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DEVISING A METHODOLOGICAL APPROACH TO DETERMINING PRIORITIES FOR DIGITAL TRANSFORMATION OF TRANSPORT ENTERPRISES

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The process that improves decision-making for prioritizing the implementation of digital technologies at a transport enterprise under the conditions of uncertainty associated with war and European integration has been investigated in this study.

The objective need to improve the efficiency of decisions is predetermined by resource constraints faced by enterprises, especially under conditions of martial law.

To solve the problem, it has been proposed using a methodological approach based on the hierarchy analysis method. A system of criteria for assessing the priority of digital technologies for transport enterprises was built, which consists of the following groups: economic, technological, organizational-managerial, social-security, and strategic. It was established that the most significant criteria for evaluating digital technologies for the studied enterprises are operational stability (0.4214), technological reliability (0.2621), physical security of infrastructure (0.2987), management flexibility under risk conditions (0.4237), protection of life and health of employees (0.4593), as well as compliance with the legislation of Ukraine and EU norms (0.2713).

The priority of implementing digital technologies for the studied group of transport enterprises was justified based on the construction of a multi-criteria model and the application of the Analytic Hierarchy Process. The following digital technologies were considered to be of the highest priority: transport monitoring and telematics systems, electronic document management, digital contracts and digital interaction platforms.

The objectivity and consistency of the results is attributed to the fact that the evaluation was based on substantiated criteria that provided a multidimensional reflection of the impact of digitalization on the activities of enterprises. A feature of the improved methodological approach is its higher universality. It is suitable for practical application in various modes of transport and for a wide continuum of digital technologies

Keywords: priority of digital technologies, transport enterprise, management, innovative development, methodological approach

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1. Introduction

The key direction in the development of transport enterprises in the world is the introduction of digital technologies as this is one of the prerequisites for business survival under conditions of instability. Transport companies operate in an environment of competition, rising costs, increasing requirements for speed and reliability of transportation. Without a clear digital transformation strategy, enterprises either digitize chaotically or fall behind altogether. It is also worth noting that under conditions of martial law and instability, digitalization is a leading direction of development, as it helps solve the problems of optimizing routes, increasing cargo safety, optimizing costs, etc. [1]. In particular, disruption of logistics routes and destruction of infrastructure can be partially solved through the use of GPS monitoring and automated transport management systems. They help quickly change routes, avoid dangerous areas, plan deliveries taking into account the current situation on the roads. It is also worth noting that the deepening of Ukraine's European integration in the transport sector encourages Ukrainian enterprises to increase the transparency of operations based on the implementation of European standards, for example, the introduction of electronic documents [2, 3]. All of the above requires a systematic digital transformation of transport enterprises. However, it faces a number of problems, the key among which is the limitation of material and managerial resources, especially under conditions of continuous military operations.

Scientific research in the field of digital transformation of transport enterprises is of important practical importance as it contributes to making sound management decisions regarding the implementation of digital technologies, provides conditions for increasing the efficiency of resource use and competitiveness of transport enterprises. In addition, based on the results of the research, phased plans for the digital transformation of enterprises and adaptation to their own strategic goals and resource limitations can be formed.

The above proves the relevance and timeliness of scientific research into the problems of digital transformation of transport enterprises, especially under conditions of uncertainty.

2. Literature review and problem statement

The results of a thorough study on digital transformation by logistics providers, as well as barriers and factors affecting their success, are reported in [4]. The study shows that the established barriers can affect the prioritization of digital solutions but a clear system of criteria for prioritizing measures for the digital transformation of enterprises is not given.

In [5], a detailed systematization of modern approaches to the digital transformation of urban transport systems is described, and a model of digital transformation is proposed, which involves the gradual implementation of measures: from basic elements to a full-fledged analytical transport management system. However, the issue of prioritizing different types of digital projects for such systems remains unresolved.

The impact of digital technologies, in particular, artificial intelligence, the Internet of Things, GPS navigation, Blockchain on the efficiency and sustainable development of transport is shown in study [6]. The author describes digital technologies and argues about their impact on the sustainable development of the enterprise. However, questions remain unresolved regarding the criteria for differentiating these technologies in terms of their priority for implementation by transport enterprises.

There are studies that focus on empirically measuring the impact of digital transformation on the sustainability of the enterprise in general and its supply chain in particular. It is this approach used in [7] that convincingly proves that digital transformation directly improves the sustainability of the supply chain and acts through such key factors as the power and transparency of the supply chain. Although the work identifies digital tools that are appropriate for enterprises with certain characteristics, it lacks consideration, first of all, of the specificity of the transport business.

Some works offer integrated or multi-criteria models for evaluating digital technologies that could be used as part of an approach to forming priorities. It is this approach to devising methods for evaluating and ranking digital technologies that is reported in study [8]. In it, the author devises a hybrid MCDM methodology that combines the CRITIC (CRiteria Importance Through Intercriteria Correlation) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods, while taking into account several criteria simultaneously. The method is recommended specifically for intermodal freight transport; however, it is unclear whether it is relevant for a wider range of transport enterprises. The reason for this may be the lack of a universal adapted methodology that would cover specific contexts, for example, limited resources, security, customer service, etc.

Some papers describe a framework model for selecting key digitalization strategies. For example, in study [9], the results of determining the priority strategy and the criteria for its selection are reported, which provide the basis for digital transformation in the supply chain. However, the work does not examine the features of digital transformation from the point of view of transport enterprises.

Quite often, studies focus on individual digital technologies and the features of their application in certain types of transport. In particular, in work [10], the results of studying digital applications in public transport are reported, an attempt is made to conduct a multi-criteria assessment of the functionality of digital applications for consumers. The criteria for the assessment are selected for technological maturity, the degree of integration with transport systems, user accessibility, and their contribution to intelligent transport planning. However, the study does not offer a generalized methodological approach for the enterprise and focuses only on one class of digital solutions.

