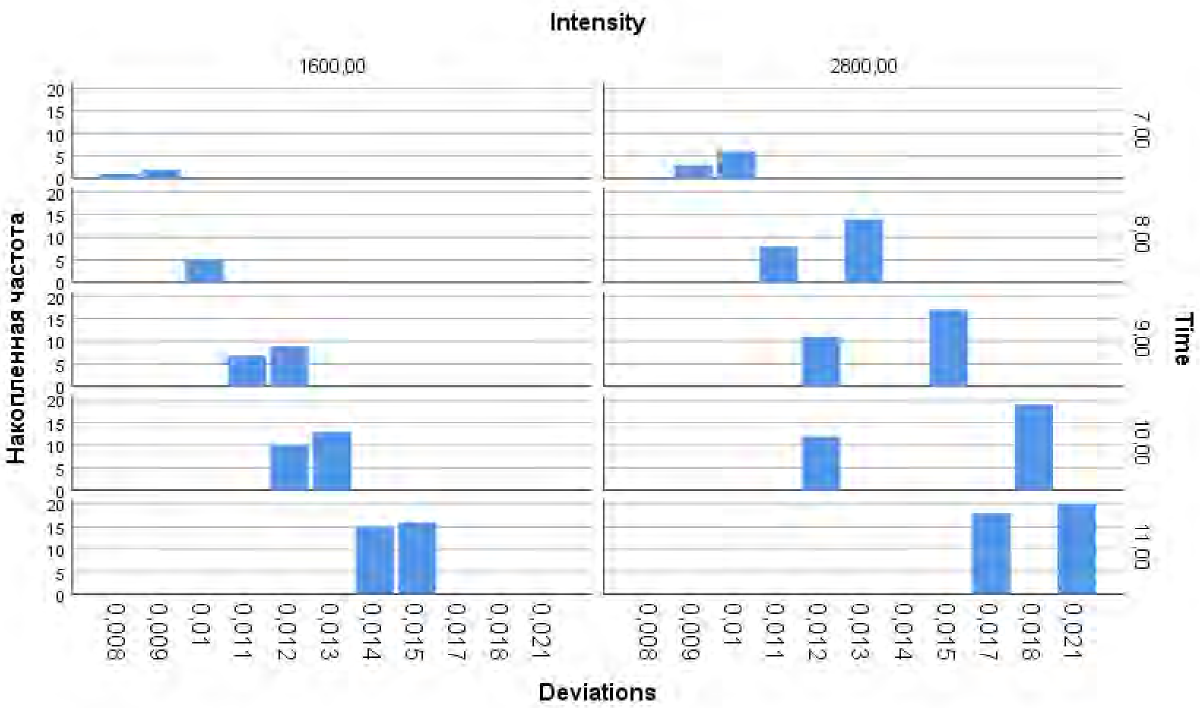


Fig. 2. Dependence of conductor size deviations on exposure parameters

3. The greater the height of the base layer of the photopolymer mask, the greater the gap between the screen and the workpiece. This can lead to a greater diffraction of the light flux, respectively, a greater parasitic illumination of the conductors, (fig. 3).

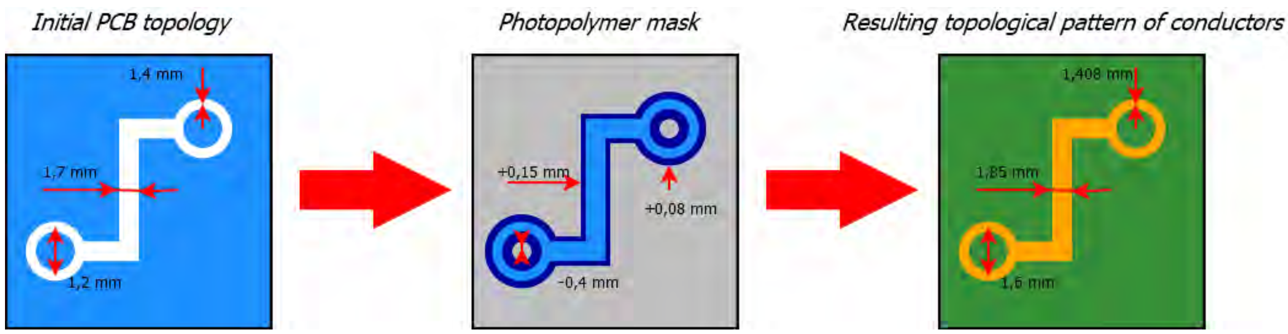


Fig. 3. Schematic representation of deviations in the experiments

A sample of the resulting topology is shown in fig. 4.

a) b) c)

Fig. 4. Production of DS using 3D exposure technology:

a) polymeric photo mask;

b) etching of the DP in ferric chloride solution ($FeCl_3$);

c) finished DP topology

Testing the basic assumptions of multiple linear regression

In order to build a multiple linear regression model, it is necessary to check the underlying assumptions that will confirm or refute the adequacy of the initial values for calculation and make sure that the parameters included in the model really affect the dependent variable.

To check the basic assumptions of multiple linear regression, the following assumptions should be reviewed: no outliers in the measurements; no multicollinearity between the independent variables; normal distribution of residuals; homoscedasticity of the variance of the residuals; linearity of the relationships [13–14].

No measurement errors

All the measurement data in this study are ordinal, so the model passes the first assumption.

This model uses four independent variables (exposure time «Time»; layer thickness «Thickness»; radiation intensity «Intensity»; wavelength «Wavelength»). Based on the rule that the minimum number of measurements for each independent variable is 20, the number of measurements must be at least 100 to build this multiple linear regression. In this case, there are 112 measurements in this model. Therefore, the model passes the second assumption. To check that there are no errors in the measurements, use IBM SPSS Statistics 26. Go to «Analyse»→ «Regression»→ «Linear», enter the model, go to "Statistics" to check for outliers and select «Casewise diagnostics». This will provide some information about the errors. Go to the «Save» button and build additional changes, namely:

– Cook's distance «Cook's»;

– standardised residuals «Residuals»→ «Standardised»;

– standardised predicted values «Predicted Values»→ «Standardised».

The standardised values of these values are necessary to see whether these values are within the normal range. After the settings, we get the table of residual statistics "Residuls Statistics[a]", (fig. 5).

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	,0100125	,0255892	,0178008	,00386310	112
Std. Predicted Value	-2,016	2,016	,000	1,000	112
Standard Error of Predicted Value	,000	,000	,000	,000	112
Adjusted Predicted Value	,0101091	,0255967	,0178070	,00386077	112
Residual	-,00328229	,00228059	,00000000	,00107548	112
Std. Residual	-2,996	2,082	,000	,982	112
Stud. Residual	-3,089	2,146	-,003	1,007	112
Deleted Residual	-,00348782	,00242340	-,00000611	,00113094	112
Stud. Deleted Residual	-3,221	2,184	-,005	1,018	112
Mahal. Distance	2,988	5,550	3,964	,884	112
Cook's Distance	,000	,119	,010	,018	112
Centered Leverage Value	,027	,050	,036	,008	112

a. Dependent Variable: Deviations

Fig. 5. Statistics of balances

Based on the fact that the maximum and minimum values of the standardised residuals «Std.Residual» and the standardised predicted values «Std.Predicted Value» do not fall outside the range of ±3. This indicates that there are no outliers in the measurement. «Cook's Distance» is 0,119, which is significantly less than one, which also supports the absence of outliers.

No multicollinearity between independent variables

The next assumption to be tested is the presence of multicollinearity between the independent variables. Go to «Analyse»→ «Regression»→ «Linear», in the «Save» tab, remove the standardised predicted values «Standardised», standardised residuals «Standardised» and Cook's distance «Cook's». Go to the «Statistics» tab, select «Descriptive» statistics and «Collinearity diagnostics». As a result, we get a correlation table, (fig. 6).

Correlations

		Deviations	Time	Thickness	Intensity	Wavelength
Pearson Correlation	Deviations	1,000	,904	,134	,300	,060
	Time	,904	1,000	,000	,000	,000
	Thickness	,134	,000	1,000	,000	,000
	Intensity	,300	,000	,000	1,000	,000
	Wavelength	,060	,000	,000	,000	1,000
Sig. (1-tailed)	Deviations	.	,000	,079	,001	,267
	Time	,000	.	,500	,500	,500
	Thickness	,079	,500	.	,500	,500
	Intensity	,001	,500	,500	.	,500
	Wavelength	,267	,500	,500	,500	.
N	Deviations	112	112	112	112	112
	Time	112	112	112	112	112
	Thickness	112	112	112	112	112
	Intensity	112	112	112	112	112
	Wavelength	112	112	112	112	112

Fig. 6. Correlation of the model

Multicollinearity is a linear dependence between independent variables, i.e. between the predicates themselves (exposure time «Time»; layer thickness «Thickness»; radiation intensity «Intensity»; wavelength «Wavelength»). Between the precursors themselves, the dependence should be incompletely observed in the measurements, or it should be minimal (less than 0,7). In this model, in the «Pearson Correlation», the relationship between the variables «Time», «Thickness», «Intensity» and «Wavelength» is zero. To make sure that there is no multicollinearity, we go to the table of regression coefficients «Coefficients», (fig. 7).

Judging by the variance inflation factor «VIF», which should be less than 5. In this model, the «VIF» between the independent variables is equal to 1, which supports the absence of multicollinearity between the predictors.

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	VIF
1	(Constant)	-,007	,003		-2,225	,028		
	Time	,001	,000	,904	34,847	,000	1,000	1,000
	Thickness	3,575E-5	,000	,134	5,180	,000	1,000	1,000
	Intensity	1,998E-6	,000	,300	11,581	,000	1,000	1,000
	Wavelength	1,584E-5	,000	,060	2,295	,024	1,000	1,000

a. Dependent Variable: Deviations

Fig. 7. Regression coefficients «Coefficients»

The tolerance indicator «Tolerance», which is equal to (1/«VIF»), is a relative indicator of «VIF» and should be greater than 0,2. This is the proportion of variance of the predictor itself, each of the specified predictors, that cannot be obtained from other predictors. In this model, it is complementary to one in all predictors.

In the «Collinearity Diagnostics[a]», when the «Eigenvalues» tend to zero, the «Condition Index» increases, and it should be less than 15, (fig. 8).

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	Time	Thickness	Intensity	Wavelength
1	1	4,751	1,000	,00	,00	,01	,00	,00
	2	,136	5,906	,00	,06	,90	,04	,00
	3	,076	7,911	,00	,59	,01	,40	,00
	4	,036	11,465	,01	,34	,09	,55	,01
	5	,001	86,773	,99	,00	,00	,00	,99

a. Dependent Variable: Deviations

Fig. 8. Collinearity Diagnostics «Collinearity Diagnostics[a]»

In this case, in the fifth dimension, this indicator is 86,773, which is a high risk of multicollinearity between predictors. In order to correct this, it is necessary to exclude one variable from the model. Using the «Variance Proportions», we exclude variables with a proportion greater than 0,9. In this case, it is «Wavelength», which is 0,99. We rebuild the model and get (fig. 9).

In the rebuilt model, all the results obtained are consistent with the previous rules. The conditionality index «Condition Index» for all variables is less than 15. Now this model fully meets the assumption of the absence of multicollinearity between independent variables.

Correlations

		Deviations	Time	Thickness	Intensity
Pearson Correlation	Deviations	1,000	,904	,134	,300
	Time	,904	1,000	,000	,000
	Thickness	,134	,000	1,000	,000
	Intensity	,300	,000	,000	1,000
Sig. (1-tailed)	Deviations	.	,000	,079	,001
	Time	,000	.	,500	,500
	Thickness	,079	,500	.	,500
	Intensity	,001	,500	,500	.
N	Deviations	112	112	112	112
	Time	112	112	112	112
	Thickness	112	112	112	112
	Intensity	112	112	112	112

a)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	7,533E-5	,001		,128	,898		
	Time	,001	,000	,904	34,178	,000	1,000	1,000
	Thickness	3,575E-5	,000	,134	5,081	,000	1,000	1,000
	Intensity	1,998E-6	,000	,300	11,359	,000	1,000	1,000

a. Dependent Variable: Deviations

b)

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				(Constant)	Time	Thickness	Intensity
1	1	3,768	1,000	,00	,01	,01	,00
	2	,133	5,314	,01	,09	,86	,05
	3	,076	7,059	,00	,55	,01	,45
	4	,023	12,762	,99	,36	,12	,50

a. Dependent Variable: Deviations

c)

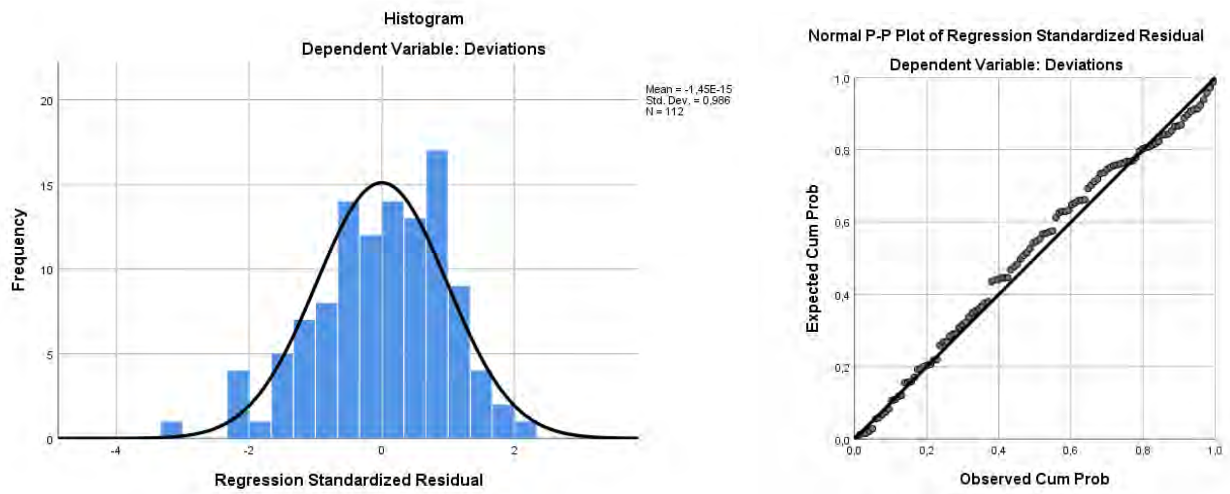
Fig. 9. Results of the above model:
a – model correlations; b – regression coefficients «Coefficientsa»;
c – diagnostics of collinearity «Collinearity Diagnostics[a]»

Normal distribution of residuals

The residual is the difference between the dependent variable and the predicted value of *Y*, through which the regression line passes. To check the normal distribution, you need to draw a distribution graph. Go to the «Analyse»→ «Regression»→ «Linear» masonry. In the «Statistics» tab, deselect «Descriptives» and «Collinearity diagnostics». In the «Plots» tab, select the «Histogram» and «Normal probability plot».

The result is a histogram. Using the histogram, you can see how much the distribution deviates from the theoretical approximation of the Gaussian line, (fig. 10, a).

