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Automated software package for selecting transport technology for grain transportation by road freight transport

Abstract. The aim of the work was to develop a software package for making a management decision to choose a transport technology for grain transportation by road from a set of alternatives. To achieve this goal, the morphological analysis method was used, which is based on selection of possible solutions for individual parts of the task. A software package for making a management decision from a set of alternatives was proposed, which consisted of four modules and four blocks. It was based on two methods: fuzzy Decision-Making Trial and Evaluation Laboratory (hereinafter – fuzzy Dematel) and gray relational analysis (hereinafter – GRA), which are used to determine the basic indicators and, on their basis, select the transport technology for grain transportation itself. The software package implemented an algorithm of eight

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steps: entering groups of indicators, their pairwise analysis, determining basic indicators based on the total matrix of relationships, entering the values of basic and reference indicators of transport technologies for grain transportation and weight coefficients, constructing gray analysis matrices, determining the index of basic indicators relative to target ones achievement. As a result, the best transport technology for grain freight road transportation was selected to meet the target (reference) indicators of the motor transport enterprise according to the following indicators: load transportation tariff; load transportation speed; diesel fuel consumption per 100 km; load volume; transportation distance; transport process energy intensity; time spent on loading and unloading operations; load safety during transportation; carrier reliability; driver satisfaction with working conditions. According to the calculation results, it was noted that the transport technology for grain transportation best meets the target indicators – load road train with dump semi-trailer. The dependences of the transport technology for load transportation basic indicators and motor transport enterprise target indicators were established, which allows improving the algorithm for making management decision to choose an effective transport technology for transportation from a set of alternative ones. The proposed process of selecting the best solution from a set of alternatives can be used in organisations that select the best technology for road load transportation of bulk cargo – grain

Keywords: transport technology; fuzzy Dematel method; gray relational analysis method; target indicators; benchmark indicators; management decisions

INTRODUCTION

Road transport is a key element in providing agro-industrial enterprises with efficient grain transportation. The costs of transport services significantly affect the cost of products and the financial results of enterprises. At the same time, the transport process depends on numerous risks, such as climate change, rising fuel prices, the technical condition of the fleet and personnel shortage. Many enterprises use their own equipment, but its effectiveness is often limited by technical characteristics – wear and tear. To optimise transportation, it is necessary to choose transport technologies that ensure minimal costs, product safety and efficient use of resources. This problem can be solved by developing an automated system for selecting transport technologies using fuzzy logic methods. This will allow to take into account various conditions of the transport process and reduce the impact of uncertainty on decision-making (Vickerman, 2024). Substantiation of delivering goods vehicles models is an important part of the modelling transport process procedure. Existing classical methods can be conditionally divided into two groups: those that take into account the stochastic characteristics of vehicles for delivering goods, and the others include those that do not take into account the stochastic vehicles characteristics (Tsopa *et al.*, 2024).

Several publications are devoted to the development of the first group. The authors of the work X. Hu *et al.* (2019) considered the determination of stochastic parameters of the load delivery process based on the development of a multi-objective software package. It was based on a heuristic-adaptive genetic algorithm, which allows to solve the problem of transportation optimisation. Comparing the results of calculations with experimental data, the paper concluded that the proposed algorithm was effective. However, the authors did not indicate any limitations in the application of the algorithm for forming load transportation schedules. In another work by L. Pečený *et al.* (2020) a cargo delivery planning program based on discrete-event modelling was proposed. For this purpose, load transportation scenario was developed taking into account the influence of organisational and technical fleet management policies. Additionally, load distribution data between carriers was also taken into account. The authors believed that the proposed approach will reduce the number of delays and failures in cargo timely delivery to customers. However, the use of discrete-event modelling assumes that no changes occur in the transportation system between certain consecutive events, which limits its application in emergency cases. C.B. Gustavo *et al.* (2021) proposed to use multidimensional functions in conjunction with XGBoost (eXtreme Gradient Boosting) to reduce fuel consumption by quarry trucks. The authors believed that using XGBoost could improve the accuracy of fuel consumption monitoring on the route, taking into account the transportation distance, lifting height, and time of one transportation cycle. However, the work did not indicate that works would need to retrain XGBoost due to shortcomings in the collected data, or when data with categorical features were obtained. An interesting solution was proposed by Q. Wang *et al.* (2021), who developed a program to establish dependencies between stochastic vehicle characteristics and truck movement trajectories using a global positioning system based on a model. However, the study itself indicates its drawback, which is related to the problem of real-time data processing.