In [11], digitalization factors in container transportation are identified and assessed. However, this approach is not universal. Seven critical interdependent factors for successful digital transformation in maritime logistics corridors are described in [12]. The system of these factors can be adapted to prioritize the areas of digitalization of enterprises operating in the specified logistics segment, but it is of little relevance for other types of transport and its segments.

Thus, our review of studies tackling the tasks of determining priorities in the process of digital transformation of transport enterprises has shown the absence of a systematic methodology for a transport enterprise as a complex system. It can be argued that the reviewed works have left unresolved the issue of devising a universal set of criteria for prioritizing digital technologies, as well as an algorithm for evaluating and selecting optimal technologies based on these criteria. The reasons for this may be, firstly, the complexity of the issues themselves and the interdisciplinary nature of this topic. Transport enterprises combine technical, logistical, economic, personnel, and information subsystems. There is actually no universal methodological approach that would take into account all these aspects at the same time. Secondly, digital solutions are changing rapidly, so methodologies become outdated and do not have time to become generally accepted. In addition, there are no single industry standards or regulatory indicators that would allow us to clearly determine the priorities of digital transformation specifically for transport enterprises. An additional factor in the lack of such studies is that a significant number of transport enterprises do not disclose detailed information about digital projects. This complicates the construction of informed methodological models.

It is worth noting that the continuum of digital technologies potentially suitable for effective use by transport enterprises is extremely wide. At the same time, the process of their digital transformation faces a number of limitations, primarily of a resource nature, which is largely due to the conditions of a full-scale war. Under such conditions, there is a need to make balanced decisions regarding the sequence and priority of the implementation of innovative technologies, taking into account the expected economic effect, increased safety, improved customer service quality, etc.

Thus, our arguments indicate the need to establish a priority in the implementation of digital technologies for each enterprise under the relevant circumstances. In this regard, there is a task to scientifically substantiate support to management decisions by devising a methodological approach to determining the priorities of digital transformation. The practical application of such an approach could allow managers to rely not only on intuitive considerations but primarily on systematic scientific justification.

3. The aim and objectives of the study

The purpose of our study is to devise a methodological basis for making management decisions regarding the priority of implementing digital technologies at transport enterprises. This will make it possible to increase the efficiency of management decisions and allow for the competitiveness of enterprises by optimizing the costs of implementing digital technologies.

To achieve this aim, the following objectives were accomplished:

– to devise criteria for assessing the priority of alternative digital technologies for transport enterprises under conditions of uncertainty;

– to substantiate the priority of implementing digital technologies at transport enterprises under conditions of uncertainty.

4. The study materials and methods

The object of our study is the process that improves decision making for determining the priority of implementing digital technologies at a transport enterprise in the context of uncertainty associated with war and European integration.

The principal hypothesis assumes that the digital transformation of transport enterprises is more effective if the priority of implementing digital technologies is determined based on the hierarchy analysis method and multi-criteria assessment. Testing the hypothesis could help provide the objectivity and consistency of management decisions for transport enterprises under conditions of uncertainty.

The study was carried out based on the following assumptions:

– it is assumed that the management of transport enterprises has a sufficient amount of reliable information to form a system of criteria and indicators for evaluating digital technologies;

– it is assumed that the experts involved in the implementation of the hierarchy analysis method have a sufficient level of professional competence and experience in the field of transport and digital technologies.

The study also adopted a number of simplifications, in particular regarding the limited list of digital technologies and the unification of types of transport enterprises.

Among the management methods for decision-making in the context of uncertainty, the most promising are the hierarchy analysis method, fuzzy set theory, and multi-criteria methods based on expected utility. This is due to the fact that these methods best meet the requirements of universality and multi-criteria selection from a set of alternatives. In addition, these methods are most adequate for the preparation, processing, and obtaining reliable expert information.

To provide the structure and systematicity of the analysis when setting the priority of the implementation of digital technologies for a group of motor transport enterprises, our study used the AHP (Analytic Hierarchy Process) method or the hierarchy analysis method. It allows experts to intuitively assess the relative weight of several criteria or several options with respect to the given criteria. In the absence of quantitative assessments, experts can still determine whether one criterion is more important than another. The merit of method's authors is that they established a consistent way of transforming such pairwise comparisons into a set of numbers reflecting the relative priority of each of the criteria [13].

The choice of the AHP method for setting the priority of digital technologies was due to the limitations of this study, in particular:

– the need to calculate a significant number of parameters of the transport enterprise that do not have a clear quantitative expression, for example, the level of safety, convenience, accessibility, innovation, etc.;

– lack of reliable statistical data on the development of transport enterprises due to martial law, destruction of logistics chains, market instability, etc.;

– high level of uncertainty in the business environment of transport enterprises;

– the need for transparency and justification of management decisions of transport enterprises in the context of deepening European integration.

The AHP method is based on the following provisions [13]:

– each complex problem can be divided into components;

– the result of the decomposition can be represented in the form of hierarchical levels, each of which consists of many elements;

– a qualitative pairwise expert comparison of the significance of elements at each level of the hierarchy can be transformed into quantitative ratios between them, which will reflect objective reality. Solving the problem of prioritizing the implementation of digital technologies at transport enterprises using the AHP method is a process of phased prioritization, the logical sequence of its implementation is shown in Fig. 1.