The plot of the accumulated probabilities shows whether the observations deviate from the theoretical straight diagonal, fig 10, b.



a) b)

Fig. 10. Graphical description of the normality of the residuals distributions:
a – histogram of the distribution deviation; b – graph of observations

In order to estimate the deviation of the data from the normal distribution (fig. 10, a) and the deviation of the observations (fig. 10, b), it is necessary to analytically examine these graphs and estimate the distribution of the residuals. In these graphs, you need to estimate the standardised residual, so you need to plot these values separately. Go to «Analyse»→ «Regression»→ «Linear» in the «Save» tab, select to save the standardised residual «Residuals»→ «Standardised» and the unstandardised residual «Residuals»→ «Unstandardised». As a result, in the «Data View» we get additional values RES_1 and ZRE_2, using these values it is possible to check the normality of the values.

Go to the «Descriptive Statistics» analysis, «Explore» analysis, and transfer the changes you have made. In the "Plots" tab, select the graph for the normality criterion «Normality plots with tests». In the table of the normal distribution criterion «Tests of Normality», in the significance indicators «Kolmogorov–Smirnov» and «Shapiro-Wilk», the significance «Sig.» should be greater than 0,05, which confirms the rule of normality of the residuals distribution, (fig. 11).

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Unstandardized Residual	,064	112	,200*	,983	112	,153
Standardized Residual	,064	112	,200*	,983	112	,153

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Fig. 11. Table of normal distribution criterion «Tests of Normality»

In this case, the significance of the standardised «Standardised Residuals» and the unstandardised residual «Unstandardised Residuals» by «Kolmogorov–Smirnov» is 0,2, and by «Shapiro–Wilk» is 0,153, which supports the normal distribution of residuals in the model.

If you build an additional histogram of the standardised values «Descriptive Statistics»→ «Explore»→ «Plots»→ «Histogram», you can compare the standardised histogram with the first histogram, then compare the standard deviation «Std.Dev.» and make sure that they are the same, and the normal distribution of residuals is preserved, (fig. 12).

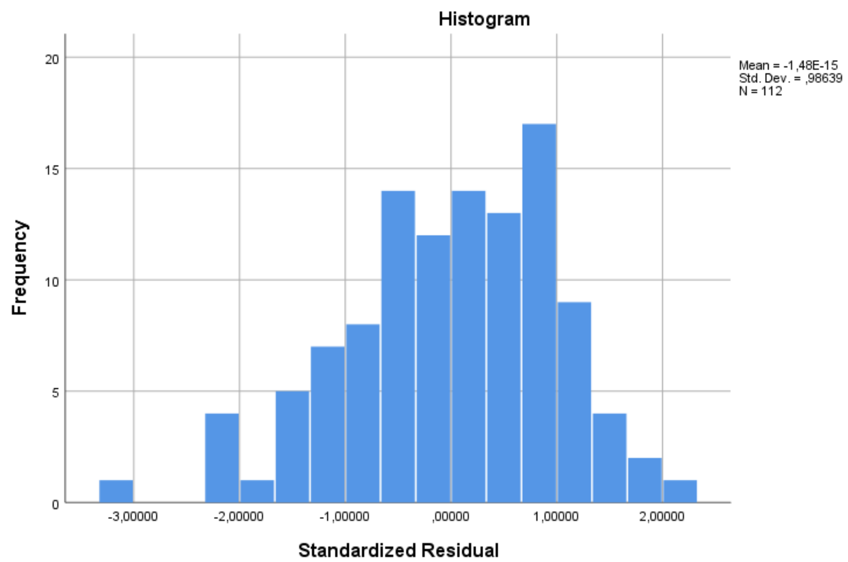


Fig. 12. Standardised balance sheet

Homoscedasticity of the variance of the residuals

Homoskedasticity is the constancy of the variance of the sudden error of a regression model. To test this assumption graphically, go to «Analyse»→ «Regression»→ «Linear»→ «Plots». Select the standardised predicted values (*ZPRED) on the *X*-axis and the standardised residuals (*ZRESID) on the *Y*-axis.

Using the resulting graph (fig. 13), it is possible to view the presence of outliers in the model, whether the values are outside ±3, in this case there are no outliers in the model.

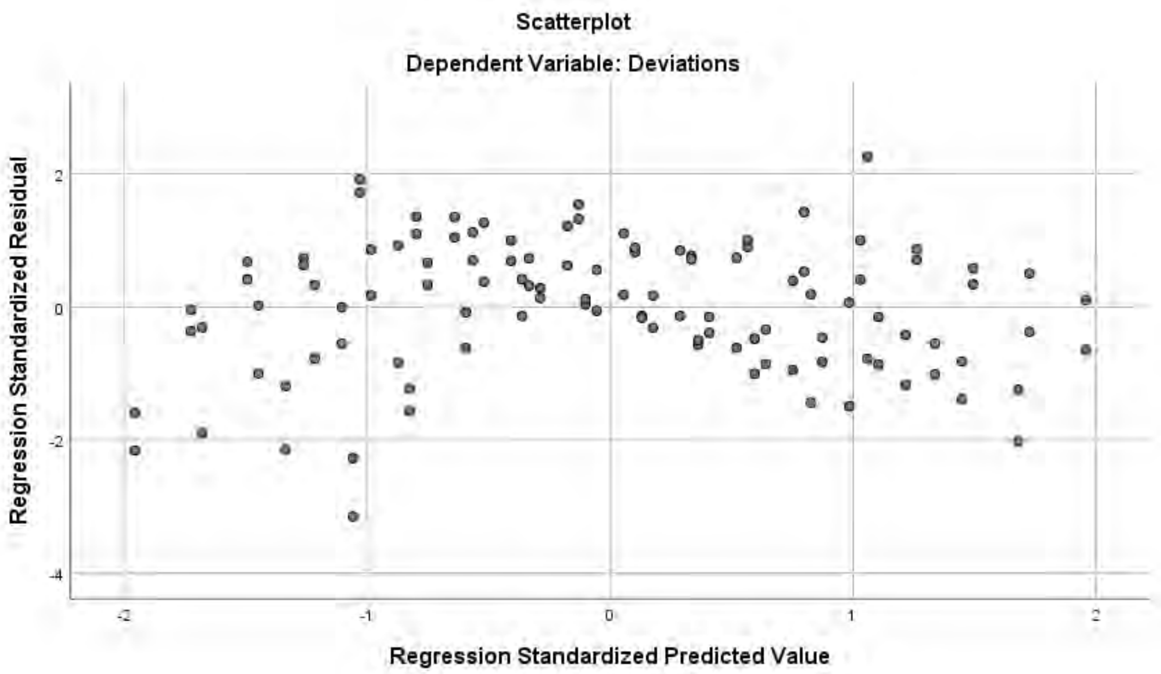
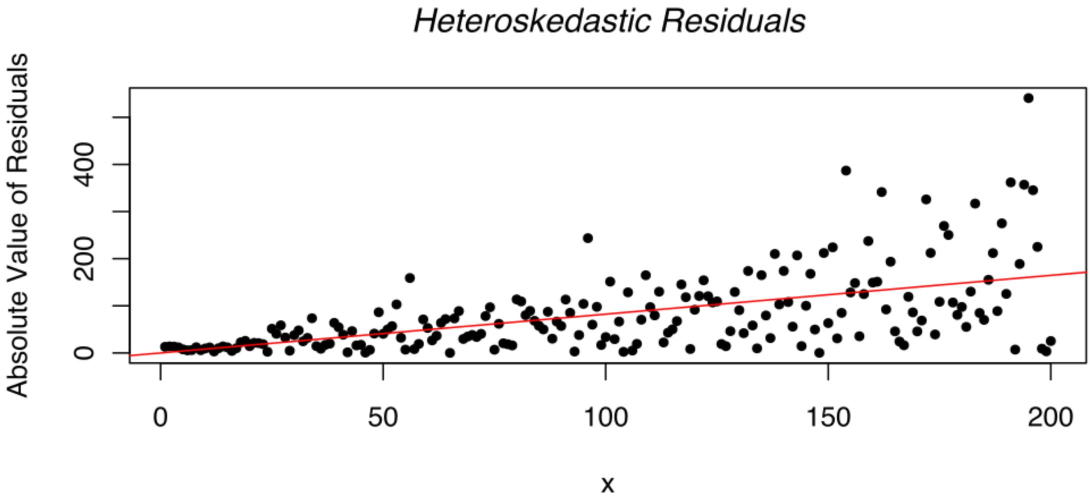


Fig. 13. The resulting homoscedastic distribution

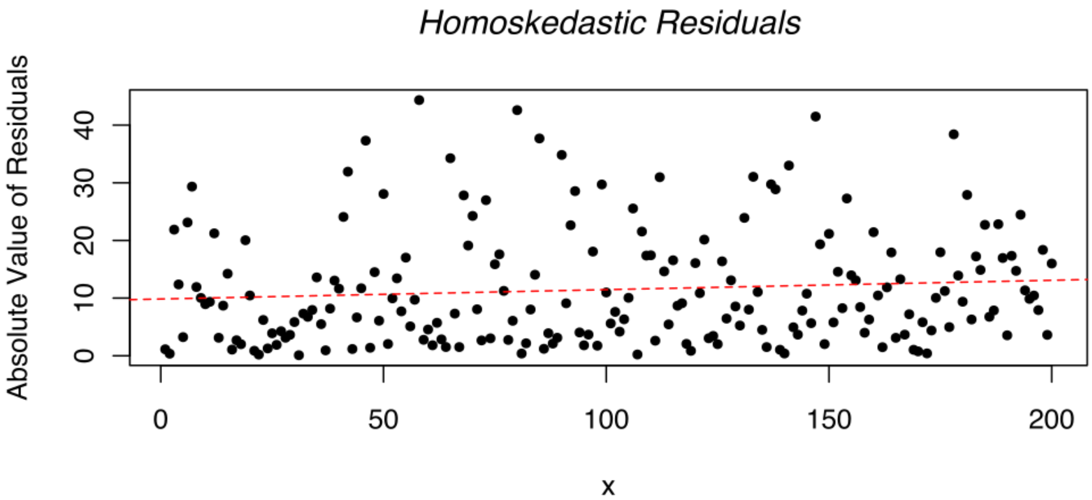
The constancy or not of the variance of errors will be expressed by whether the spread in *Y* is the same with increasing *X*. To explain what homoscedasticity is, let's consider heteroscedasticity, (fig. 14).

Heteroskedasticity (fig. 14, a) is not the constancy of the error variance, it causes the residual distribution to have a regular shape due to the variability of the error variance. The data have a natural shape. If there is a regularity in the shape of the distribution, it is bad for the model, it is necessary that the distribution of values on the *Y*-axis varies randomly. Because when a model is built, the success of the prediction model is not the same over the entire range of values.

The problem with graphically assessing the homoscedasticity of a model is that it is easier to see deviations from heteroscedasticity, but it is difficult to be completely sure that the rules of homoscedasticity of a model are preserved. Therefore, we will use specialised criteria for checking homoscedasticity.



a)



b)

Fig. 14. Homoscedasticity and heteroscedasticity of distributions:
a – example of heteroscedasticity distribution;
b – example of homoscedasticity distribution

To do this, we load additional code into SPSS to check for homoscedasticity. Copy the code, go to «File»→ «New», create a syntax editor «Syntax Editor». In the «BPKTEST» stack, enter the names of the model variables and start building the "Run Selection" calculation.

At the end of the calculation, we look at the «Breush-Pagan» criterion and the «Koenker» criterion. The null hypothesis of these criteria is homoscedasticity. Accordingly, in order to maintain the assumption of multiple linear regression, it is necessary that the values of these criteria are greater than 0,05. In this case, the assumption of homoscedasticity is fulfilled with «Breush-Pagan» equal to 4,480 and «Koenker» equal to 4,638, (fig. 15).

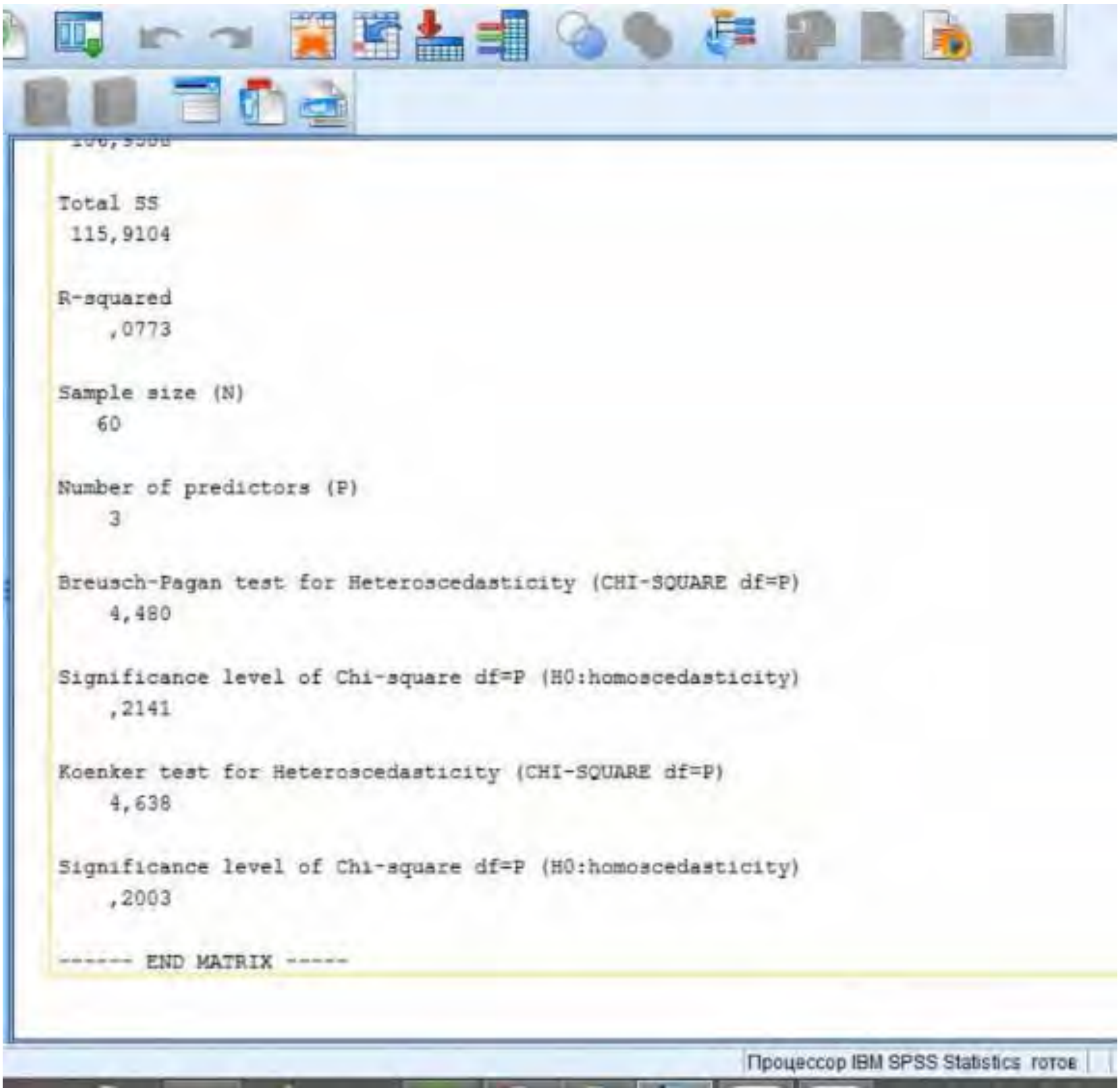
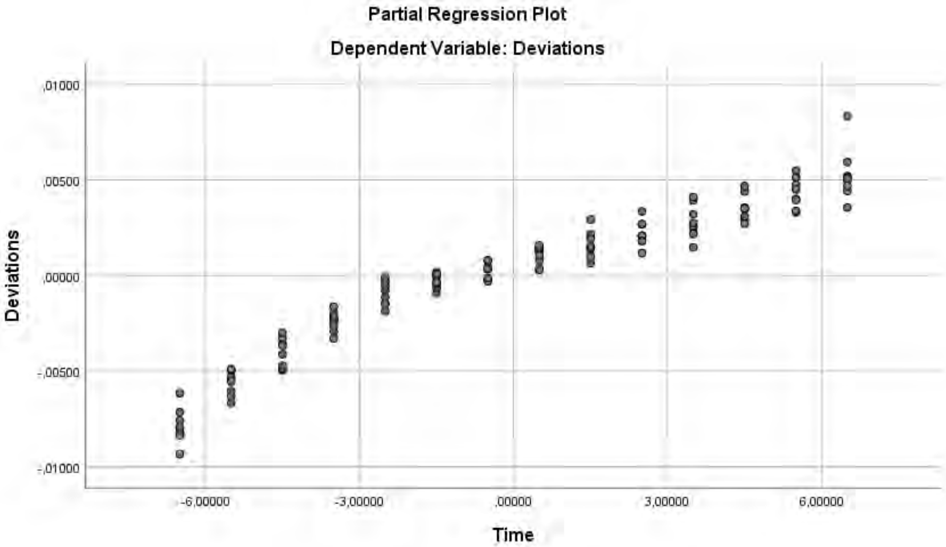