In the development of the second group, existing studies are devoted to studying the influence of specific vehicle efficiency indicators and route characteristics on the efficiency of the load delivery process. For example, Z. Lyu *et al.* (2022) proposed an adaptive polyploid memetic algorithm (APMA) to improve the efficiency of the load transportation planning process. The algorithm is based on the concept of polyploidy, when it is proposed to evaluate the efficiency of transportation based on the objective function analysis, taking into account possible alternative scenarios that differ in minor changes in input parameters (inventory level, operations number, flexibility of supply chain operations, carbon dioxide emissions reduction, etc.). The program allows, based on the analysis of the objective function, to find the best solution for planning the cargo transportation chain. However, a drawback that requires further research is the processing of a significant number of possible solutions that have minor differences and require additional analysis. M.A. Dulebenets (2021) solved the problem of reducing the load delivery time uncertainty due to possible failures during the cargo reloading (transfer) from one carrier to another in a mixed transportation system. To reduce uncertainty, the authors proposed a software complex built on the identification of opportunity fuzzy chances. It allows you to estimate, based on various input data, the equipment breakdowns probability or loss of time during the unloading-loading process, which affects the actual time of cargo transfer to the other party. Unfortunately, the authors limited themselves only to calculating possible time losses and did not propose solutions for possible compensation of these delays by using a different transportation route. Researchers F. Essghaier *et al.* (2021) proposed to increase the efficiency of load delivery by developing rational work and rest regimes for drivers (RWRs) and implementing them in the transport process. To this end, based on mathematical modelling, two RWR schemes were proposed, which, according to the researchers, will make it possible to increase the daily duration of truck driving up to 10 hours, during any one week. It is indicated that the increased driving duration should be compensated by an equivalent rest time, when replacing a 45-minute break with several breaks lasting at least 15 minutes each. C. Sénquiz-Díaz (2021) concluded that the most effective route planning method is the branch and network method, which allows obtaining a route with the shortest distance for cargo delivery. However, it is not clear how this method allows for the determination of other important indicators: time, fuel consumption. The authors reported that for such tasks, a combination of several calculation methods can be made. I. Skovron *et al.* (2020) and M. Feng & Y. Cheng (2021) solved optimisation problems using the PROMETHEE method to make a decision for fleet selection taking into account various criteria such as efficiency, sustainability, cost, etc. or the cross-data analysis method, which indicates a positive and significant relationship between different factors of the transport process. However, the presented approach has limitations in terms of iterations number with variable indicators of the transport process and requires improvement of existing algorithms.

The presence of many variable parameters in the considered works and the given formalisation of the research conditions do not allow for a qualitative analysis of the obtained results and the development of recommendations that allow using any of the proposed approaches as universal for choosing the optimal (rational) transport technology for transporting goods by vehicles. Therefore, solving the problem of making a management decision to choose a transportation route from a set of alternatives is relevant. Its solution would guarantee the maximum result for a transport company engaged in the delivery of agricultural products.

The purpose of the work was to develop a software package for making a management decision to choose a transport technology for transporting grain by road freight transport from a set of alternatives.

MATERIALS AND METHODS

To achieve the goal, the morphological analysis method was used, which is based on the selection of possible solutions for certain parts of the task (Feng & Cheng, 2021). For this purpose, several morphological typical features (indicators) of grain transportation technologies by road transport (carrying capacity, diesel fuel consumption, loading and unloading time, operating speed, etc.) were identified, which allow to make the necessary management decision. The identified features are presented in the form of tables, the so-called morphological boxes (matrix), which simplified the determination of the most influential on the transportation process.

Further, based on the system analysis, an automated software package was generated for making a management decision on the choice of a transport technology for grain transportation by road from a set of alternatives (Kim & Kim, 2020). It consisted of an initial data module (1), a memory module (2), an information output and visualisation module (3), and a calculation module (4). The calculation module included block 1 for forming a total matrix of pairwise relationships of transport technology certain indicators, block 2 for determining basic indicators and a block for forming a gray analysis matrix, block 3 for processing data on and a block for selecting the best solution from a set of alternative solutions, and block 4 for determining the rating of alternative solutions (Fig. 1).