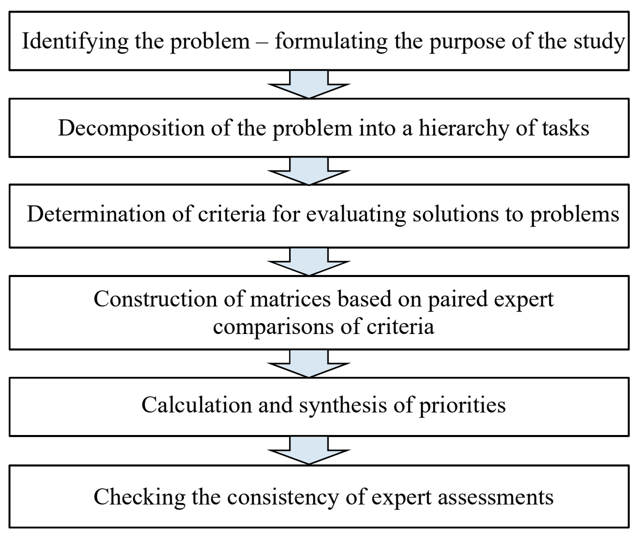

Fig. 1. Logical sequence of conducting research using the Analytic Hierarchy Process method

The result of pairwise expert comparisons of the criteria for the feasibility of implementing digital technologies at a transport enterprise will be a matrix of pairwise comparisons of the following general form:

$$\begin{array}{c} \\ F_1 \\ \dots \\ F_n \end{array} \begin{array}{c} \begin{matrix} F_1 & \dots & F_n \end{matrix} \\ \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \end{array}.$$

In our study, when comparing criteria, qualitative expert assessments were used, which were numerically expressed on a special scale of relative importance. The AHP method uses a special scale from 1 to 9. According to it, components of equal importance are assigned a value of 1. With a moderate advantage of one criterion over another, a score of 3 is used. With a significant advantage – 5; with a very strong advantage – 7; and with an absolute advantage – 9. The values 2, 4, 6, and 8 are intermediate estimates between two adjacent levels of the intensity of the advantage (1, 3, 5, 7, respectively) [14]. In order for the numerical comparisons to be justified, in our study no more than 7–9 criteria (elements) were compared for each group.

The quality and reliability of any expert survey depends on the consistency of the subjective judgments of the specialists involved in the study. That is why, to assess the level of homogeneity of expert judgments, it is necessary to use certain indicators, for example, the difference between the maximum eigenvalue $\lambda_{\max}$ and the order of the matrix n (for both inverse and symmetric matrices, this indicator is always $\lambda_{\max} \geq n$) [13, 15].

The degree of consistency can be expressed using the consistency index (CI – Consistency Index) and the consistency ratio (CR – Consistency Ratio). According to the provisions of matrix theory, the full calculation of the consistency of an inverse symmetric matrix is based on taking into account the maximum eigenvalue $\lambda_{\max}$ and the number of compared elements ($\lambda_{\max} = n$). This indicator is calculated from the following formula

$$CI = \frac{\lambda_{\max} - n}{n-1}, \quad (1)$$

where n is the number of comparison elements (criteria).

The acceptability of the expert judgment consistency index (CI) is determined by comparing it with the random index (RI), which is obtained as an experimental result of processing a significant number of arbitrary matrices of pairwise comparisons. The values of RI for pairwise comparison matrices with dimensionalities from 3 to 15 are presented in Table 1. The consistency ratio (CR) is calculated from the following formula

$$CR = \frac{CI}{RI}. \quad (2)$$

Table 1

Experimental value of RI for some pairwise comparison matrices

n	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54	1.56	1.58	1.59

If $CR < 0.2$, then the consistency of expert assessments is considered acceptable. In case of exceeding the permissible level of inconsistency, the expert is recommended to revise his/her own assessments, relying on a more detailed and in-depth study of the problem under study. For this purpose, the elements of the matrix of pairwise comparisons, which are characterized by the greatest degree of inconsistency, are determined, after which they are adjusted.

The final stage of the AHP method is hierarchical synthesis, the main task of which is to establish priorities of alternatives relative to elements of higher levels of the hierarchy, including taking into account the purpose of the study.

From the standpoint of the mathematical apparatus used in this modeling method, the solution to the problem is reduced to determining the main eigenvector of the matrix, corresponding to the largest eigenvalue ($\lambda_{\max}$), and its subsequent normalization. For matrices of pairwise comparisons, the weight coefficient is considered as an eigenvector of the matrix, which is calculated using the following approach

$$\begin{bmatrix} a_{1,1} & \cdots & a_{1,n} \\ \vdots & \ddots & \vdots \\ a_{n,1} & \cdots & a_{n,n} \end{bmatrix} \begin{bmatrix} W_1 \\ \dots \\ W_n \end{bmatrix} = n \begin{bmatrix} W_1 \\ \dots \\ W_n \end{bmatrix}.$$

From a practical point of view, it is advisable to use an approximate approach, which provides a sufficient level of accuracy of calculations and is distinguished by ease of application [15]. The approximate calculation of the components of the principal eigenvector of the matrix is carried out according to the following formula [16]

$$W_i = \sqrt[n]{\prod_{j-1}^{n} a_{ij}}, \quad (3)$$

at $i = 1, 2, \dots n$.

According to the mathematical tools, the calculation of the maximum eigenvalue of a matrix is carried out based on the following formula

$$\lambda_i = \frac{\sum_{j=1}^{n} a_{ij} \times W_j}{W_i}, \quad (4)$$

at $i = 1, 2, \dots n$,

$$\lambda_{\max} \approx \frac{\sum_{i=1}^{n} \lambda_i}{n}. \quad (5)$$

The next stage of our study was the calculation of the priority vector (P_i) by normalizing numbers W_i, which are determined in the following way [16]

$$P_i = \frac{W_i}{\sum_{i=1}^{n} W_i}; \quad i = 1, 2, \dots n. \quad (6)$$

The calculation of W_i for $i = 1, 2, \dots n$ (provided that $B = A^n$, where n is a natural number, and b_{ij} are elements of matrix B) is carried out according to the following analytical formula

$$P_i = \frac{\sum_{j=1}^{n} b_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} b_{ij}}. \quad (7)$$

The above mathematical apparatus forms the basis for devising a methodology for making informed management decisions regarding the implementation of the most priority digital technologies for transport enterprises under conditions of uncertainty.