Fig.15. Mathematical test of homoscedasticity of the model

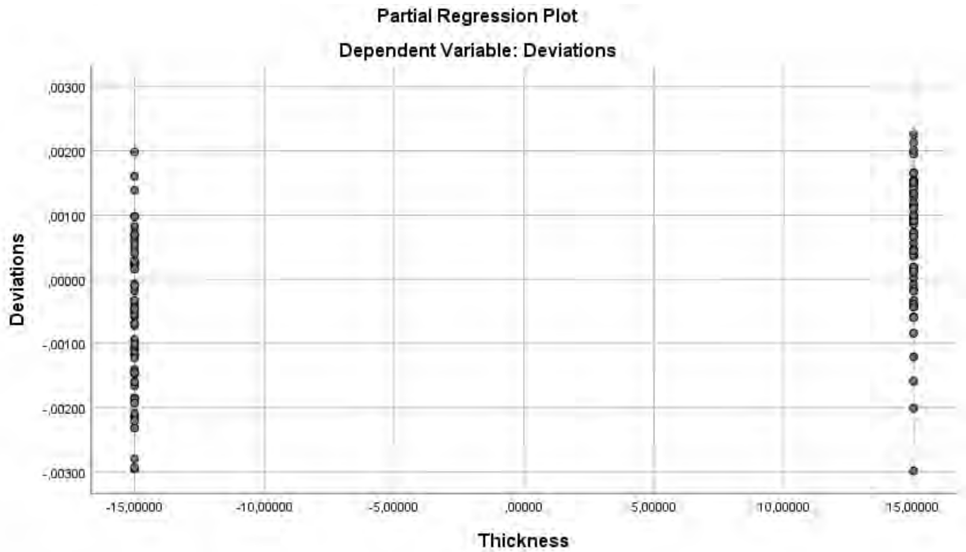
Linearity of communication

To assess the linearity of the relationships, we use partial regression plots. Go to «Analyse»→ «Regression»→ «Linear»→ «Plots», and check the box to «Produce all partial plots». This function will allow you to get private regression plots for each change, (fig. 16).

Based on the distributions obtained, it is possible to clearly see that there is no nonlinear pattern in the graphs. Therefore, we can conclude that the model meets the requirements of linearity of the relationship.



a)



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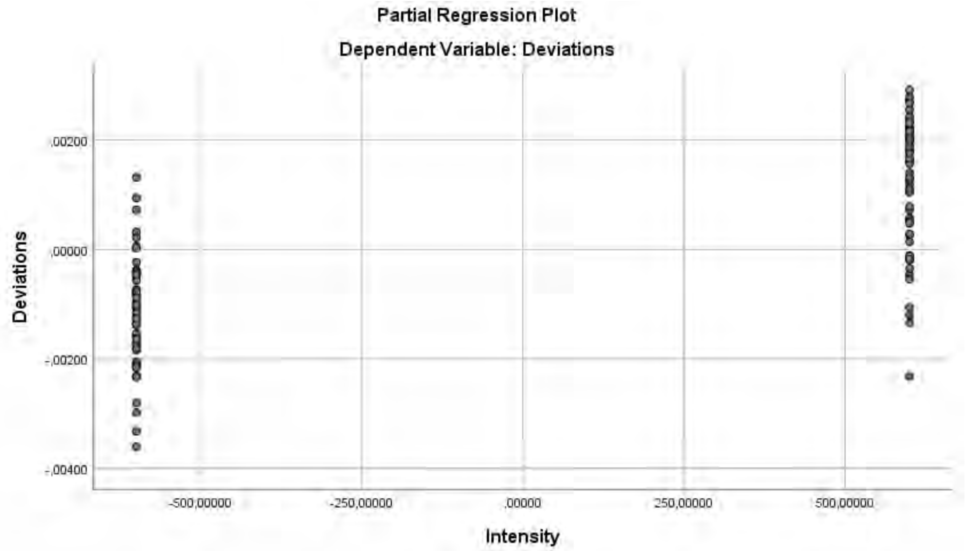

c)

Fig. 16. Values of private regressions:
a – regression of deviations from the exposure time;
b – regression of deviations from the layer thickness;
c – regression of deviations from the exposure intensity

Building a model of multiple regression of the influence of exposure parameters on the geometric dimensions of a topology

We enter the data obtained into the IBM SPSS Statistics programme to conduct a basic linear regression analysis of the exposure parameters.

Using the "Summary for the model" calculations, we obtain the value of the coefficient of determination «*R*» – 0,962. This is an indicator of the correspondence between the values calculated by the model (linear regression) and the experimental results obtained, (fig. 17).

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	,962[a]	,925	,922	,00111683	,925	441,002	3	108	,000

a. Predictors: (Constant), Intensity, Thickness, Time

b. Dependent Variable: Deviations

Fig. 17. Summary of models

For greater verification accuracy, we recalculate the result to the model with non-standardised predicted values and calculate the correlation of the parameters of deviation from the standardised values (calculated deviations), (fig. 18).

Correlations

		Deviations	Unstandardized Predicted Value
Deviations	Pearson Correlation	1	,962**
	Sig. (2-tailed)		,000
	N	112	112
Unstandardized Predicted Value	Pearson Correlation	,962**	1
	Sig. (2-tailed)	,000	
	N	112	112

**. Correlation is significant at the 0.01 level (2-tailed).

Fig. 18. Correlation of values

The value of «*R*» when re-calculated is 0,962, which proves that there is a correlation between the obtained and predicted values.

The coefficient of multiple determination «R^2» is 0,925. This means that the parameters included in the system have a 92,5% impact on the result. The adjusted «R^2» coefficient is 0,922 or 92,2%. The standard error of the estimate is 0,00111683.

Using the ANOVA table, we test the hypothesis that («R^2» = 0). Since the level of «Significance» is <0,05, the validity of the previous results is confirmed, (fig. 19).

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,002	3	,001	441,002	,000[b]
	Residual	,000	108	,000		
	Total	,002	111			

a. Dependent Variable: Deviations

b. Predictors: (Constant), Intensity, Thickness, Time

Fig. 19. Results of significance calculations

To determine the weight of each variable, we will use the "Beta coefficient", which shows how much the value of the parameter changes from an increase in one of the factors. To find the Beta coefficients, the calculation will be performed using standardised «Z-scores». This is necessary to make sure that the standardised values and non-standardised values coincide, (fig. 20).

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Correlations		
		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part
1	(Constant)	7,533E-5	,001		,128	,898			
	Time	,001	,000	,904	34,178	,000	,904	,957	,904
	Thickness	3,575E-5	,000	,134	5,081	,000	,134	,439	,134
	Intensity	1,998E-6	,000	,300	11,359	,000	,300	,738	,300

a. Dependent Variable: Deviations

Fig. 20. Results of calculating the «Beta coefficients»

Based on the level of significance of the coefficients, it is possible to compare whether the «Beta coefficient» of a given factor is different from zero. In this case, all values of «Significance» are <0,05, which proves that all factors are included in the model correctly. The results of Pearson's correlations of factors on response (fig. 21).

The experiments show that when using the photopolymer 3D printing technology, it is possible to transfer the topology image to the PCB by combining the processes of applying the photoresist and simultaneously exposing the topology in one unit. During the experiments and the construction of a linear regression model, high-quality adhesion of the photopolymerised PCB to the surface of the workpiece was observed, as a result of which, during chemical etching, it was possible to avoid etching the ends of the tracks, in contrast to the results of using classical photoresist films, (fig 21).

Correlations

		Deviations	Time	Thickness	Intensity
Pearson Correlation	Deviations	1,000	,904	,134	,300
	Time	,904	1,000	,000	,000
	Thickness	,134	,000	1,000	,000
	Intensity	,300	,000	,000	1,000
Sig. (1-tailed)	Deviations	.	,000	,079	,001
	Time	,000	.	,500	,500
	Thickness	,079	,500	.	,500
	Intensity	,001	,500	,500	.
N	Deviations	112	112	112	112
	Time	112	112	112	112
	Thickness	112	112	112	112
	Intensity	112	112	112	112

Fig. 21. Results of Pearson correlation calculations

Based on the obtained values of the «Beta-coefficients», the following conclusions can be drawn:

– an increase by one unit of time results in an increase in the value of dimensional deviation by 0,904;

– an increase of one unit of radiation intensity leads to an increase in the value of dimensional deviation by 0,3;

– an increase of 30 units of thickness leads to an increase in the value of dimensional deviation by 0,134;

This proves that time is the most important factor in 3D exposure. The regression equation looks like this:

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 = 0,002 + 0,904 x_1 + 0,134 x_2 + 0,3 x_3,$$

where Y is the factor of deviation of the geometric dimensions of the PCB topology; b_0, b_1, b_2, b_3 are the coefficients of linear regression of the influence of parameters on the factor; x_1, x_2, x_3 are the parameters of influence on the factor.

Conclusions

The paper presents practical results related to the creation of printed circuit board topology using photopolymer exposure of the conductor structure. A general procedure for converting a 2D PCB topology into a 3D format for photopolymer printing is proposed. The parameters that can affect the deviation of the geometric dimensions of the topology in this production are considered. The obtained efficient values of 112 samples were verified. The optimal exposure values with the minimum values of topology deviation are revealed. A model of multiple regression of the influence of exposure parameters on the deviation of geometric dimensions of the topology was built.

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TECHNOLOGY OF USING DIGITAL TWINS IN THE CONTROL OF INDUSTRIAL EQUIPMENT

Novoselov S., Sychova O.

The paper describes the technology of program control of the digital twin of the analog signal input module. The proposed program of the digital twin of the analog signal input module in technical means of automation provides ample opportunities for performing various practical tasks in the field of process automation and PLC (programmable logic controller) programming. The task of improving the process of training of professional personnel has been solved by developing a digital twin of the analog signal input module, which makes it possible to study the principles of ADC operation using PLC and technological programming languages.

Introduction

Virtual models of real automation devices are an important tool for distance learning in the process of training specialists to maintain industrial equipment using PLCs and I/O modules. Digital twins of real equipment make it possible to perform practical tasks from any location with Internet access. In general, virtual models have many advantages in teaching technical disciplines and can provide more effective learning and real-world experience.

A digital twin is a software analog of a physical device that simulates the internal processes, technical characteristics, and behavior of a real object under the influence of interference and the environment. An important feature of a digital twin is that it uses information from the sensors of a real device operating in parallel to provide input to it. It can work in both online and offline modes. Further, it is possible to compare the information of the virtual sensors of the digital twin with the sensors of the real device, to identify anomalies and their causes [1–3].

Thus, the creation of virtualization tools for real devices used in industrial automation is a very urgent task.

The aim of the work is to improve the process of training professional personnel by developing a digital twin of the analog signal input module, which makes it possible to study the principles of ADC operation using PLC and technological programming languages.

Automation tools with analog signal input function

In training centers and higher education institutions, various devices are used to study the methods of converting signals from sensors into digital code for its further transmission via industrial networks to a PLC.

Examples of such training models are:

– a model of an industrial controller with an expansion module that allows you to connect analog signals (Fig. 1);

– a separate expansion module for converting analog signals and transmitting digital code over an industrial network using the modbus protocol (Fig. 2).

The module for inputting analog signals can be part of a modular PLC (Fig. 1). In this case, the modules in the PLC are connected via the internal SPI bus. The number and composition of modules can vary depending on the current task.

Thus, the main task is to create a virtual layout that will allow students to explore the principles of analog signal processing by automation. The program under development should provide an opportunity to work out methods for creating technological programs for PLCs using ADC functions remotely, without access to real devices.