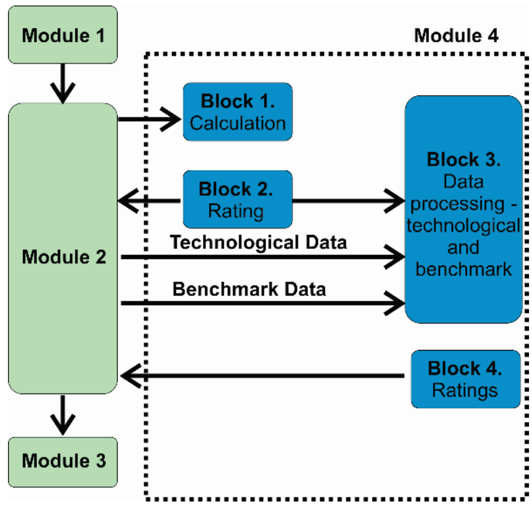


Figure 1. Functional diagram of the software complex
Source: developed by the authors

The software complex contained the following elements: data input/output forms in the form of a modular structure, a multifunctional software tool implemented in the Python programming language, using a data storage library (for example, Tkinter or PyQt), which ensured the appropriate calculations. The data of the indicator groups were entered by experts through a special window in module 1. Then they were stored in module 2 and, if necessary, transferred to module 4 in block 1 or block 3. Also, the results of determining the basic indicators from block 2 and the results of calculating the best transport technology from block 4 were transferred to module 2. All data stored in module 2 were transferred to module 3 for visualisation.

The software package is based on two methods: the fuzzy Dematel method for determining the basic indicators of transport technology (Bazaluk *et al.*, 2024; Tsopa *et al.*, 2024b) and the gray relational analysis (GRA) method for analysing the set of alternatives (Quan *et al.*, 2018; Lu *et al.*, 2023). At the first stage, an analysis of all indicators of the transport technology of grain transportation by truck was carried out to determine the basic indicators using the fuzzy Dematel method. At the second stage, the best transport technology of grain transportation was selected using the GRA method.

In theory, gray relational analysis allowed finding the relationship between different transport technologies of grain transportation by truck. When using the gray analysis method, a comparison was made of target (reference) indicators defined by the customer with actual indicators, which allows establishing the degree of similarity and determining the best transport technology of grain transportation by truck. The software complex included 8-Step algorithm (Fig. 2).

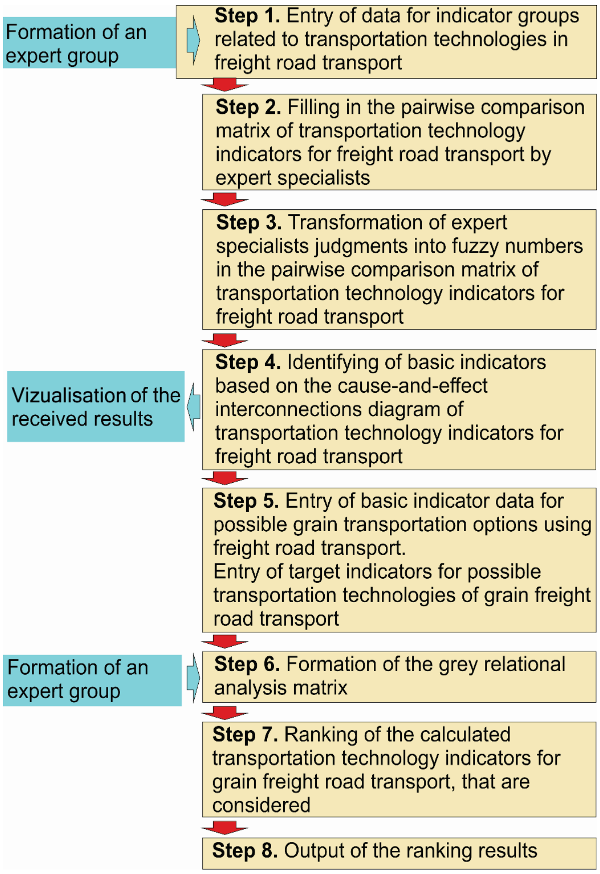


Figure 2. Algorithm for determining the best transport technology for cargo transportation
Source: developed by the authors

Step 1. In module 1, experts entered data on all indicators of transport technology for grain transportation: economic; environmental; safety; energy; technical; ergonomic, transport, etc. (Fig. 3).