5. Results of determining the priorities for the implementation of digital technologies for transport enterprises

5. 1. Design of a system of criteria for assessing the priority of alternative digital technologies for implementation at transport enterprises

The construction of a system of criteria for assessing the priority of alternative digital technologies must begin with the formulation of the general goal of implementing the digital transformation of the enterprise. Its essence should be to support decisions on the implementation of digital technologies at the transport enterprise in order to form a system for organizing the transport process, focused on increasing the efficiency, safety, and sustainability of the enterprise's functioning. The design of such a digital system will ensure the adaptation of the transport enterprise to the challenges of martial law, integration into the European transport space, as well as increased uncertainty in the business environment.

Further development of the methodological approach was aimed at decomposing the defined goal of digitalization of the transport enterprise into a system of criteria with the help of which it is possible to establish how much a separate innovative technology will contribute to its achievement. Groups of criteria were identified, according to which it was proposed to further evaluate alternative digital technologies for implementation at a transport enterprise (Fig. 2). The following were proposed to be included in the main groups of criteria: economic; technological; organizational and managerial; strategic; social and security criteria.

The expediency of identifying such groups of criteria is due to the fact that they are able to comprehensively reflect the main areas of influence of digital technologies on the activities of a transport enterprise. In particular, economic criteria make it possible to assess the financial efficiency and feasibility of investments in digital solutions. Technological criteria characterize the level of innovation, reliability, compatibility, and ability of technologies to integrate into the existing infrastructure of the enterprise. Organizational and management criteria make it possible to determine how the implementation of digital technologies will affect the management structure and decision-making processes. Strategic criteria reflect the ability of technologies to support the long-term development goals of the enterprise, increase its competitiveness and form sustainable advantages in the market. Social criteria take into account the impact of digitalization on personnel, working conditions, the level of implementation of European social protection standards, etc. Security criteria are important for assessing the level of information, operational and transport security, which is especially relevant for the transport industry under conditions of martial law.

Thus, defining these groups of criteria provides a comprehensive, balanced, and objective assessment of alternative digital technologies, taking into account all aspects of their implementation.

For further research, alternative digital technologies were identified that have a significant impact on the activities of a transport enterprise in modern conditions. Among them, in particular, are the following: T_1 – transport monitoring systems and telematics (Fleet Management and GPS/GLONASS); T_2 – integrated enterprise management systems (ERP, TMS, WMS); T_3 – analytical systems and data processing (Big Data, AI); T_4 – Internet of Things (IoT) for monitoring the technical condition of transport; T_5 – electronic document management and digital contracts (EDI (Electronic Data Interchange), Blockchain); T_6 – digital platforms for user interaction.