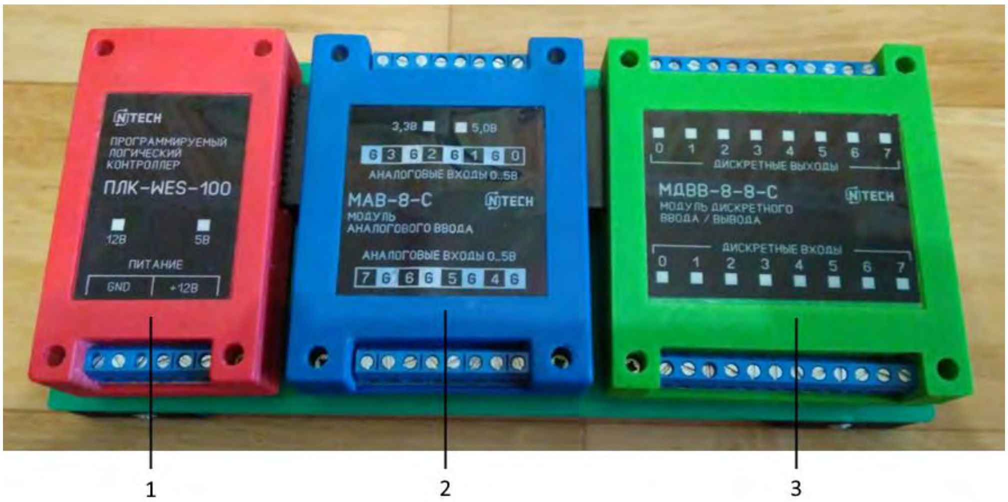

Fig. 1. Exterior of the modular PLC:
1 – central processing unit based on the Raspberry mini-PC;
2 – analog input module; 3 – discrete I/O module

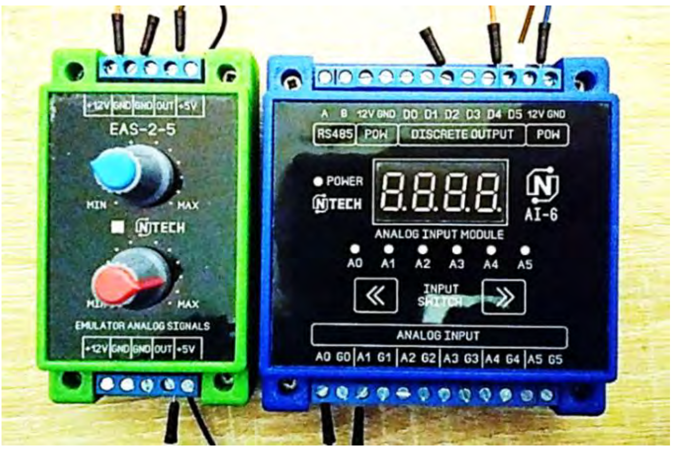

Fig. 2. Expansion module for converting analog signals

Creating an architecture for combining a digital twin with an IDE for developing technological programs for PLCs

Fig. 3 shows the architecture of combining a digital twin with an IDE for developing technological programs for PLC. The virtual laboratory work is aimed at studying the principles of converting analog signals from sensors into digital code to enable its transmission by means of industrial networks to PLCs [4].

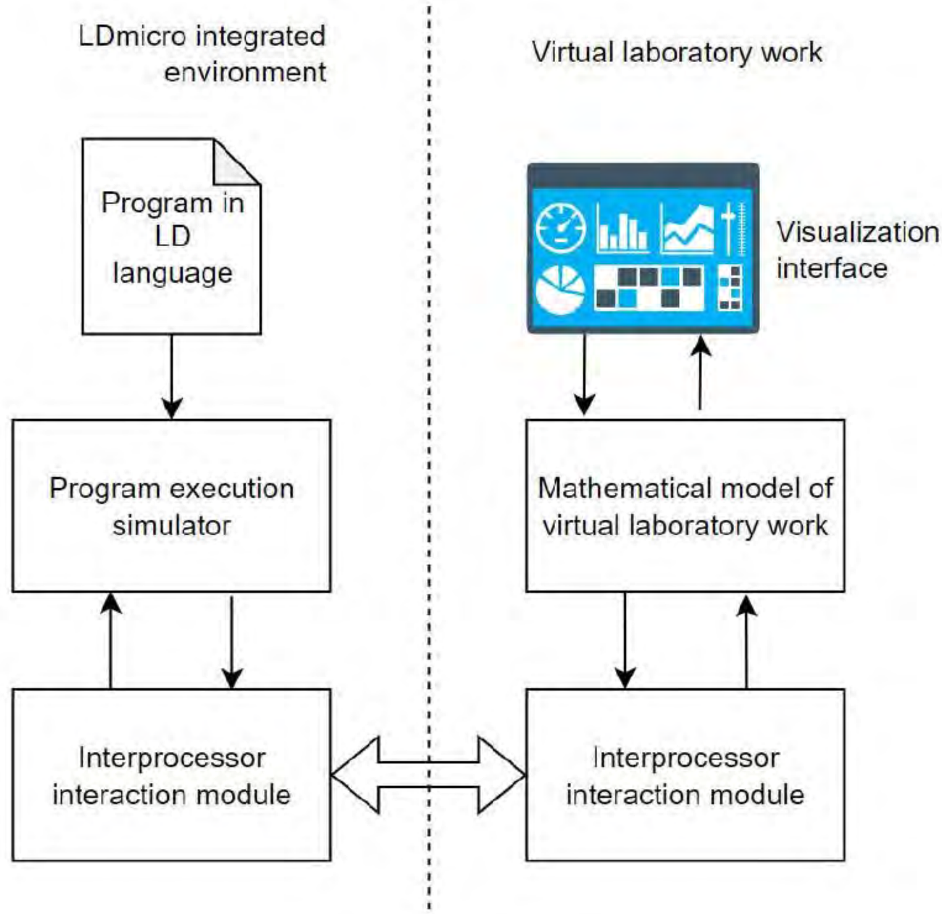

Fig. 3. Architecture of combining a digital twin with IDE development of technological programs for PLC

Using the virtual layout, the ADC parameters are selected and the environment is configured in the form of a digital multi-digit display with dynamic indication.

The digital twin is used to study the

– the principle of reading and converting an analog signal into a digital signal;

– the principle of displaying information by a built-in digital indicator;

– the principle of operation of a resistive voltage divider;

– the principle of measuring and displaying the input voltage, the value of which exceeds the ADC reference voltage;

– the principle of working with ADC by means of a programmable logic controller.

The combination of a digital twin with a PLC occurs at the stage of creating a technological program in the integrated LDmicro environment [5]. LDmicro is a free programming environment designed to create programs for logic circuit controllers (PLCs) in the linear logic language (LADDER). It is designed to simplify the creation of programs for small PLCs, such as controllers used in home, educational, and research purposes [6]. The development environment supports the introduction of a visual representation of the program in the form of a line diagram, which allows users to understand and analyze the operation of programs more easily.

Other features of LDmicro include importing and exporting projects, simulating a program, debugging and debugging programs, creating and editing symbols and libraries, generating documentation, and more.

Thanks to the open source code, it was possible to combine two independent tools: LDmicro and virtual laboratory work. To combine these programs, the technology of interprocessor interaction in the form of Named Pipes is used.

Named Pipes is a mechanism for interacting between processes in an operating system. They allow you to transfer data between processes through a channel that has its own name. This mechanism is a type of interprocess communication (IPC). Named channels can be used to communicate between processes running on the same machine or on different machines in a network. Channels are also used to transfer data, messages, and other objects between processes.

One of the advantages of using named channels is the interaction between processes written in different programming languages and running on different operating systems. They also allow you to transfer large amounts of data, which is not possible through other interaction mechanisms.

The disadvantage of named channels is that they are somewhat slower than other mechanisms of interaction between processes. In addition, the use of named channels requires some additional knowledge and understanding of the mechanisms of working with files and data streams from the programmer.

Description of the basic principle of ADC operation modeling in the digital twin program

When measuring any parameter, such as voltage or temperature, it is advisable to display its real value, not the ADC readings. In this case, it is necessary to convert the ADC readings to the real values of the measured parameter [5, 7].

If the maximum voltage at the ADC input does not exceed the Reference Voltage, then the following formula is used:

$$V = \frac{V_r \times ADC}{ADC_{\max}}, \quad (1)$$

where V_r – reference voltage value, B; ADC – measured value with ADC; $ADC_{\max}$ – the maximum value at the ADC output, which depends on its bit depth.

For example, consider the following input conditions: the reference voltage is 5 V, the ADC bit depth is 10 bits, and the ADC output is 736.

Let's convert the ADC value to a real voltage. To do this, we determine that the maximum value at the ADC output $ADC_{\max} = 1023$ $\left(2^{10} = 1024\right)$. Thus, by substituting the values in formula (1), we obtain:

$$V = \frac{V_r \times ADC}{ADC_{\max}} = \frac{5 \times 736}{1023} = 3.59 \approx 3.6\,B.$$

In LDmicro, all operations are integer, so to work with floating point numbers, you must first find the integer part and then the fractional part.

This is done as follows. To determine the integer part, it is necessary to use the formula:

$$V_{\text{int}} = \text{int}\left\{\frac{V_r \times ADC}{ADC_{\max}}\right\}, \quad (2)$$

where int – operator for determining the remainder of division.

To determine the fractional part, the following formula is used:

$$V_{\text{mod}} = \text{mod}\left\{\frac{V_r \times ADC}{ADC_{\max}}\right\}, \quad (3)$$

where mod – operator for determining the remainder from division.

Description of the graphical interface of the digital twin

The user interface of the virtual layout "Analog-to-digital converter" is shown in Fig. 4. The upper part of the working window of the program is a separate virtual device "Seven-segment four-digit digital indicator" (Fig. 4, item 1). It can be used both independently and in combination with an analog-to-digital converter.

The lower part (Fig. 4, pos. 2) has the necessary controls to study the methods of inputting analog signals using PLC.

The upper part of the virtual laboratory work "Seven-segment four-bit digital indicator" is designed to display current information by means of PLC and to study methods of organizing dynamic display for working with multi-bit digital indicators.

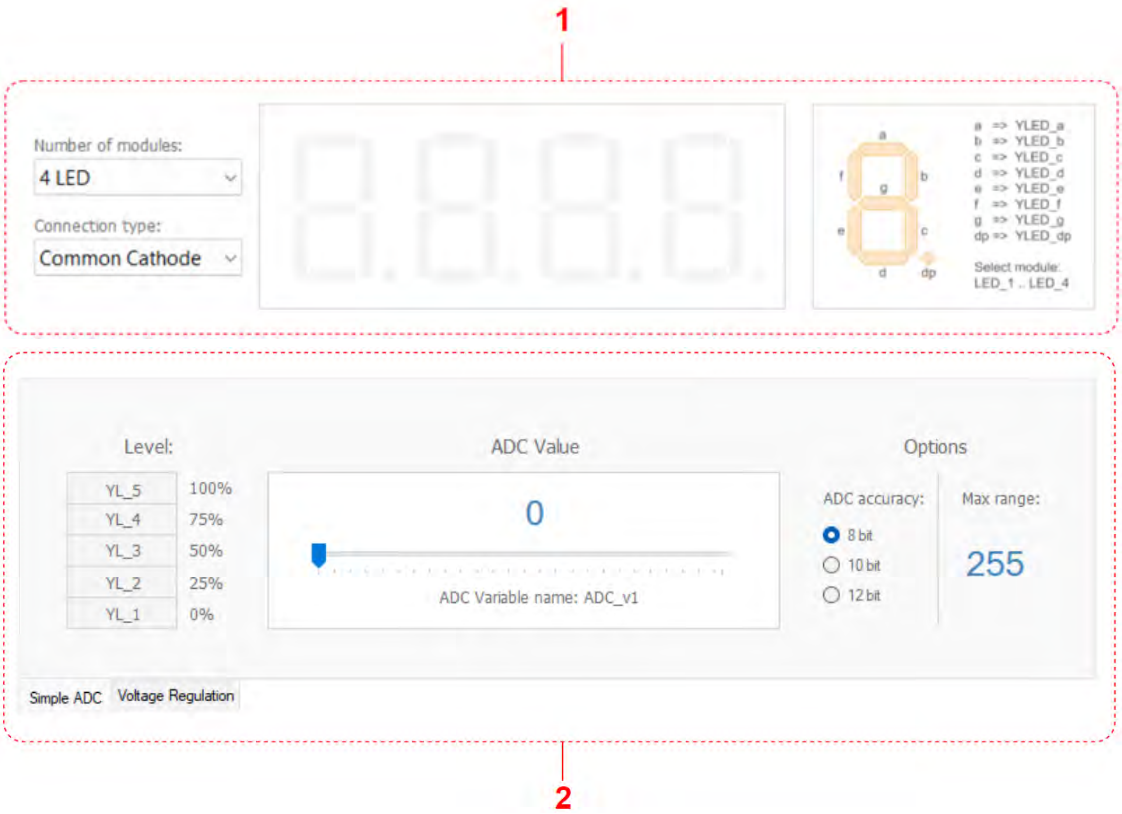

Fig. 4. User interface of the virtual layout "Analog to digital converter"

The main visual upper part of the program is the module of the seven-segment digital indicator 1 (Fig. 5). If you connect to the layout using one of the available interfaces, such as Named Pipes, the digital indicator module will display signs that are a combination of the enabled segments. Each segment can be controlled independently.

Fig. 5. Seven-segment four-digit digital display

Fig. 6 shows an example of the program operation and display of the measured voltage value using a virtual layout [8–10].

The value of the ADC_v1 variable is set by the user using a linear slider and the full range of values can be 0...1023 units. Therefore, in order to correctly display each digit of the specified range, the contents of the ADC_v1 variable must be prepared in advance – divided into four separate variables for thousands, hundreds, tens and units.

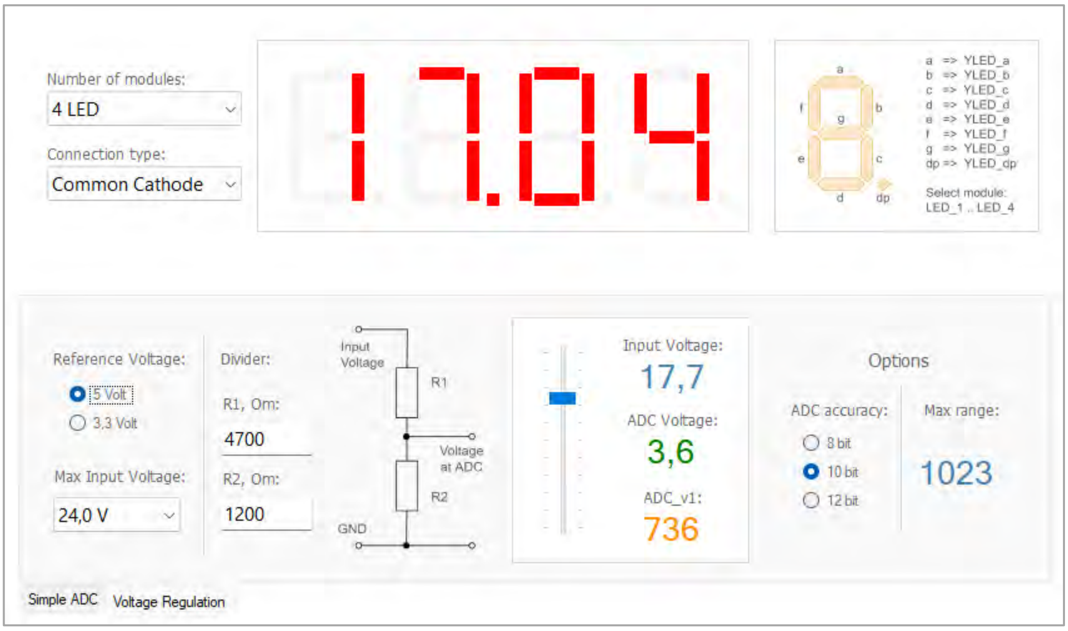

Fig. 6. An example of the program operation and display of the measured voltage value using a virtual layout

To get thousands from a number stored in ADC_v1, divide this number by 1000 and put the integer value of the division into the variable "th". There are two types of division in LDmicro:

– integer division "DIV" (the specified variable stores the integer result of the division);

– division with remainder "MOD" (the specified variable stores the integer value of the remainder of the division).