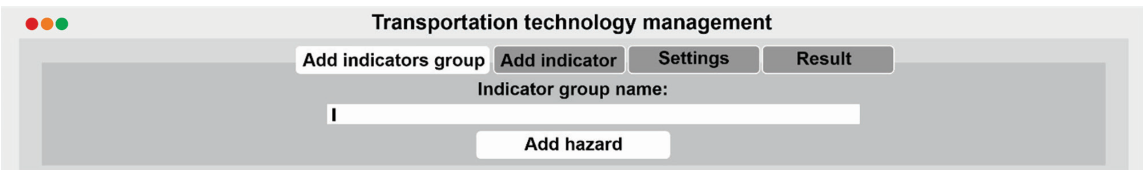
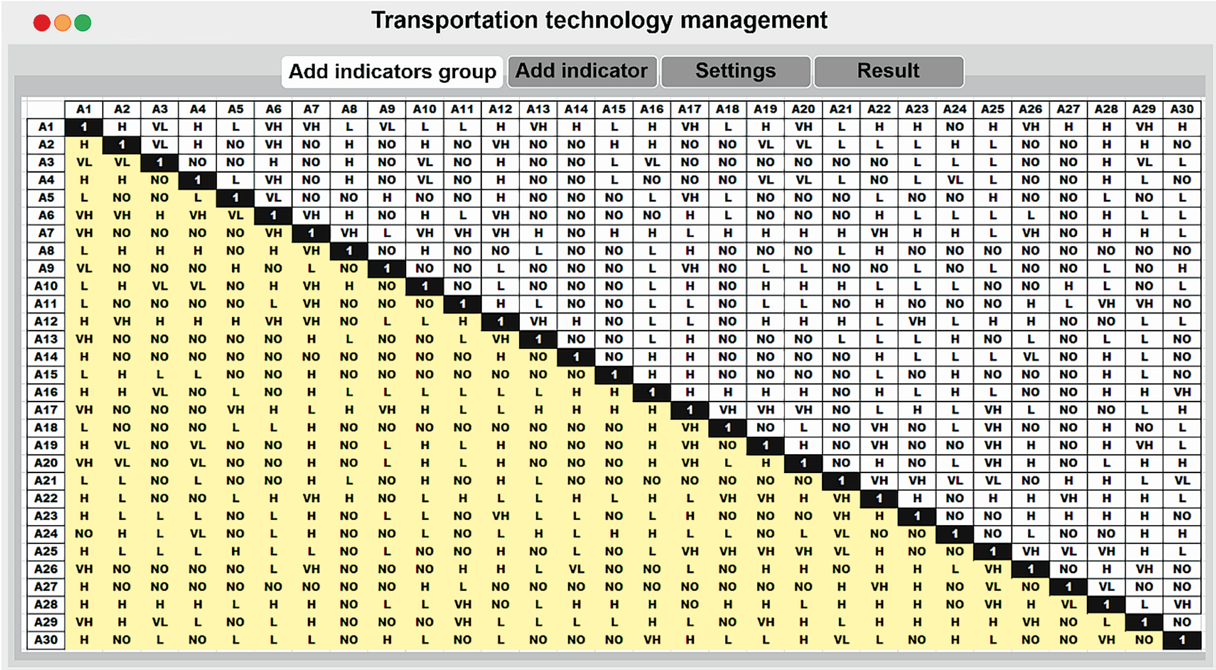


Figure 3. Window for entering transport technology indicators
Source: developed by the authors

Step 2. Module 2 contains expert judgments on the mutual influence of selected indicators in linguistic terms (Fig. 4), which are then transferred to block 1 of module 4.



	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
A1	1	H	VL	H	L	VH	VH	L	VL	L	L	H	VH	H	L
A2	H	1	VL	H	NO	VH	NO	H	NO	H	NO	VH	NO	NO	H
A3	VL	VL	1	NO	NO	H	NO	H	NO	VL	NO	H	NO	NO	L
A4	H	H	NO	1	L	VH	NO	H	NO	VL	NO	H	NO	NO	L
A5	L	NO	NO	L	1	VL	NO	NO	H	NO	NO	H	NO	NO	NO
A6	VH	VH	H	VH	VL	1	VH	H	NO	H	L	VH	NO	NO	NO
A7	VH	NO	NO	NO	NO	VH	1	VH	L	VH	VH	VH	H	NO	H
A8	L	H	H	H	NO	H	VH	1	NO	H	NO	NO	L	NO	NO
A9	VL	NO	NO	NO	H	NO	L	NO	1	NO	NO	L	NO	NO	NO
A10	L	H	VL	VL	NO	H	VH	H	NO	1	NO	L	NO	NO	NO
A11	L	NO	NO	NO	NO	L	VH	NO	NO	NO	1	H	L	NO	NO
A12	H	VH	H	H	H	VH	VH	NO	L	L	H	1	VH	H	NO
A13	VH	NO	NO	NO	NO	NO	H	L	NO	NO	L	VH	1	NO	NO
A14	H	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	H	NO	1	NO
A15	L	H	L	L	NO	NO	H	NO	NO	NO	NO	NO	NO	NO	1
A16	H	H	VL	NO	L	NO	H	L	L	L	L	L	L	H	H
A17	VH	NO	NO	NO	VH	H	L	H	VH	H	L	L	H	H	H
A18	L	NO	NO	NO	L	L	H	NO	NO	NO	NO	NO	NO	NO	NO
A19	H	VL	NO	VL	NO	NO	H	NO	L	H	L	H	NO	NO	NO
A20	VH	VL	NO	VL	NO	NO	H	NO	L	H	L	H	NO	NO	NO
A21	L	L	NO	L	NO	NO	H	L	NO	H	NO	H	L	NO	NO
A22	H	L	NO	NO	L	H	VH	H	NO	L	H	L	L	H	L
A23	H	L	L	L	NO	L	H	NO	L	L	NO	VH	L	L	NO
A24	NO	H	L	VL	NO	L	H	NO	NO	L	NO	L	H	L	H
A25	H	L	L	L	H	L	L	NO	L	NO	NO	H	NO	L	NO
A26	VH	NO	NO	NO	NO	L	VH	NO	NO	NO	H	H	L	VL	NO
A27	H	NO	NO	NO	NO	NO	NO	NO	NO	H	L	NO	NO	NO	NO
A28	H	H	H	H	L	H	H	NO	L	L	VH	NO	L	H	H
A29	VH	H	VL	L	NO	L	H	NO	NO	NO	VH	L	L	L	L
A30	H	NO	L	NO	L	L	L	NO	H	L	NO	L	NO	NO	NO