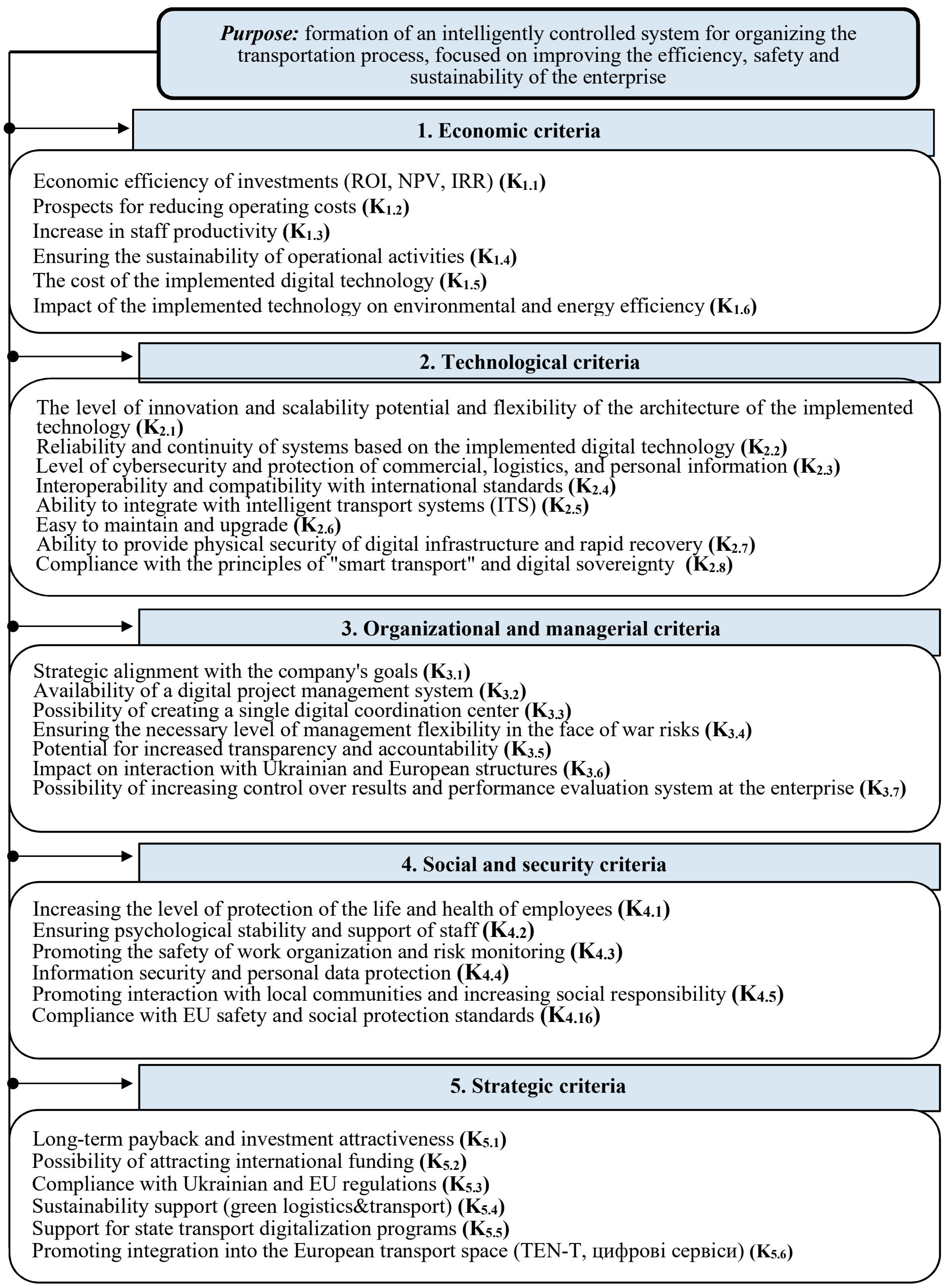

Fig. 2. Decomposition of the system of criteria for assessing the priority of implementing digital technologies at a transport enterprise

As a result, the above-mentioned criteria for assessing the feasibility of implementing digital technologies and the list of alternative digital technologies for transport enterprises formed the basis for building a hierarchical multi-criteria choice model. On its basis, a methodology was devised for selecting a priority digital technology for implementation at a transport enterprise in order to improve the management mechanism for its development.

5. 2. Substantiating the priority of implementing digital technologies at transport enterprises under conditions of uncertainty

The assessment of digital technologies based on the established priority criteria was carried out taking into account the specified situational factors for three transport enterprises in Ukraine: TOV "VEST-EXPRESS", TOV "CARGO SUPPLY", TOV "ARDI LOGISTICS".

The generalized hierarchical multi-criteria model for selecting the optimal digital technology for the development of the studied transport enterprises is shown in Fig. 3.

The selection of the priority digital technology for implementation was carried out by experts based on the proposed criteria (Fig. 2) taking into account such aspects as the degree of influence of the specified technologies on the functioning of the enterprise under martial law and the deepening of the processes of European integration in the transport sector.

A group of 8 experts was involved in the study to conduct the assessment. They were selected according to the following criteria: experience in managing or consulting enterprises in the transport sector; knowledge of digital transformation; education, role in the organization, and analytical abilities.

The experts were asked to determine, using pairwise comparisons, from the proposed criteria for digital technologies, those that are the most priority in terms of creating additional opportunities for the development of each of the studied enterprises at this stage of their functioning. The assessment of the priority of the feasibility criteria was carried out in points based on a scale of relative importance. The calculation of the priority ranks of the criteria for digital technologies for the development of the studied enterprises was carried out based on analytical formulas (1)–(7); their results are given in Table 2.

Based on the results of the expert survey, a list of the most significant criteria was compiled, which should be taken as a basis for establishing the priority of the implementation of digital technologies in terms of their ability to ensure the development of transport enterprises. The specified list of criteria was taken as a basis for further development of a management decision on the choice of priority digital technologies in these business conditions.