In the first step, let's perform the division operation "DIV":

{DIV th := ADC_v1 / 1000}.

To get the value of hundreds, you need to determine the remainder of dividing the input variable by 1000:

{MOD th_rem := ADC_v1 % 1000}.

In the third step, we can determine the number of hundreds that is included in the number stored in the variable th_rem:

{DIV hnd := th_rem / 100}.

To determine the number of tens, you need to determine the remainder of dividing the variable th_rem (the remainder after determining the number of thousands) by 100:

{MOD hnd_rem := th_rem % 100}.

The fifth step is to determine the number of tens:

{DIV ten := hnd_rem / 10}.

The last step is to determine the number of units in the number stored in the variable hnd_rem:

{MOD unit := hnd_rem % 10}.

Putting all of these operations together, we get the following LD diagram for converting an input number into four different variables for thousands, hundreds, tens, and units (Fig. 7).

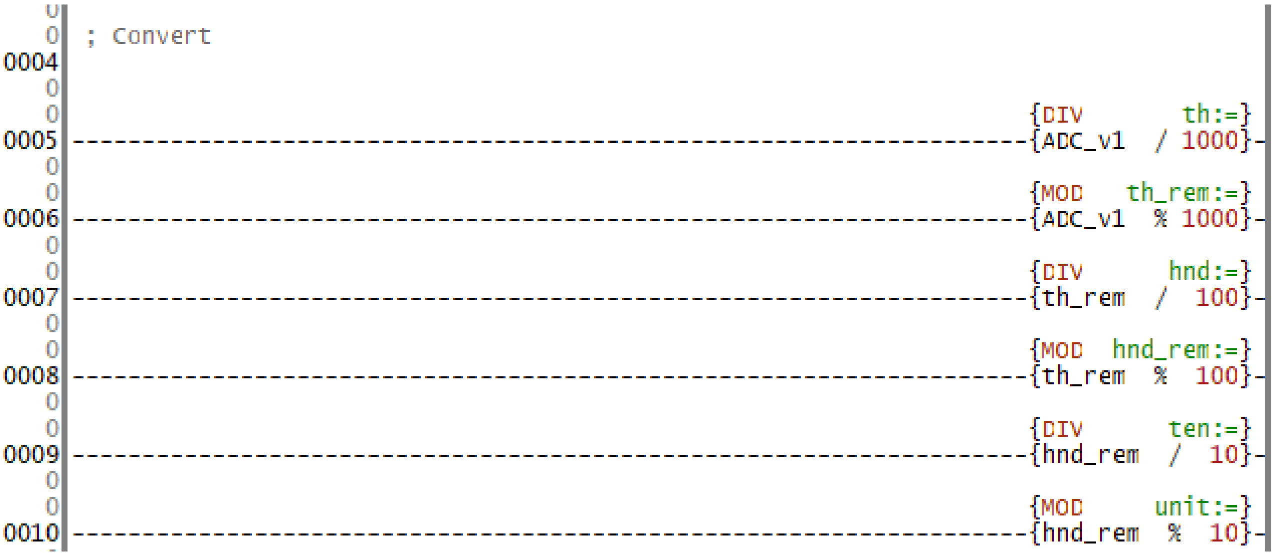

Fig. 7. Operation of converting an input number into four variables for each digit of the indicator

Conclusions

The paper describes the technology of program control of the digital twin of the analog signal input module. The developed program of the digital twin of the analog signal input module in technical means of automation provides ample opportunities for performing various practical tasks in the field of process automation and PLC programming.

A prototype for virtual laboratory work was selected. This device is a model of a modular industrial controller based on the Raspberry PI mini-PC. The purpose of the real device is analyzed and the principle of its operation is described for the further creation of a software implementation of the digital twin. The principle of modeling ADC operation in a virtual program is considered. The graphical interface of the program is described, an example of its operation is given, and the measured voltage value is displayed using a virtual layout.

Thus, the task of improving the process of training professional personnel through the development of a digital twin of the analog signal input module, which makes it possible to study the principles of ADC operation using PLC and technological programming languages, has been fulfilled..

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MANAGEMENT OF DIFFERENT NATURE PROJECTS IN THE MIND-ECONOMY OF THE BANI-WORLD

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The existing designations of the modern world state in the form of four-component abbreviations are considered. The expediency for new abbreviations to appear that more adequately correspond to its current essence is shown. It has been established the lack of studies revealing from the standpoint of a common model peculiarities of project activities aimed at various goals by the subjects of economic network relations (SENRs). The main features of the modern economy, which correspond to MIND-economy ("meaningful-intellectual-network-digital economy") are revealed. A 3D model of the SENR in the form of a tetrahedron is proposed, which has known components: object, process, project and environment. Within the framework of this model, the specifics of the "project" component's activity in the SENR's projects of operation support, growth and development, and scenario planning are revealed. A graphical abbreviated model of the modern world and a probable future scenario based on VUCA, TUNA, BANI and TESD-worlds is proposed.

Introduction

«Happiness is the meaning and purpose of life,
the only purpose of human existence»
Aristotle (384–322 BC)

Nowadays, both in scientific sources and in the field of providing educational services aimed to form competencies, requirements for positions candidates, etc., new four-component acronyms (abbreviations) appear, which claim to reveal the actual essence of the present and future world, economy, thinking, frameworks, institutions, approaches, etc. The most "popular" ones are SPOD, VUCA, BANI, DEST, RUPT, TUNA, YOLO, FOMO, TESD. They are very often used as marketing "lures" (for example, "The future of business education in the BANI-world: trends, problems, products", "What is the world of BANI and how can we prepare children for it?", "Transformational leadership in international business: from the VUCA-world to the BANI-world", and many others). The attitude towards such a galaxy of acronyms is ambiguous. Some researchers believe that such acronyms do not make sense and are more annoying, others build the logic of the change over time of some abbreviations by others, and some are looking for different variants of their decoding (not only in a negative, but also in a positive context). In our opinion, the main criterion to apply such abbreviations is the benefit that socio-economic entities of various scales (from an individual, family, enterprise to a region, industry, country, etc.) receive from them in terms of their continuous existence and development in space and time.

In reality, there are simultaneously sectors of life activity with various significantly different parameters (for example, in the production of technology of the third, fourth, fifth technological setups). The degree of their stability, predictability, complexity, certainty is different. And for each of them, essentially different acronyms are best suited. Therefore, it can be argued that the modern world is a mosaic world of various entities. This is one of the reasons for the chaos (in the head) of the perception of the modern world. However, the entity that defines the development of the world nowadays is the acronym that appeared last, BANI-world. From these positions, the emergence of new acronyms is appropriate. And it concerns the construction of a complete system of acronyms of various scales, starting with those that characterize the world as a whole (suprasystem level in the terminology of systems thinking, systems approach or methodology according to the 3M-Pyramid model [1]), the economy (as one of the four target systems, which describe life activities: economic, political, social and mental, the level of the method according to the "3M-Pyramid" model) of the four subsystems of each system (methodics according to the "3M-Pyramid" model) and systems in the environment (environments according to the "3M-Pyramid" model).

We pay attention to the number of letters in acronyms and models. There are four of them. And it is not by chance, because the four is connected with the understanding of the deep essence of the life existence [2].

The last of those mentioned in 2020 in Jamais Cascio's article "Facing the Age of Chaos" appeared the acronym BANI-world [3]. According to author, VUCA (Volatility, Uncertainty, Complexity, Ambiguity) describes the present, and thus has the effect of influencing how the world is perceived and what is happening in it now. And BANI (Brittleness, Anxiety, Nonlinearity, Incomprehensibility) characterizes the future, the chaotic character of which must be accepted as soon as possible, and thereby make it more accessible. This perception will help to overcome as soon as possible the problem of the time gap between a faster and unpredictable change in the external environment compared to the change in thinking patterns and perception of the world, readiness to understand that it is necessary to think in a new way.

In [4], we showed that project management as a specific branch of activity responded to changes in the world by changing the dominant management paradigm (methodology), expanding the sectoral spectrum of its application, and significant changes in methods and techniques. And this is natural, since any existence and development of entities of any scale at the level of target systems in space and time is impossible without the implementation of projects of various essences. At the same time, there should be four types of such diverse projects of the same consideration scale. Currently, the known classifications contain three types of projects. So, for example, according to the classification, which has existed since the 1990s, these are pioneering, repetitive and standard projects [5]. According to another classification: projects to support functioning, growth, and development projects. At the same time, there are practically no studies which reveal projects' essence from the standpoint of a common model (reveal distinguishing features and fundamental features of implementation as well). Therefore, it is necessary to search for the fourth type of projects and describe them within one model. Our research is devoted to the solution of this task.

Essence of MIND-economy

To further reveal the research goal, it is necessary to adjust the epistemological space within which the VARIORUM scientific school, whose representatives are the authors of this study, conducts research. This space is defined by axiological, gnosiological, ontological and methodological aspects [6]. The gnosiological aspect stays on three basic postulates (the primacy of integrity, systematicity, and triad-quartility). In [7], it was supplemented with the postulate of contextual intersubjectivity, according to which, when making collective decisions, preference is given not to an individual source of knowledge (a source of information), but to an intersubjectivist source of interacting subjects who perceive and understood any life fact in a specific context.

The triadic-quartile postulate says that the minimum representation of any integrity perceived by a person is triadic (represented by three components), and the sufficient representation is quartile. But to reveal the connections between the interacting components of triads and quartiles, it is suggested to apply the postulate of duality in the following interpretation: any connection between the components represents opposite flows of information and/or energy and/or material and/or meaning, which do not interfere with each other. This postulate applies to any two components, the boundary between which is considered as a membrane. Such a boundary in the form of a MEMS-environment we used to describe the process of perception of yawing by operators of the universe (representatives of animate and inanimate nature) in the context of the inmeasurelogy science [2].

The axiomatics of the epistemological space include the following statements: human-centeredness – a strategy for the development of civilization, economics and psychology of subjective decision-making take place in conditions of irreversibility of the past, uncertainty of the present, unrecognizability of the future [6]. This makes it logical to supplement the methodological component of the research epistemology with the anthropometric principle (according to other sources – anthropocentric, anthropomorphic, anthropic). Taking into account the various formulations of this principle [8–11], we will use the following one: a person is the completion of the evolution of the universe, the focus of the universe, is the goal of all events that take place in it, to which human images and their properties are transferred (to inanimate objects and animals, plants, natural phenomena, supernatural beings, abstract concepts, etc.). The transfer of human images and their properties makes more important the basic tools of the analogies method. In this method, attention is focused on the need to "capture" internal, and not external, more important and essential properties and features of the compared objects. A condensed form of analogy is a metaphor [12]. Metaphor involves the use of artistic creativity. An exemplary metaphor is the following comparison by Aristotle: "...old age belongs to life as evening belongs to day, therefore one can call evening as "old age of the day"... and old age – as "evening of life" [13].

With regard to the term, which integrates any business entities (economic agents, economic entities, actors, person, household, enterprise, region, etc.). In the network economy, the main feature (condition) for the existence of any entities is the presence of a large number of relationships of various content, through which information, energy, material flows and meaning flows are implemented. To name them, it is meaningfully more correct to use the term "subject of economic network relations" (hereafter SENR), which, depending on the specific representation in the real world, exists in the appropriate space-time scale. This designation is similar to the term "subject of international relations", which includes states, nations, peoples, social classes, social strata, groups and other communities of people, as well as political parties, movements and public organizations as systems. The SENR has four aspects (contexts) of integral life activity: political, economic, mental and social. They are supersystems for all other smaller-scale components under consideration. At each scale level, the SENR is considered as a system.

To implement the system postulate, a four-component graphic 2D system model of the relationships between components was used in the scientific school for 19 years. In 2019, it was transformed into a system 3D model in the form of a regular tetrahedron. This made it possible to develop quantitative and qualitative methods to work with soft, vague, subjective messages, to use the "measure" category for this [7, 14].

The historical analysis of various stages of the civilization development shows that at each new stage there is a refinement and expansion of both the general scientific categorical apparatus and individual subject areas. The need for such actions stems from the semantic concept of information and the thesaurus model of communication [15]. The analysis of the publications of the transition period from the VUCA world to the BANI world allows to clearly follow the trend of a hypertrophied increase in the use of the terms "digital economy" and "network economy". These terms are interconnected, reflect the direction of research for further 5-10 years, and have taken a stable position among categorical (indicative) markers. Against this background, such terms as "economy of attention, meaning, free time, access, subscription, diversity, stratification", "platform, intellectual, mixed, collaborative economy" and others began to appear in the cluster of informative markers. Among the given terms as informative markers, the terms "economy of meaning" and "intellectual economy" have the greatest information capacity for transmitting new information. To date, there are no established, generally accepted definitions of them.

Regarding the term "economy of meaning". It is important to distinguish the "economy of common sense" [16] from the "economy of meaning" [17]. Measurement systems are a distinguishing feature between them. "The theories we create, hypotheses we test, and beliefs we hold are all shaped by our systems of measurement" [18].

The term "economy of meaning" should be considered as the equivalent of "economy of goals", which is "managed" by systems of arbitrarily established quantitative benchmarks of measurement, for example, GDP. And the economy of meaning is "managed" by evaluation systems that are extremely anthropometric in nature, in which there are practically no production indicators and the indicators of the SENR welfare are used, and which are aimed at assessing the well-being not only of the current moment, but also of its sustainability in the perspective of future generations [18]. The difficulty of constructing anthropometric systems to measure meaning is related to two aspects. The first is a weak representation of the category "meaning" in the thesaurus of economic sciences and economic activity, the second is the ambiguity of the term "meaning". Meaning is often associated with determining the place of the context as an essential condition for the real unfolding of the processes of world perception and world understanding, including in the form of various discourses [19]. Leaving the study of the ambiguity of the term beyond the scope of this article, we offer the following definition: meaning is a moral and ethical formation of thinking activity, which arises as a value against the background of the life and activity of an individual, his real interaction with the surrounding world, and determines the choice of his life strategies in the process of self-realization.

Meaning is a moral-ethical formation of thinking activity that arises as a value against the background of the life and activity of the SENR, its real interaction with the surrounding world and determines the choice of its life strategies in the process of self-realization.

The anthropometric principle was applied when formulating the definition. But it should be remind that "man is the only living creature to whom the world is given as a single coherent whole that extends in space and time beyond the boundaries of the existing situation, and at the same time includes the previous (what is before) or the future (what is ahead) of the subject, and not just what surrounds him. This anthropological characteristic turns out to be the key to understanding the essence of man. ... Relations connecting the subject with the world are given the status of a special reality, primary, in particular, in relation to the characteristics of the subject" [20].