	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30
A1	H	VH	L	H	VH	L	H	H	NO	H	VH	H	H	VH	H
A2	H	NO	NO	VL	VL	L	L	L	H	L	NO	NO	H	H	NO
A3	VL	NO	NO	NO	NO	NO	NO	L	L	L	NO	NO	H	VL	L
A4	NO	NO	NO	VL	VL	L	NO	L	VL	L	NO	NO	H	L	NO
A5	L	VH	L	NO	NO	NO	L	NO	NO	H	NO	NO	L	NO	L
A6	NO	H	L	NO	NO	NO	H	L	L	L	L	NO	H	L	L
A7	H	L	H	H	H	H	VH	H	H	L	VH	NO	H	H	L
A8	L	H	NO	NO	NO	L	H	NO	NO	NO	NO	NO	NO	NO	NO
A9	L	VH	NO	L	L	NO	NO	L	NO	L	NO	NO	L	NO	H
A10	L	H	NO	H	H	H	L	L	L	NO	NO	H	L	NO	L
A11	L	L	NO	L	L	NO	H	NO	NO	NO	H	L	VH	VH	NO
A12	L	L	NO	H	H	H	L	VH	L	H	H	NO	NO	L	L
A13	L	H	NO	NO	NO	L	L	L	H	NO	L	NO	L	L	NO
A14	H	H	NO	NO	NO	NO	H	L	L	L	VL	NO	H	L	NO
A15	H	H	NO	NO	NO	NO	L	NO	H	NO	NO	NO	H	L	NO
A16	1	H	H	H	H	NO	H	L	H	L	NO	NO	H	H	VH
A17	H	1	VH	VH	VH	NO	L	H	L	VH	L	NO	NO	L	H
A18	H	VH	1	NO	L	NO	VH	NO	L	VH	NO	NO	H	NO	L
A19	H	VH	NO	1	H	NO	VH	NO	NO	VH	H	NO	H	VH	L
A20	H	VH	L	H	1	NO	H	NO	L	VH	H	NO	L	H	H
A21	NO	NO	NO	NO	NO	1	VH	VH	VL	VL	NO	H	H	L	VL
A22	H	L	VH	VH	H	VH	1	H	NO	H	H	VH	H	H	L
A23	L	H	NO	NO	NO	VH	H	1	NO	NO	H	H	H	H	NO
A24	H	L	L	NO	L	VL	NO	NO	1	NO	L	NO	NO	H	H
A25	L	VH	VH	VH	VH	VL	H	NO	NO	1	VH	VL	VH	H	L
A26	NO	L	NO	H	H	NO	H	H	L	VH	1	NO	H	VH	NO
A27	NO	NO	NO	NO	NO	H	VH	H	NO	VL	NO	1	VL	NO	NO
A28	H	NO	H	H	L	H	H	H	NO	VH	H	VL	1	L	VH
A29	H	L	NO	VH	H	L	H	H	H	H	VH	NO	L	1	NO
A30	VH	H	L	L	H	VL	L	NO	H	L	NO	NO	VH	NO	1

Figure 4. A window with a pairwise comparison matrix developed by experts comparing the relationship between indicators