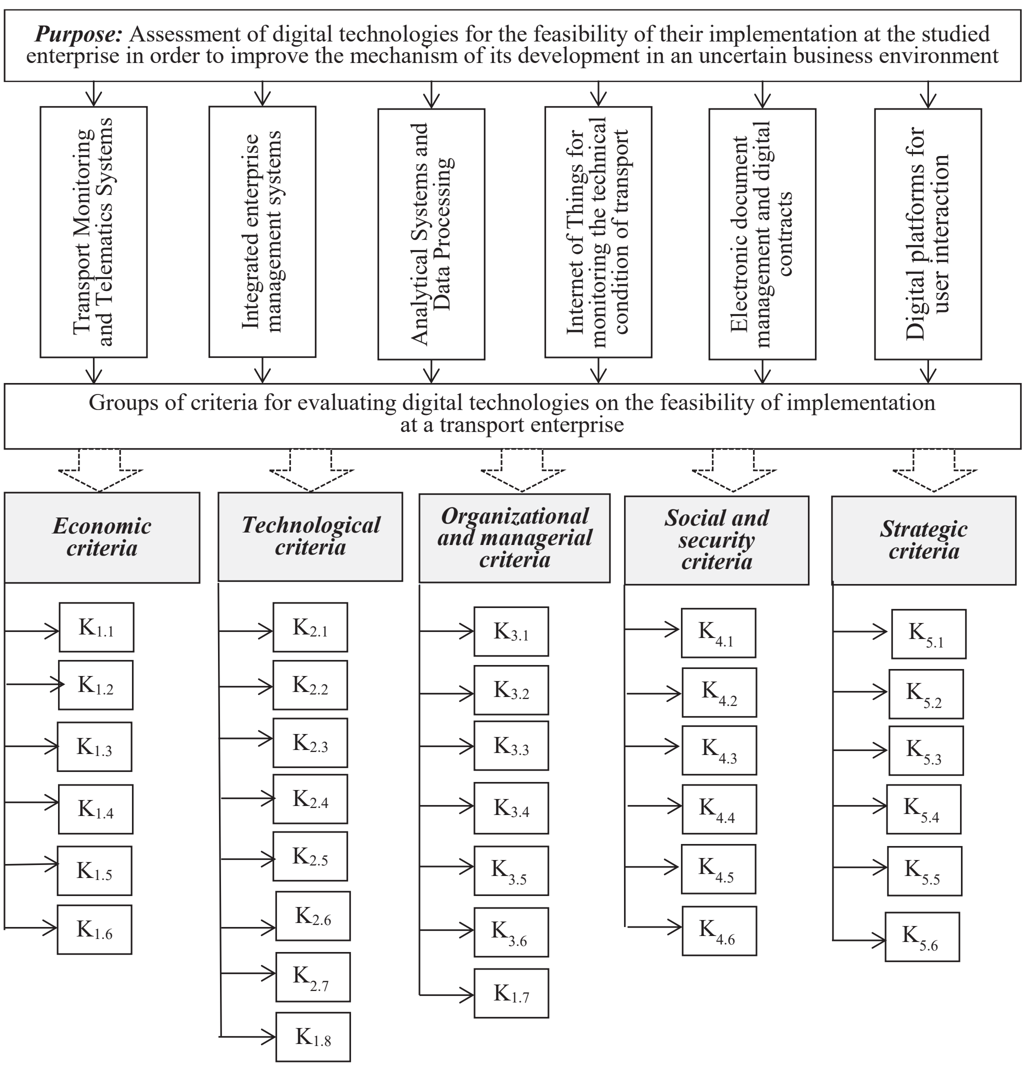

Fig. 3. Hierarchical multi-criteria model for selecting the optimal digital technology

Table 2

Priority ranks of criteria for the feasibility of implementing digital technologies for the development of the studied transport enterprises

Criterion	Vector of priorities
$K_{1.1}$	0.1234
$K_{1.2}$	0.1376
$K_{1.3}$	0.0500
$K_{1.4}$	**0.4214**
$K_{1.5}$	**0.1965**
$K_{1.6}$	0.0711
$K_{2.1}$	0.0316
$K_{2.2}$	**0.2621**
$K_{2.3}$	0.2106
$K_{2.4}$	0.0668
$K_{2.5}$	0.0620
$K_{2.6}$	0.0436
$K_{2.7}$	**0.2987**
$K_{2.8}$	0.0246
$K_{3.1}$	0.0476
$K_{3.2}$	0.1225
$K_{3.3}$	0.0449
$K_{3.4}$	**0.4237**
$K_{3.5}$	0.0482
$K_{3.6}$	0.1256
$K_{3.7}$	**0.1875**
$K_{4.1}$	**0.4593**
$K_{4.2}$	**0.2202**
$K_{4.3}$	0.1143
$K_{4.4}$	0.1235
$K_{4.5}$	0.0276
$K_{4.6}$	0.0551
$K_{5.1}$	0.1239
$K_{5.2}$	0.0939
$K_{5.3}$	**0.2713**
$K_{5.4}$	**0.2465**
$K_{5.5}$	0.0492
$K_{5.6}$	**0.2153**

So, the following were selected as priority criteria for evaluating digital technologies by experts:

– ensuring the stability of operational activities ($K_{1.4}$);

– the cost of the implemented digital technology ($K_{1.5}$);

– reliability and continuity of systems based on the implemented digital technology ($K_{2.2}$);

– the ability to ensure the physical security of the digital infrastructure and rapid recovery ($K_{2.7}$);

– ensuring the necessary level of management flexibility under conditions of military risks ($K_{3.4}$);

– the ability to increase control of results and the efficiency assessment system at the enterprise ($K_{3.7}$);

– increasing the level of protection of the life and health of employees ($K_{4.1}$);

– ensuring psychological stability and support for personnel ($K_{4.2}$);

– compliance with Ukrainian legislation and EU standards ($K_{5.3}$);

– supporting sustainable development (green logistics & transport) ($K_{5.4}$);

– promoting integration into the European transport area (TEN-T, digital services) ($K_{5.6}$).

At the next stage of the survey, using the above list, experts assessed the priority of digital technologies in terms of their ability to ensure the development of the enterprise under the conditions of the above-mentioned external challenges. Based on the results of the expert assessment, we calculated priority vectors and constructed a matrix of normalized ranks of digital technologies. The results of calculating the ranks of priorities of digital technologies for the studied transport enterprises in relation to each of the priority criteria are given in Table 3.

To accomplish the results, the matrix of priorities of digital technologies of transport enterprises was multiplied with the matrix of normalized ranks of priority criteria for the implementation of technologies in modern conditions. The results of calculating these priorities for the implementation of digital technologies for the group of studied transport enterprises are given in Table 4.

Thus, as can be seen from the analysis of Table 4, the following digital technologies were prioritized for implementation at the studied enterprises:

T_1 – transport monitoring and telematics systems (Fleet Management and GPS/GLONASS);

T_5 – electronic document flow and digital contracts (EDI (Electronic Data Interchange), Blockchain);

T_6 – digital platforms for user interaction.

At the same time, for TOV "WEST-EXPRESS" it is advisable to recommend: T_1 – transport monitoring and telematics systems (Fleet Management and GPS/GLONASS); T_5 – electronic document flow and digital contracts (EDI (Electronic Data Interchange), Blockchain). For TOV "CARGO SUPPLY" the priorities for implementation were T_5 – electronic document flow and digital contracts (EDI (Electronic Data Interchange), Blockchain); T_6 – digital platforms for user interaction. And for TOV "ARDI LOGISTICS" – all three of the digital technologies listed above.

The advantages of these digital technologies for the studied enterprises are explained by a number of reasons. First of all, it should be noted that all of them are, compared to others, inexpensive to implement, which is especially important for small and medium-sized enterprises, to which the studied group belongs. At the same time, the selected priority technologies are able to provide tangible positive changes for the development of enterprises, especially under conditions of martial law. For example, digital transport monitoring systems and telematics allow real-time monitoring of the location, technical condition, and routes of vehicles. For small and medium-sized enterprises, this minimizes the misuse of transport, optimizes logistics routes, and reduces fuel costs. During active hostilities and the threat of loss of vehicles, telematics allows one to quickly track the movement of equipment, prevent theft or damage, as well as quickly respond to emergencies. Owing to analytics from telematics systems, enterprises can plan maintenance, identify inefficient drivers, avoid malfunctions and disruptions, which is critical for businesses under conditions of limited resources during wartime.