An indicator of a subjectively "correct" meaning is a person's happiness. This is confirmed by Aristotle's statement given in the epigraph. For a quantitative presentation of this indicator, it is advisable to use the position of the Japanese 2D model of the search for happiness Ikigai. Today, in the VUCA and BANI world, this model has spread quite quickly across all continents [21]. The model has four components of the meaning of happiness. In Fig. 1, it is represented in the form of a tetrahedron.

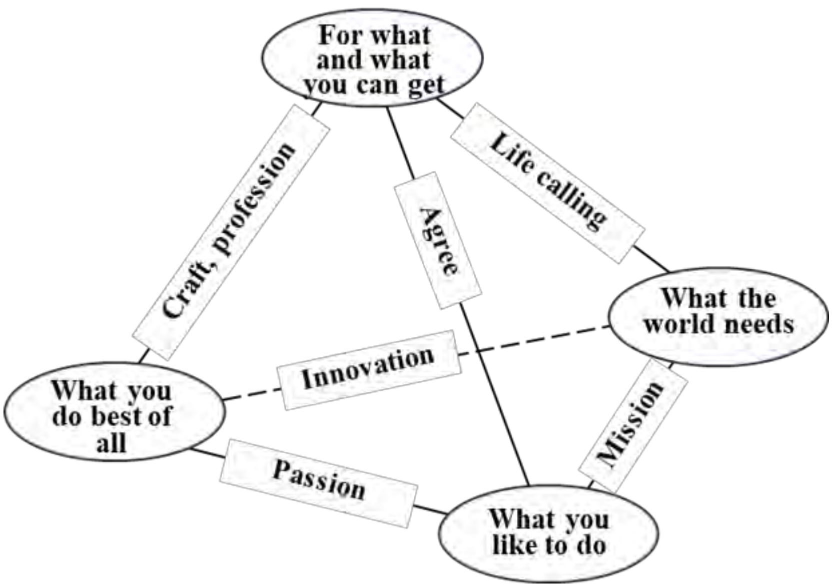

Fig. 1. 3D-model of searching the happiness according to Ikigai
Source: developed by the authors

This representation made it possible to add two more connections (innovation and agreement) to the previously known ones and reveal their essence. In such a composition, the model corresponds to the understanding of the economy of meaning.

Regarding the intellectual economy. Despite the fact that the journal "Intellectual Economy" [22] was launched back in 2009, there are very few publications in it and other periodicals that are directly devoted to the intellectual economy as itself. It is considered, that the authors claim that the intellectual economy arose from the intersection of the following concepts: knowledge economy; information economy; green economy (economy of sustainable development); bioeconomy; circular economy; SMART economy; innovative economy; creative economy; the economy of intellectual property.

The analysis of the definitions given in [23–26], showed that the knowledge society, the economic system, and knowledge, which is a resource in the form of intellectual capital, are common distinguishing features of the intellectual economy. At the same time, the term "intelligence" is not used, which, according to logic, should be a key category in the definition. This gives reason to claim that the existing definitions of the intellectual economy belong to the cluster of such definitions, which includes the economy of goals. This cluster is not focused on the meaning of intelligence as the main resource of any origin in the modern BANI-world. We propose the following definition: **intelligence** is the main resource of SENR-systems, which ensures timely detection, systematic description and effective solution of problem situations in an innovative way for the continuation of their (systems) existence in the BANI-world. Then, the basic construction of the definition of the intellectual economy should be as follows: the **intellectual economy** is a system in which the use of intelligence is the basis of any activity of SENR-systems. From the standpoint of the anthropometric principle, intelligence is possessed by any SENR. In [27, 28], the economic system is considered in the form of four spatio-temporal subsystems (hereinafter SS) – factors of economic activity: object, process, project, and environment, which have six connections between them. Such a model is fundamentally different from the well-known model of G.B. Kleiner, in which only four connections between the listed SS are considered, which makes it possible to describe only the functioning in a sufficiently simplified manner, leaving the issues of growth and development open.

With this in mind, it is appropriate to offer an extended version of the definition, as follows: the **intellectual economy** is a supersystem of production, distribution, exchange and consumption in space and time, in which the use of intelligence from the standpoint of the concept of sustainable development is the basis of any activity of economic systems (SENR), which related to their functioning, growth and development due to the integral activity of object, process, project and environmental subsystems. The level of supra-systemicity determines the meaning of the entire economy, the level of systems – the meaning of SENR, and the level of SS – the meaning of management of objects, processes, projects and the environment. Such a three-level sense fully corresponds to the 3M model [1] and the understanding of the life world according to D. Leontiev: "The life world of any subject (in our case of the scale of systems – note of the authors) differs from the objective world in general only by its boundaries; if the latter includes everything that exists, the entire universe, then the subject's life world is only a part of it. ... The relevant side of his life activity is formed by a set of activities in which life relationships find their realization" [20].

In our opinion, the main shortcoming in the approaches to consider the essence of the modern economy is that it is considered in different ways, but almost always in the same context. In order to overcome this shortcoming, it is necessary to introduce a term that will contain the previously highlighted four markers: digital, network, intellectual and meaning. For this purpose, we propose the term "meaning-intellectual-network-digital economy". This version of the term implies that any issue of the modern economy should be considered systemically and holistically using the 3D model shown in Fig. 2.

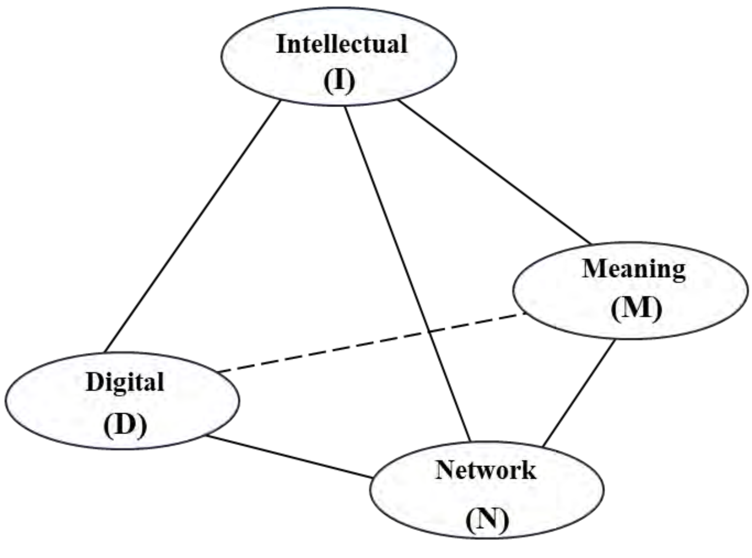

Fig. 2. 3D-model of the MIND-economy meaning
Source: developed by the authors

The essence of the relationships between the model components has been partially revealed above and will be more fully revealed in further research.

Models to manage project of various essences in the MIND-economy

Let's consider the place of projects in the four-component 2D model of the SENR system, which was proposed in [27]. We transform it into a 3D model in the form of a tetrahedron (Fig. 3).

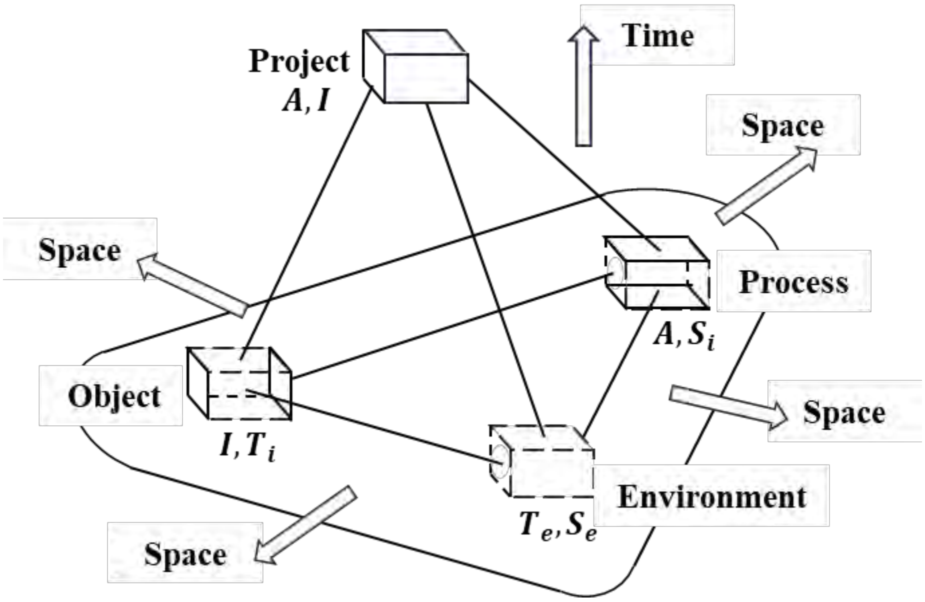

Fig. 3. 3D-model of SENR in the form of a tetrahedron
Source: developed by the authors

The project is an equal basic SS, the same as the object, process and environment, which are separated in space and time and possess the properties of relative integrity and stability. A distinctive feature of SS is the different dependence on the degree of certainty of space-time boundaries. Omitting the logic of the proof, it can be seen from Fig. 3 that the projects have defined boundaries in space and time (solid contour lines) in contrast to the environment, which is characterized by undefined boundaries (dash-dotted lines). For the object, the boundaries are defined in space and undefined in time, and for the process, on the contrary, the boundaries are defined in time and undefined in space.

To describe the essence of the SERN-system states, we will use Aristotle's 10 categories as fully as possible: existing (being), quantity, quality, relation, space, time, state, actions, undergoing change (accepting changes from some other object) and possession (the presence of a constant external circumstances of the subject) [29].

According to the systemic economic theory and spatio-temporal structural dynamics, it is sufficient to use four entities for continuous existence to describe the state of the SENR (a system consisting of the above-mentioned SSs): availability of access to a certain volume of space (S) and a reserve of time (T); if there are opportunities and abilities to effectively use the allocated time (A – activity) and available space (I – intensity) (hereinafter, activity (A) and intensity (I)). It is the relationship between these entities, their quantitative and qualitative characteristics that determine the specifics of actions and undergoing change in space and time for various purposes of activity.

For the SS "environment" existing is access to a certain amount of suprasystem (external) space (S_e) and suprasystem (external) allocated time (T_e), and for the SS "project" – the abilities and possibilities of effective use of the allocated time (A) and available space (I). The "object" has the ability to effectively use the available space (I) and the internal SS allocated time(T_i), and the "process" has the ability to effectively use the allocated time (A) and the internal SS available space (S_i).

The state, activity, and changeability of each of the SS depends on what purpose of activity is implemented in a specific period of time by the SENR-system as an integral entity: activity for functioning, growth, or development. Let's consider how the role of the project differs for these activity goals.

Functioning is a cyclically recurring state of SS possession of four entities (T, S, A, I) and balanced tolerance of changes, which are related to the release of goods/services unchanged in quality and quantity in time and space (hereinafter goods) from the position of mutual agreement with external environment. And the external environment receives goods through already existing channels. Therefore, on the 3D-model of the SENR-system functioning (Fig. 4), the excess part of the external reserve of time (ΔT_e), the external reserve of a defined volume of space (ΔS_e), stimulation of activity (A) and intensity (I) between SSs "object" – "environment" – process" are shown by arrows of the same length.

The role of the SS "project", which is limited in space and time, but has the ability to effectively use the allocated time (A) and available space (I), in this activity is as follows. As the planned tasks are completed, a reserve of time appears in the SS "object", and a reserve of space appears in the SS "process", which are not used. The "project" SS learns about this through the appropriate communication channels, and due to its limited nature, perceives it as a significant internal threat to the continuous activity of the SENR in internal space and time. Therefore, due to complete temporal and spatial limitations, such a state of the SS "project" reacts with an insignificant transfer of energy (an insignificant message) to stimulate activity to increase the efficiency of using the reserve of time of the SS "object" and intensify the filling of the reserve of space of the

SS "process". In the model (Fig. 4), this behaviour of the project is indicated by arrows of activity (A) and intensity (I) of a much smaller size in relation to the arrows of the reserve of the defined volume of internal space (ΔS_i) and the reserve of internal allocated time (ΔT_i), from SS "process" and SS "object", respectively.

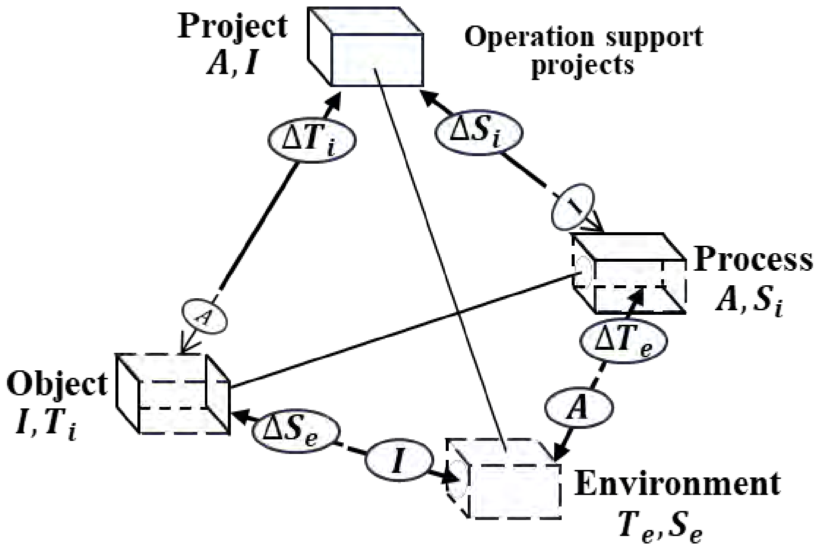

Fig. 4. 3D-model of SENR during its operation period
Source: developed by the authors

The activity's stability and cyclicality during operation leads to a significant lack of load in the "project" SS. At the same time, the SENR has tasks of strategic importance, the solution of which is its main task (will be considered further).

From the standpoint of the anthropometric principle and the essence of the SENR operation, it is appropriate to consider that each of the SSs "object", "process" and "environment" demonstrate their qualifications. The necessary balance of qualifications between them ensures stable production of goods or provision of services. But for various reasons, the balance of qualifications is naturally constantly disturbed. This leads either to a decrease in the intensity of work in the SS "object" and/or activity in the SS "process". The "project" also reacts to such a state of the SS as a significant threat to the continuous operation of the SENR. Then the "project" SS task is to restore the necessary balance of qualifications to ensure the continuation of the cyclical functional activity of the SENR. The result (and not the product) of the SS "project" activity is the intensification of the use of time in the SS "object" and/or the intensification of the use of space in the SS "process". Based on its own essence of the SS "project" (complete limitation of activity in time and space) and its essence in the process of functional activity of the SENR, it can be stated that in such conditions it demonstrates its intelligence through the development and implementation of relevant projects. The projects generated by SENR-system during the operation were named "support functioning projects" in well-known studies.

When the objective of achieving growth appears in the SENR's activity, the essence of the SS's activity changes fundamentally. A connection between the SS "object" and the SS "process" appears (Fig. 5).