Source: developed by the authors

Step 3. In block 1 of module 4, the experts' judgments were transformed into fuzzy numbers using a fuzzy scale, which involves the use of triangular fuzzy numbers $\tilde{z}$, which are defined as follows: $\tilde{z} = (l, m, u)$, where l, m and u are real numbers and $l \leqslant m \leqslant u$. The membership function $\mu_{\tilde{z}}$ is defined as follows (Tsopa *et al.*, 2024):

$$\begin{cases} \frac{x-l}{m-l} & if \quad l \le x \le m \\ \frac{u-x}{u-m} & if \quad m \le x \le u \\ 0 \quad y & otherwise\,. \end{cases} \tag{1}$$

The obtained fuzzy numbers provided the opportunity to reduce the uncertainty and subjectivity of expert assessments. This allowed to increase the accuracy and reliability of the model in the process of choosing the best transport technology. The judgments were expressed using a rating scale from 1 to 9, which was previously entered in module 2. 1 point characterises the worst performance, and 9 points – with the best. The collected expert judgments were processed in block 2 with equal weight for all experts and used to create the corresponding matrix of pairwise comparisons.

$$\tilde{z}^k = \begin{bmatrix} 0 & \tilde{z}_{12}^{(k)} & \dots & \tilde{z}_{1n}^{(k)} \\ \tilde{z}_{21}^{(k)} & 0 & \dots & \tilde{z}_{1n}^{(k)} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \tilde{z}_{n1}^{(k)} & \dots & \dots & 0 \end{bmatrix}, \tag{2}$$

where $\mu_{\tilde{z}} = 1, 2, 3, \dots, p$; $\tilde{Z}_{ij}^{(k)} = (l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)})$. Without loss of generality $\tilde{Z}_{u}^{(k)} = (i = 1, 2, \dots, n)$ will be considered as a triangular fuzzy number $\tilde{Z} = (0, 0, 0)$, when necessary. Next, the average matrix was calculated from the set of matrices $\tilde{z}_1$, $\tilde{z}_2$, $\tilde{z}_3$, ..., $\tilde{z}_p$. from each involved expert. After its normalisation, a general fuzzy matrix $\tilde{z}_k$, was obtained, which was used to identify and analyse the cause-and-effect relationships between indicators. After constructing the normalised fuzzy matrix $\tilde{z}_k$, an analysis of direct relationships was performed, based on the assumption that:

$$r_k = max_{i=1}^{n}(\textstyle\sum_{j=1}^{n} u_{ij}^{k}). \tag{3}$$

To transform the criteria scale into a scale of comparable values, a linear transformation was used, and normalised fuzzy matrix of direct relationships obtained as a result of expert evaluation:

$$\bar{x}^k = \begin{bmatrix} \bar{x}_{11}^{(k)} & \bar{x}_{12}^{(k)} & \dots & \bar{x}_{1n}^{(k)} \\ \bar{x}_{21}^{(k)} & \bar{x}_{22}^{(k)} & \dots & \bar{x}_{2n}^{(k)} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ \bar{x}_{n1}^{(k)} & \bar{x}_{n2}^{(k)} & \dots & \bar{x}_{nn}^{(k)} \end{bmatrix}, \tag{4}$$

where $k = 1, 2, 3, \dots, p$:

$$\bar{x}_{ij}^{(k)} = \frac{\tilde{z}_{ij}^{(k)}}{r^k} = \left(\frac{l_{ij}^{(k)}}{r^k}, \frac{m_{ij}^{(k)}}{r^k}, \frac{u_{ij}^{(k)}}{r^k}\right). \tag{5}$$