As for digital technologies of electronic document management and digital contracts (EDI (Electronic Data Interchange), Blockchain), under conditions of martial law and limited access to physical offices, electronic document management ensures the continuity of business processes, rapid coordination of agreements, invoices and reporting. Blockchain technologies also provide data protection, confirmation of document authenticity, and help prevent fraud, which is especially important under crisis conditions when the risk of abuse increases.

Table 3

Matrix of normalized ranks of digital technologies in terms of priority of their implementation for the studied group of enterprises

TOV «WEST-EXPRESS»												
A	$K_{1.4}$	$K_{1.5}$	$K_{2.2}$	$K_{2.7}$	$K_{3.4}$	$K_{3.7}$	$K_{4.1}$	$K_{4.2}$	$K_{5.3}$	$K_{5.4}$	$K_{5.6}$	$\sum$
T_1	0.1689	0.3444	0.4240	0.2820	0.4549	0.4429	0.4351	0.0839	0.3366	0.4315	0.1455	**3.4042**
T_2	0.2208	0.0454	0.0695	0.0658	0.2113	0.2636	0.0882	0.2734	0.1043	0.0834	0.2498	1.4257
T_3	0.0546	0.0279	0.0283	0.0247	0.0677	0.1521	0.0485	0.0841	0.0607	0.1416	0.0869	0.6902
T_4	0.0980	0.0778	0.2594	0.1680	0.0970	0.0757	0.2441	0.0541	0.0671	0.2624	0.0514	1.4036
T_5	0.4150	0.1551	0.1734	0.4167	0.0244	0.0416	0.0250	0.0494	0.3574	0.0534	0.4384	**1.7114**
T_6	0.0427	0.3494	0.0453	0.0429	0.1447	0.0240	0.1591	0.4550	0.0740	0.0278	0.0280	1.3649
TOV «CARGO SUPPLY»												
T_1	0.1112	0.2434	0.024	0.1237	0.0658	0.1419	0.1001	0.0679	0.1366	0.09831	0.1053	1.1129
T_2	**0.2108**	0.1554	0.0489	0.1658	0.2113	0.1436	0.0882	0.1834	0.1547	0.1834	0.0498	1.5455
T_3	0.0647	0.0279	0.0581	0.0248	0.0137	0.1522	0.0342	0.0341	0.0708	0.1616	0.0249	0.6421
T_4	0.0228	0.03457	0.235	0.1445	0.0929	0.0636	0.3995	0.0834	0.0789	0.2588	0.0364	1.4140
T_5	**0.4859**	0.6761	0.1037	0.3627	0.0774	0.0566	0.0274	0.0434	0.3553	0.0674	0.5384	**2.2559**
T_6	0.0992	0.4549	0.0945	0.0699	0.2247	0.0731	0.1991	0.6552	0.1749	0.0197	0.1991	**2.0652**
TOV «ARDI LOGISTICS»												
T_1	0.1239	0.3994	0.4371	0.2802	0.3896	0.2329	0.2251	0.0933	0.4468	0.3315	0.1055	**2.9598**
T_2	**0.2008**	0.0823	0.0457	0.0583	0.2314	0.1998	0.0932	0.1994	0.1123	0.0777	1098	1.3009
T_3	0.0544	0.0272	0.0282	0.0259	0.0548	0.1626	0.0544	0.0888	0.0593	0.1328	0.0309	0.6884
T_4	0.0111	0.0674	0.1059	0.1888	0.0763	0.0671	0.1341	0.0341	0.0433	0.1943	0.0229	0.9224
T_5	**0.4935**	0.2341	0.1999	0.4789	0.1244	0.1994	0.1251	0.1402	0.3127	0.0534	0.4082	**2.3616**
T_6	0.0997	0.3734	0.1153	0.1221	0.1998	0.1367	0.1378	0.4799	0.1968	0.1978	0.1671	2.0593

Note: A – alternative digital technologies

Table 4

Priorities for implementing digital technologies for the studied transport enterprises

Technologies	TOV «WEST-EXPRESS»	TOV «CARGO SUPPLY»	TOV «ARDI LOGISTICS»
T_1	**3.4042**	1.1129	**2.9598**
T_2	1.4257	1.5455	1.3009
T_3	0.6902	0.6421	0.6884
T_4	1.4036	1.4140	0.9224
T_5	**1.7114**	**2.2559**	**2.3616**
T_6	1.3649	**2.0652**	**2.0593**

Digital platforms for user interaction are particularly attractive to small and medium-sized businesses as they create opportunities for market expansion without additional investments. Platforms allow small carriers to quickly find customers, compete with large companies, and provide a stable flow of customers even under unstable economic conditions. Such platforms simplify the interaction between the customer, carrier, and consignee, reduce the number of intermediaries, and minimize the risks of misunderstandings. In wartime, the ability to quickly modify routes, find alternative carriers or logistics solutions is key to preserving the business. Digital platforms provide this efficiency. In addition, digital platforms can be used for internal employee interaction. Under conditions of military challenges, such constant interaction provides psychological stability and support for personnel.

The transport business must overcome not only military challenges but also European integration challenges, which are associated with the need to comply with a number of standards. In particular, transport operators must meet the standards of transparency, environmental friendliness, and transport safety. The use of GPS/GLONASS and Fleet Management systems meets the requirements of EU directives on digital control of transport activities. In addition, transport companies planning international transport must comply with document flow standards. Harmonization of business processes with EU norms provides for electronic data exchange between information systems of different organizations in standardized formats, for example, EDI – Electronic Data Interchange. This is a basic requirement for transport and logistics companies. The use of EDI simplifies communication with foreign partners, speeds up customs procedures and facilitates data exchange with the systems of European logistics operators. Regarding the use of digital platforms by transport companies, it is worth noting that they allow Ukrainian companies to participate in joint transport with European partners, adhering to standards of transparency and digital interaction. This contributes to the expansion of the number of international customers and facilitates the integration of companies into the EU transport system.