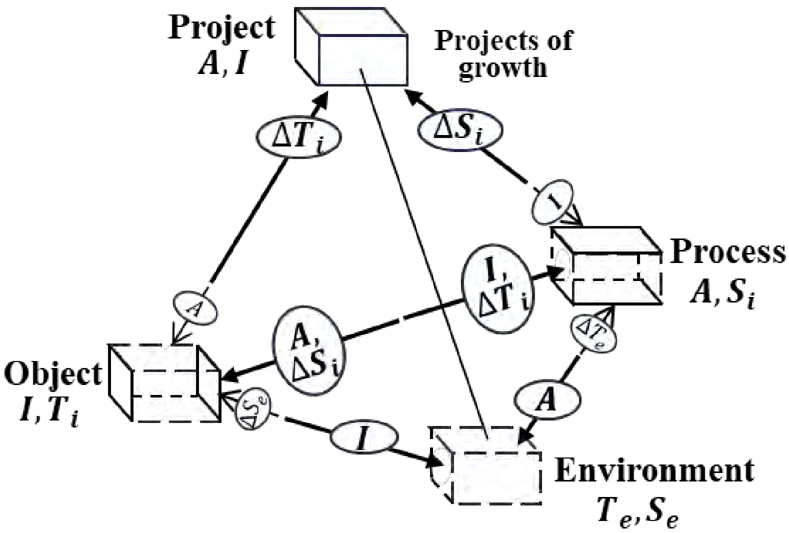

Fig. 5. 3D-model of the SENR within its growth period
Source: developed by the authors

According to R. Ackoff's definition, "growth is a quantitative increase in the size or mass of a system" [30]. "To grow means to increase in size or number" [31]. Therefore, during growth, the essence of the SENR-system does not change. The result of growth is the regulated release of a greater number of goods that are already being produced, without a change in their quality. SS "object" and SS "process" do correspond for that, the activity of which has all the signs of integrity due to the balanced possession of the SS by all four entities (T, S, A, I) and balanced suffering. Therefore, in fig. 5 arrows between them have the same length.

The SS "environment" during the SENR's growth receives energy from this pair of SSs (in terms of the anthropometric principle) in the form of intensity (I) and activity (A) in order to increase the ability to use the available external space more efficiently due to its slight expansion (ΔS_e) and activate the efficiency of using the time allocated for this (ΔT_e).

The expansion of external space and allocated time in the external environment automatically requires an adequate expansion of internal space and an increase of internal allocated time. The SS "project" learns about this through connections with the SS "process" and the SS "object" (Fig. 5). And SS "project" reacts to such changes as significant threats to continuous activity. Therefore, in fig. 5 arrows between SS "environment" and SS "object" and SS "process" have different lengths. SS "project" reacts to changes by developing complex projects: in SS "object" to fill additional extended space (ΔS_i), which it received from SS "process" adequately to the signal from SS "environment" (ΔS_e); to fill the additionally allocated time of the SS "process" (ΔT_i), which is received from the SS "object" following the signal from the SS "environment" (ΔT_e). In traditional project terminology, complex fillings are called "reconstruction projects". They involve full or partial preservation of existing structures and processes.

Under such an organization of activities, during growth, there is a harmonization of the activities of the SENR-system in the external and internal environments to increase the production and distribution of the products produced, and from the standpoint of the anthropometric principle, the SS "object", SS "process" and SS "environment" are balanced to demonstrate their competences. And if (as well as during operation) the balance of these competencies is disturbed, the SS "project" restores it with the help of individual projects. Therefore, the SS "project", as well as during operation, shows its intelligence, and the cluster of all the projects described above has the common name "growth projects" or "promotion projects" [32].

Let's consider the activities of the SENR in the process of reaching the goal of its development. The essence of SSs activity and their interaction also fundamentally changes compared to growth. The direct connection between the SS "object" and the SS "process" disappears. Instead, there is a connection between SS "project" and SS "environment" (Fig. 6).

This connection is necessary to implement the essence of development. According to R. Ackoff, "development is an increase in the system's desire and ability to satisfy its needs and the legitimate desires of others. A desire is legitimate if its fulfilment does not reduce the ability and desire of others to satisfy their needs and desires" [30]. "Development is more reflected in the quality of life than in the standard of living" [31]. The transformation of this definition into the SENR-system, taking into account the anthropometric principle, shows that new entities (desires and abilities) must appear in its internal environment to satisfy the desires of other systems located in the external environment. It is possible to satisfy them only at the expense of products obtained using innovations of varying levels of destruction of existing products and technologies (preferably disruptive). In the BANI-world, the needs of the internal environment of the SENR-system are transformed into a tool that ensures the continuity of its existence in the space and time of the MIND-economy.

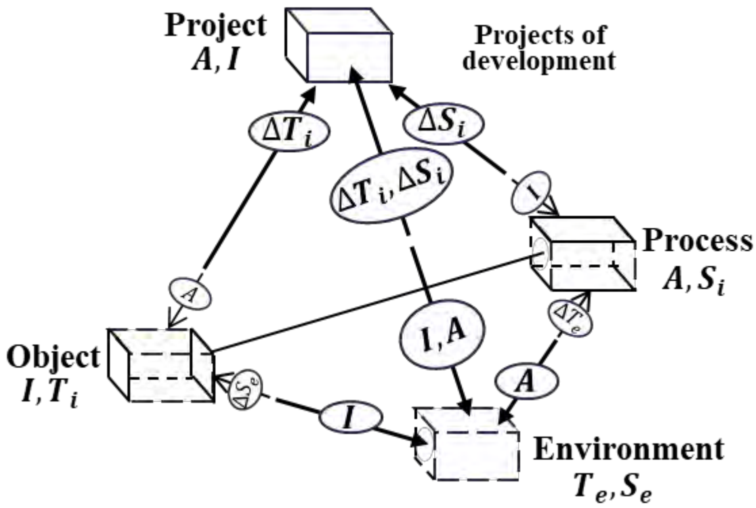

Fig. 6. 3D-model of the SENR within its development
Source: developed by the authors

SS "project" receives information directly from SS "environment" about the emergence of the possibility of significant expansion in the external environment, access to a certain additional amount of space (ΔS_e) and time reserve (ΔT_e) due to the presence of dissatisfaction with the needs and desires of existing and potential consumers. The reaction to this is the response of the SS "project" that it has the ability to effectively use a certain amount of space due to a significant increase in the activity's intensity (I) and a reserve of time due to a significant increase in activity (A). Such a reaction is supported by the fact that the SS "object" provides the SS "project" with an additional supply of internal time (ΔT_i), and the SS "environment" – the ability to increase the intensity (I) and effectively use a certain amount of external space (ΔS_e). On the part of the SS "process", the SS "project" receives an additional defined internal volume of space (ΔS_i), and the SS "environment" – opportunities to increase activity (A) to effectively use the additional reserve of external time (ΔT_e).

In such a situation, all four SSs need to show their intelligence to solve a complex, unambiguously uncertain situation in space and time. When implementing the SENR-system development, all SSs work to balance the integral activities of SS "project" and SS "environment". All projects implemented in such a situation are called "development projects" regardless of the degree of innovation.

If one looks at the considered activities on a larger scale, then they are implemented, on the one hand, in conditions of sufficient short-term certainty and unambiguity in the spatio-temporal segment of the external environment, where the SENR works, and on the other hand, on an even larger scale, in conditions of different worlds – VUCA, TUNA, BANI (Fig. 7). TUNA (Turbulent, Uncertain, New, Ambiguous) is an acronym used at the University of Oxford instead of VUCA in executive education programs, where the philosophy and method of the Oxford Scenario Planning Approach (OSPA) are in use, which were launched in the early 2000s [33].

Fig. 7. Abbreviated model of the modern world and a probable scenario of the future
Source: developed by the authors

The main purpose of the abbreviated model is to explicitly and holistically demonstrate that the external environment changes uncertainly and ambiguously in conditions of unstable turbulence and the emergence of complex new. And this leads to brittleness, anxiousness, non-linearity and incomprehension (three lower horizons of the model). This is the main reason why what was arranged yesterday won't work tomorrow, and what works for someone won't necessarily work for others. In such conditions, leaders (all managers) who try to predict the future using traditional strategic planning look silly [33]. The solution is offered in the development and implementation of scenario planning projects. The project as inflow means that its participants refuse the mode of prediction, and develop a large number of scenarios, where they learn not to create a set of scenarios, but to develop actions based on scenarios for their own (not a case-) organizations. Therefore, combining learning with real problems of real customers is an integral part of training and interactive learning cycles of restructuring and adapting scenarios. This demonstrates the non-linearity of scenario planning projects, the result of which is the scenario management of the modern world, which is represented by the abbreviated model. To implement them, the project participants, who are not called "scenario planners" or "scenario coordinators", but "students of scenario", dispose their intelligence in the absence of restrictions and focus on something that corresponds to the organization's goals, vision and mission.

The abbreviated model (Fig. 7) also contains the fourth upper four-element component of TESD. According to scientists, it reflects one of the likely directions of processes transformation in the world by 2030 [34]. It is believed that the world will have a turbulent business environment (T), the self-centeredness of the government will be entrenched (E), there will be silencing of information and suppression of the will of the people (S), disorder and chaos will reign in society (D). The presence of the TESD component provides an opportunity to challenge the future here and now, which will allow making better decisions, including investment ones, in the present time.

The described processes of interaction between the SSs of the SENR-system is possible to consider as the rules of behaviour and interaction of the SS with each other under different conditions of the external environment within the framework of a common internal environment. Their implementation guarantees the mutual self-support of the SSs in the internal environment (without the intervention of external management entities) and the balance, harmony and continuity of the activity of the SENR-system in the suprasystem – the MIND-economy. Therefore, such a SENR-system is autopoietic in which the level of consciousness of each component does not exceed the level of renewal (functioning, growth, development, strategic development) and vice versa [35].

In the SENR activity, the scenario planning projects of the SS "project" are best implemented during operation. Thus, to the three types of projects (functioning support, growth and development), a fourth is added – a scenario planning project. The essence of the given models helps any SENR-systems to develop their own business theory and to implement P. Drucker's opinion, that every organization should have its own business theory, which every employee of the organization knows and understands. Without such a theory, the organization faces a loss of understanding of its market, its product, and the inability to adapt business to new conditions. Without such a theory, the organization will not be able to achieve success and develop according to its own scenario [36]. In addition, these models confirm the validity of using the term "intellectual" in the title of MIND-economy.

Conclusions

The modern world is in an environment of bifurcation, where global transformations are taking place. The uniqueness of this state lies in the impossibility to predict the further path of civilization development due to the fact that the world changes uncertainly and ambiguously in conditions of unstable turbulence, and the emergence of complex new things leads to fragility, anxiety, nonlinearity and immensity. Such a state is holistically denoted by the abbreviations VUCA-TUNA-BANI-world. And in the next seven to eight years, the TESD-world might be added to them – the world of an even more turbulent business environment, in which the self-centeredness of the government will take place, information will be silenced and the will of the people will be suppressed, and disorder and chaos will reign in society. In such conditions, it is very difficult for the subjects of economic network relations of various scales to carry out their activities. A deep understanding of the modern economy essence can help. The analysis of existing multifaceted definitions of economies using the semantic concept of information and the thesaurus model of communication made it possible to prove that the term "meaning-intellectual-network-digital economy" (MIND – economy) most adequately reflects the essence of the economy current state. Therefore, any issue in the economy should be considered systemically and holistically using a tetrahedral 3D-model, the components of which are the elements included in the name of the economy. From the point of view of the system approach, MIND-economy should be considered as a suprasystem, in which the target systems are SENRs of various scales.

A similar 3D-model is built for the SENR-system, the subsystems (SS) of which are "object", "process", "project" and "environment". Each SS in the spatio-temporal dimension has its own limitations: the object is limited in space, the process – in time, the project – in space and time, and the environment is not limited by these parameters. From the point of view of systemic economics, each SS has two of the four entities: T – time, S – space, A – activity and I – intensity. During the implementation of any activity between SSs, these entities are exchanged. SS "project" possesses activity and intensity. It is this combination that determines the peculiarities of its activity during its functioning, growth and development, where the SS "project" shows its intelligence. And the intelligence of this component ensures the detection of situations when insufficient qualifications during operation and competence during the growth of other SSs pose threats to the continuous existence of the SENR-system in the space and time of the MIND-economy suprasystem. The greatest intelligence of the SS "project" manifests itself during the implementation of scenario planning projects, which are expedient to perform during the functional activity of the SENR-system. The proposed models can be considered as a mental toolkit to build a business theory of each specific SENR-system, without which, according to P. Drucker, the organization will lose understanding of its market, its product, the opportunity to adapt its business theory to new conditions and develop according to its own scenario.

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FORMATION OF AN INFORMATION SYSTEM FOR STAKEHOLDER MANAGEMENT OF *SHIPBUILDING 4.0* TECHNOLOGY PLATFORM PROJECTS

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In order to create an effective information system for managing the digitalization processes of enterprises and organizations in the shipbuilding industry of Ukraine, their main stakeholders are identified. A methodology for qualimetric ranking of stakeholders by the level of influence on digitalization projects is proposed. In accordance with the main provisions of the theory of project stakeholder management, the information needs of project managers are identified.

Introduction

An urgent problem of further development of Ukraine's economy is the revival of its shipbuilding industry [1–4].

Today, the further development of shipbuilding in the world is associated with the introduction of elements of the *Shipbuilding 4.0* technology platform into the shipbuilding industry. The substantive part of the technological platform involves the introduction of digital technologies at all stages of the product life cycle, the end result of which is the creation of a "digital twin" [5–13]. The adopted main directions of the *Shipbuilding 4.0* technological platform include the development and implementation of digital modeling and numerical experiments, robotization of technological processes, production of new materials, use of additive technologies, the Internet of Things, etc.

Given the global trends in shipbuilding, it is clear that the revival of this industry in Ukraine requires the development and implementation of a number of relevant digitalization projects. The effectiveness of solving project tasks depends on several factors, among which one of the most important is the project management methodology adopted by the project team. Among the constituent elements of the methodology, an important place is occupied by the management processes (Fig. 1) of project stakeholders [14], which in the context of digitalization of management processes requires the creation of an appropriate information system.

Given the significant impact of the shipbuilding industry on the economy of Ukraine, the creation of an information system for managing digitalization projects, in particular by stakeholders of the *Shipbuilding 4.0* technology platform projects, is an urgent scientific and applied task of national importance.