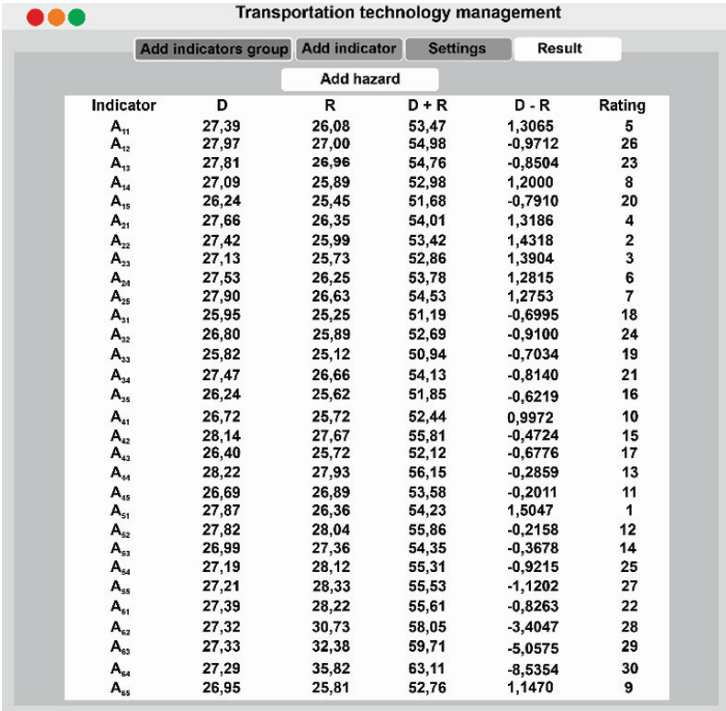
Similarly to the usual fuzzy Dematel method, it was assumed that there is at least one value i that satisfies the condition $\sum_{j=1}^{n} u_{ij}^{k} < \sum_{j=1}^{n} r^{k}$. In this case, the average value of all experts $\tilde{X}$ judgments was calculated as:

$$\tilde{X} = \frac{\tilde{x}^1 + \tilde{x}^2 + \ldots + \tilde{x}^p}{p}, \tag{6}$$

$$\tilde{X} = \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \ldots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22} & \ldots & \tilde{X}_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots \\ \tilde{X}_{n1} & \tilde{X}_{n2} & \ldots & \tilde{X}_{nn} \end{bmatrix}, \tag{7}$$

where $\tilde{X}_{ij} = \frac{\sum_{k=1}^{p} \tilde{x}_{ij}^{(k)}}{p}$.

Step 4. In block 2 of module 4, a cause-and-effect diagram was created, based on which the ranking of indicators is automatically provided according to the priority rule by the cumulative percentage – 80% of the total weight of all indicators (Fig. 5). The indicators with the highest rating, which were used in further calculations, were determined as basic. The sum of the rows and columns of the fuzzy general dependency matrix was denoted, respectively, by the vectors D_i and R_i. The data contained in these vectors are functional for creating a cause-and-effect diagram, since its horizontal axis, denoted as (D_i+R_i), determines the indicators influence, while its vertical axis, denoted as (D_i-R_i), indicates the mutual influence degree between the indicators.



Indicator	D	R	D + R	D - R	Rating
A_{11}	27,39	26,08	53,47	1,3065	5
A_{12}	27,97	27,00	54,98	-0,9712	26
A_{13}	27,81	26,96	54,76	-0,8504	23
A_{14}	27,09	25,89	52,98	1,2000	8
A_{15}	26,24	25,45	51,68	-0,7910	20
A_{21}	27,66	26,35	54,01	1,3186	4
A_{22}	27,42	25,99	53,42	1,4318	2
A_{23}	27,13	25,73	52,86	1,3904	3
A_{24}	27,53	26,25	53,78	1,2815	6
A_{25}	27,90	26,63	54,53	1,2753	7
A_{31}	25,95	25,25	51,19	-0,6995	18
A_{32}	26,80	25,89	52,69	-0,9100	24
A_{33}	25,82	25,12	50,94	-0,7034	19
A_{34}	27,47	26,66	54,13	-0,8140	21
A_{35}	26,24	25,62	51,85	-0,6219	16
A_{41}	26,72	25,72	52,44	0,9972	10
A_{42}	28,14	27,67	55,81	-0,4724	15
A_{43}	26,40	25,72	52,12	-0,6776	17
A_{44}	28,22	27,93	56,15	-0,2859	13
A_{45}	26,69	26,89	53,58	-0,2011	11
A_{51}	27,87	26,36	54,23	1,5047	1
A_{52}	27,82	28,04	55,86	-0,2158	12
A_{53}	26,99	27,36	54,35	-0,3678	14
A_{54}	27,19	28,12	55,31	-0,9215	25
A_{55}	27,21	28,33	55,53	-1,1202	27
A_{61}	27,39	28,22	55,61	-0,8263	22
A_{62}	27,32	30,73	58,05	-3,4047	28
A_{63}	27,33	32,38	59,71	-5,0575	29
A_{64}	27,29	35,82	63,11	-8,5354	30
A_{65}	26,95	25,81	52,76	1,1470	9

Figure 5. Window with the result of ranking basic indicators by priority indicator
Source: developed by the authors

Step 5. In module 1, experts entered the values of basic indicators for each transportation technology (in the form of matrix), as well as data on target (reference) indicators for choosing the best solution from the set of alternatives, which are displayed as a series $K^* = [k_1{}^* \, k_2{}^* \cdots k_n{}^*]$. Additionally, experts determined and entered in module 1 the weight coefficients of basic indicators, according to which a matrix was designed in the form $Wk = [w_{k1}, w_{k2}, \cdots, w_{kl}]$.