6. Discussion of results of defining priorities for the implementation of digital technologies at transport enterprises

The identified priorities for the implementation of digital technologies for the group of transport companies under study confirm the hypothesis that the use of a multi-criteria approach allows for the formation of their objective priorities under conditions of uncertainty. The objectivity and consistency of the results is attributed to the fact that the expert assessment was based on substantiated groups of criteria (Fig. 2), which provided a multidimensional reflection of the impact of digitalization on the activities of enterprises. An important aspect of the reliability of the results is the verification of the consistency of expert assessments using the consistency index (CI) and the consistency coefficient (CR), which were calculated using formulas (1), (2).

Calculation of weight coefficients and priority vectors using formulas (3)–(7) allowed us to identify the most significant digitalization criteria (Table 2).

Further evaluation of alternative digital technologies of a transport enterprise based on the selected criteria made it possible to determine the integral values of priority ranks (Tables 3, 4). Expert assessment showed the dominance of the following technologies: transport monitoring systems and telematics, electronic document management and digital contracts, and digital user interaction platforms. The advantage of these technologies is explained by their significant impact on safety, efficiency of management, compliance with European requirements, and relatively low implementation costs. The latter factor is critically important for small and medium-sized transport enterprises under conditions of war and integration into the European transport space.

However, the results of our study have certain limitations that must be taken into account in their practical application. First, they depend on the quality and objectivity of expert judgments, which is especially sensitive in a period of lack of statistical data. Second, the results are focused on Ukrainian transport enterprises and wartime conditions, which limits the direct transfer of conclusions to other countries or industries. Third, the rapid development of digital technologies may necessitate periodic updating of the list of both criteria and alternative technologies.

A feature of the proposed method and the results is their higher versatility: the possibility of application for different types of transport and a wide continuum of digital technologies, while existing studies are mostly focused on individual sectors or individual technologies and are more fragmentary [8–10].

The limitations of the proposed methodological approach are its dependence on the quality of the expert group; the need to conduct a significant number of comparative iterations; the complexity of formalizing quality criteria; the need to achieve an acceptable level of the index of consistency of expert judgments. These limitations lead to an increase in the cost and time of the assessment.

Further development of the study may involve improving the methodological approach through the additional application of other MCDM (Multi-Criteria Decision Making) methods, in particular, TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), VIKOR (VIšekriterijumsko KOmpromisno Rangiranje), etc. This will increase the versatility, flexibility, and practical significance of the proposed methodological approach.

7. Conclusions

1. A system of criteria for assessing the priority of digital technologies for transport enterprises has been designed. It contains five groups of criteria, in particular, economic, technological, organizational and managerial, social and security, and strategic. A feature of the devised system of criteria is its ability to take into account the limitations associated with military uncertainty, resource constraints, and European integration requirements. It has been established that the most significant criteria for assessing digital technologies are operational stability ($K_{1.4}$ – 0.4214), technological reliability ($K_{2.2}$ – 0.2621), physical security of infrastructure ($K_{2.7}$ – 0.2987), flexibility of management in risk conditions ($K_{3.4}$ – 0.4237), protection of life and health of employees ($K_{4.1}$ – 0.4593), and compliance with the legislation of Ukraine and EU norms ($K_{5.3}$ – 0.2713). The resulting list of significant criteria confirms the dominance of security and strategic factors under current conditions. The resulting structure of criteria is explained by the need to simultaneously ensure economic efficiency, managerial adaptability, and compliance with European standards for Ukrainian transport enterprises.

2. We have substantiated the priority of implementing digital technologies at transport enterprises under conditions of uncertainty for the studied group of transport enterprises based on the construction of a multi-criteria model and the application of the AHP method. It was established that according to the set of weighted criteria, the following digital technologies received the highest priorities: T_1 – transport monitoring systems and telematics (3.4042; 2.9598), T_5 – electronic document management and digital contracts (1.7114; 2.2559; 2.3616), and T_6 – digital interaction platforms (1.3649; 2.0652; 2.0593). Their advantage is explained by the combination of a high impact on safety, management efficiency, compliance with European requirements, as well as a relatively low cost of implementation, which is especially important for small and medium-sized enterprises in wartime. A comparison of the results showed the dominance of these technologies for all studied enterprises. However, the structure of priorities is different, for example, for TOV "WEST-EXPRESS", the key ones are T_1 and T_5. For TOV "CARGO SUPPLY", the recommended priorities for implementation are T_5 and T_6; and for TOV "ARDI LOGISTICS" – T_1, T_5 and T_6. Thus, the proposed methodological approach provides quantitatively confirmed, transparent, and adaptive support for management decisions regarding the digital transformation of transport enterprises.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors used the GPT-5.2 artificial intelligence model in the chapter of this paper that reviewed the literature. The AI tool was applied to search for scientific sources over the past 5 years based on keywords and criteria entered by the authors. It accelerated the process of searching and preliminary classification of sources, allowing the authors to effectively identify relevant publications. All results were carefully checked manually by confirming publication in scientific journals, checking DOIs, and assessing the relevance of the data to the research topic. The conclusions were based solely on manually checked sources, so the GPT-5.2 model served as an auxiliary tool that optimized the workflow but did not directly affect the scientific reliability of the conclusions.

Authors' contributions

Yevhenii Vorobiov: Conceptualization, Investigation, Writing – review & editing, Funding acquisition; **Olena Palyvoda:** Methodology, Writing – review & editing, Supervision, Project administration; **Iryna Tarnovska:** Formal analysis, Data curation, Visualization, Funding acquisition.

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