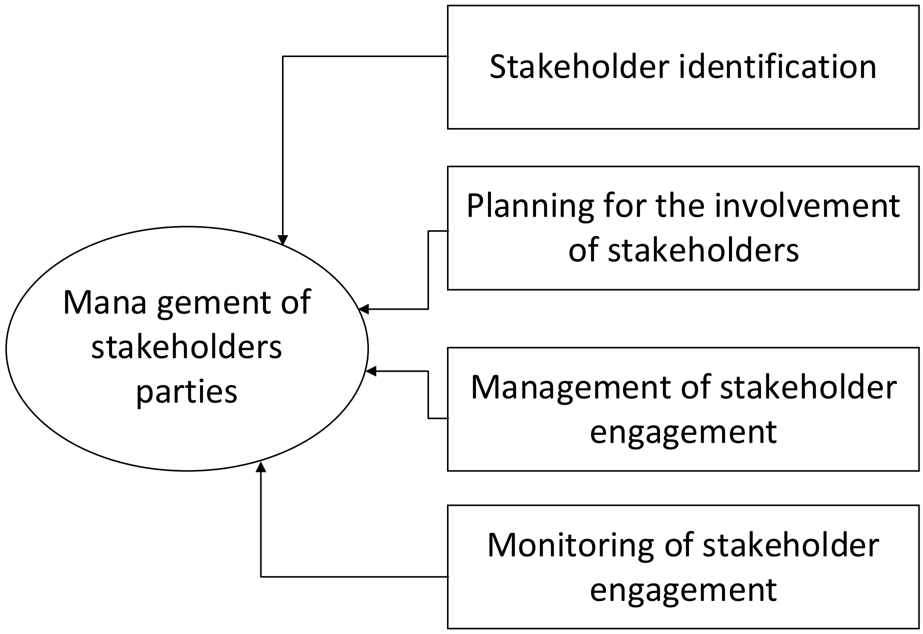

Fig. 1. Stakeholder management processes

Identification of stakeholders in *Shipbuilding 4.0* technology platform projects

According to the definition of the concept of an information system [15], in general, it should contain the following interconnected basic elements: information search and collection units, information storage unit, information processing and transmission unit (Fig. 2).

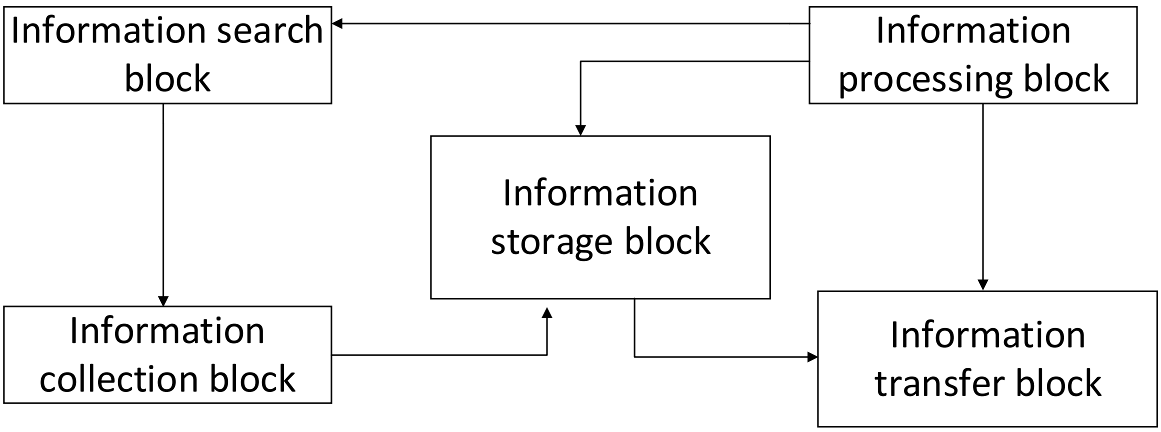

Fig. 2. Main components of the information system

The target function of using the information system for *Shipbuilding 4.0* technology platform projects is to increase the efficiency of digitalization projects by improving stakeholder management:

$$E_1 \gg E_0, \text{ if } E_1 \to \max, \quad (1)$$

where E_1 – is the efficiency of project stakeholder management using the information system;

E_0 is the efficiency of project stakeholder management without the use of the information system.

The main indicators of the effectiveness of the implemented projects are the terms and quality of work performed, project budgets, as well as the amount of value acquired by the project team: knowledge and experience in project management, improvement of the project team's position in the project management services market:

$$\frac{T_{real}}{T_Z} \le 1; \quad \frac{B_{real}}{B_Z} \le 1; \quad \frac{Q_{real}}{Q_Z} \ge 1; \quad K_1 > K_0; \quad P_1 > P_0; \quad L_1 - L_0 > 1, \qquad (2)$$

where T_{real} – project execution time;

T_Z – project implementation time specified in the terms of the contract;

B_{real} – budget of the completed and accepted project;

B_Z – the project budget determined by the terms of the contract;

Q_{real} – quality of the completed and accepted project;

Q_Z – quality defined by the terms of the contract;

K_1, P_1 – the amount of knowledge and experience gained by the project team based on the results of its implementation, respectively;

K_0, P_0 – the amount of knowledge and experience of the project team before its implementation, respectively;

L_1 – the numbered position of the project team in the market for the provision of services after the project is completed;

L_0 – the numbered position of the project team in the service market before the project is implemented.

The creation of a project stakeholder management information system is preceded by the identification of stakeholders [14], as well as the determination of their impact on project performance.

Expert research of the possible range of stakeholders in the development of the shipbuilding industry based on the development and implementation of the *Shipbuilding 4.0* technology platform (representatives of the management of more than 30 major enterprises and organizations of the shipbuilding industry of Ukraine were interviewed) made it possible to develop a generalized structural diagram of project stakeholders (Fig. 3).

The main stakeholders of the Shipbuilding 4.0 technology platform projects include shipbuilding industry enterprises and infrastructure organizations, authorities, territorial communities, shipbuilding customers, financial and credit institutions, supervisory authorities, and public organizations.

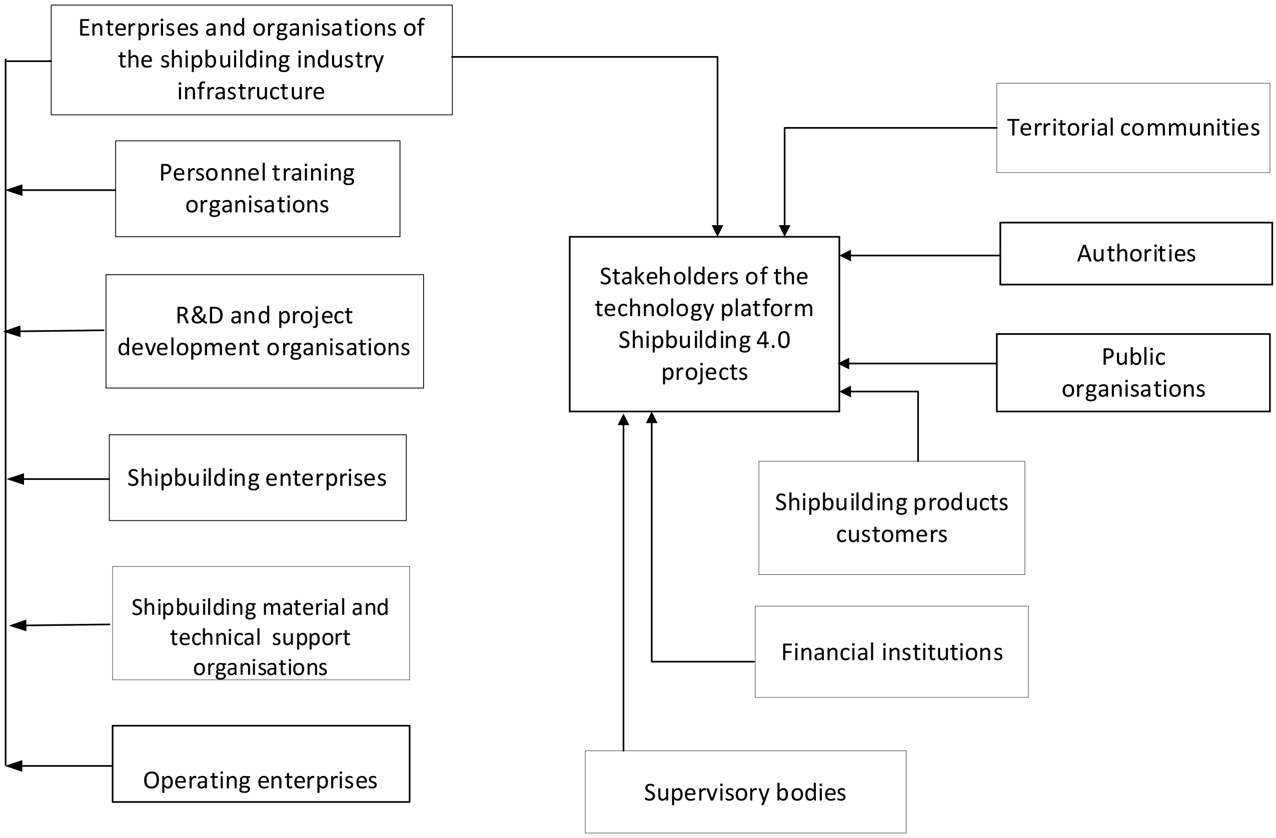

Fig. 3. Block diagram of the main stakeholders of *Shipbuilding 4.0* technology platform projects

According to the proposed structural scheme, the group of enterprises and organizations of the shipbuilding industry infrastructure includes training organizations, research and design organizations, shipbuilding enterprises, shipbuilding logistics organizations, and operating enterprises.

Determining the impact of stakeholders on *Shipbuilding 4.0* technology platform projects

Given the existing models of stakeholder management, the impact of stakeholders in *Shipbuilding 4.0* technology platform projects was determined based on an improved methodology. The methodology is based on ranking stakeholders by their impact on project performance throughout its life cycle. The following qualimetric classification of stakeholder rank is proposed: stakeholders whose impact on the project is critical – rank K; stakeholders whose impact on the project is significant – rank Z; stakeholders whose impact on the project is insignificant but should be taken into account – rank V ; stakeholders whose impact on the project may not be taken into account – rank MV . It should be noted that the ranking of project stakeholders is a dynamic characteristic that depends on the phase of the project and the circumstances that have developed during its implementation:

$$K,Z,V,MV = f\left(F,O\right), \tag{3}$$

where F is the phase of the project life cycle;

O is a set of circumstances that may arise during the formation and implementation of the project and reduce its effectiveness.

In accordance with the life cycle of creating a physical shipbuilding object and its "digital twin" (Fig. 4), as well as the main components of the *Shipbuilding 4.0* technology platform, the ranks of stakeholders are expertly determined according to their accepted classification (Table 1).

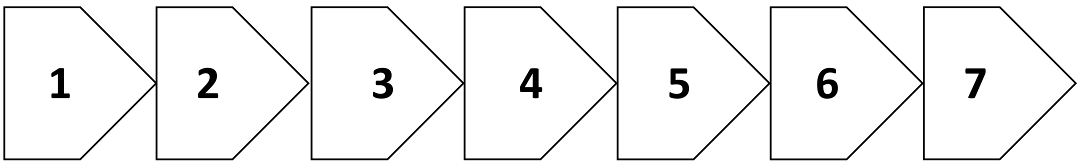

Fig. 4. Phases of the life cycle of creating a physical shipbuilding facility and its "digital twin":
1 – decision-making on the creation of a shipbuilding facility;
2 – development of technical specifications; 3 – design of facility accounting;
4 – facility design; 5 – facility creation; 6 – comprehensive testing;
7 – facility operation, decommissioning and utilization

In the event of unforeseen circumstances in the process of project formation and implementation, the rank of stakeholders is determined according to the accepted classification, but subject to their potential ability to minimize the negative impact of circumstances on project effectiveness.

In determining the stakeholders of digitalization projects, it is necessary to take into account the interests and influence of stakeholders on the "failure" of projects. Potential processes that generate a negative attitude towards *Shipbuilding 4.0* technology platform implementation projects and allow identifying relevant organizations, enterprises, and individuals include the following: economic competition in the domestic and foreign shipbuilding markets; political processes in the country and abroad; military aggression, etc.

Table 1

The rank of stakeholders determined by the level of their influence on the phases of the life cycle of shipbuilding and "digital twins"

Key stakeholders of the projects	Phases of the life cycle of creating a "digital twin" Rank of the project stakeholder						
	1	2	3	4	5	6	7
Public authorities	*K*	*MV*	*MV*	*MV*	*MV*	*V*	*V*
Territorial communities	*K*	*MV*	*MV*	*MV*	*Z*	*MV*	*K*
Shipbuilding enterprises	*K*	*K*	*K*	*K*	*K*	*K*	*V*
Public organizations	*K*	*MV*	*MV*	*MV*	*MV*	*V*	*K*
Supervisory organizations	*K*	*K*	*K*	*K*	*K*	*K*	*K*
Training organizations	*Z*	*MV*	*MV*	*MV*	*MV*	*V*	*V*
Research and development and design organizations	*Z*	*Z*	*Z*	*K*	*Z*	*K*	*Z*
Customers of shipbuilding products	*K*	*K*	*K*	*K*	*K*	*K*	*K*
Financial and credit institutions	*K*	*K*	*MV*	*MV*	*K*	*MV*	*Z*
Logistics organizations	*K*	*K*	*V*	*K*	*K*	*V*	*K*
Operational enterprises	*Z*	*V*	*V*	*V*	*Z*	*K*	*K*

Based on the expert determination of the stakeholders in the "failure" of projects and the developed ranking methodology, it is possible to form a matrix of their rank of influence.

Effective stakeholder management of *Shipbuilding 4.0* technology platform projects is ensured by the availability of relevant information about stakeholders and information about their interests [14]. The formation of a project management information system, including stakeholder management, requires the generalization of such information. At the same time, the information array required for effective management must meet the following conditions:

$$I_{real} \geq I_m, \quad (5)$$

where I_{real} – available information support for stakeholder management processes;

I_m – Necessary information support for effective stakeholder management processes.

In order to determine the information needs for stakeholder management of *Shipbuilding 4.0* technology platform projects, a matrix of the required information support for effective stakeholder management processes was developed (Table 2).

Table 2

Matrix of necessary information support for the processes of effective stakeholder management of Shipbuilding 4.0 technology platform projects

Key stakeholders of the projects	Key relevant information about stakeholders	Significant information about stakeholder interests
Public authorities	Status of the enterprise or organization according to the following criteria: state ownership; belonging to the relevant group on property grounds; availability of institutional initiative; belonging to another state; positioning in the relevant markets of resources and services; degree of influence on other industries	Governmental, technological, economic, political, corporate, and individual interests
Territorial communities		
Shipbuilding enterprises		
Public organizations		
Supervisory organizations		
Training organizations		
Research and development and design organizations		
Customers of shipbuilding products		
Financial and credit institutions		
Logistics organizations		
Operational enterprises		

Conclusions

In the course of the study, we came to specific conclusions.

1. Further development of the shipbuilding industry in Ukraine requires the formation and implementation of relevant digitalization projects based on the *Shipbuilding 4.0* technology platform.

2. The effectiveness of digitalization projects is ensured by the creation of a project management information system.

3. One of the ways to increase the efficiency of digitalization projects is to create an information system for managing project stakeholders of the *Shipbuilding 4.0* technology platform.

4. The determined rank of stakeholders by the level of their influence on the phases of the life cycle of shipbuilding facilities and "digital twins", as well as the

developed matrix of the necessary information support for the processes of effective project stakeholder management, form the elements of the information system for project stakeholder management of the *Shipbuilding 4.0* technology platform.

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