Step 6. In block 3 of module 4, a matrix was designed to determine the relationship between the basic and target indicators of the transportation technology (Lu *et al.*, 2023):

$$K = \begin{bmatrix} k_1^* & k_2^* & \cdots & k_n^* \\ A_{11} & A_{12} & \cdots & A_{1n} \\ \vdots & \vdots & & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mn} \end{bmatrix}, \tag{8}$$

where A_{ij} is the value of the i indicator of the k-group of indicators of the j solution; series $K = [k_1 \, k_2 \cdots k_n]$ – is a series of target (reference) values.

The indicators A_{ij} of the matrix K of all m sets of solutions and the values of the *1st group*, *2nd group*, ..., *k-th* – group indicators for one dimension are reduced to relative units by dividing into target indicators $k_1, k_2, \cdots, k_n$ by the corresponding indicators A_{mi}:

$$\xi_{1i} = A_{1i}/k_i. \tag{9}$$

The target (reference) set of indicators was transferred to the series $K = [k_1, k_2, \cdots, k_n]$. Then, using the set of indices K of the reference sequence (determined by the achievable goal) and the matrix A of the compared sequence, the gray ratio coefficient of the j solution for the i group of indicators was obtained by the formula:

$$\xi_{ij} = \frac{\min\limits_{\substack{1\le i\le m\\1\le j\le n}} |k_j - A_{ij}| + \rho \max\limits_{\substack{1\le i\le m\\1\le j\le n}} |k_j - A_{ij}|}{|k_j - A_{ij}| + \rho \max\limits_{\substack{1\le i\le m\\1\le j\le n}} |k_j - A_{ij}|}, \quad (10)$$

$$E = \begin{bmatrix} \xi_{11} & \xi_{12} & \cdots & \xi_{1n} \\ \xi_{21} & \xi_{22} & \cdots & \xi_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \xi_{m1} & \xi_{m2} & \cdots & \xi_{mn} \end{bmatrix}. \quad (11)$$

Step 7. In block 4 of module 4, the achievement index of basic indicators relative to target (reference) indicators of transportation technologies was calculated for each alternative solution for choosing a transportation technology using the formula:

$$R = E \times W = \begin{bmatrix} \xi 1_{11} & \xi 1_{12} & \cdots & \xi 1_{1n} \\ \xi 1_{21} & \xi 1_{22} & \cdots & \xi 1_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \xi 1_{m1} & \xi 1_{m2} & \cdots & \xi 1_{mn} \end{bmatrix} \times \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wl \end{bmatrix} = \begin{bmatrix} r1 \\ r2 \\ \vdots \\ rm \end{bmatrix}. \quad (12)$$

Based on the obtained results of the gray relation matrix (R) an analysis and ranking of transport technologies was carried out. This allowed us to determine the best technology for grain transportation.

Step 8. The results of ranking the set of alternative solutions according to the target (reference) indicators were transferred to module 2 and visualised through module 3 (Fig. 6).

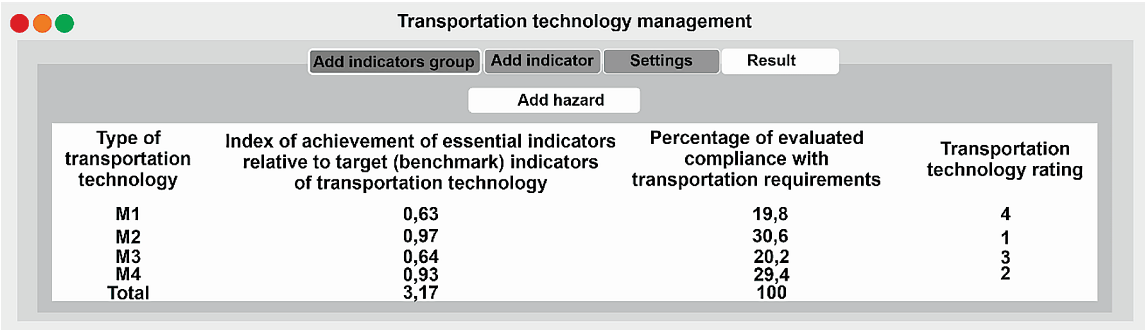


Figure 6. Window with the result of ranking basic indicators by priority indicator

Source: developed by the authors

To select a transport technology for cargo transportation, 5 experts with different experience in organisations transporting agricultural products were selected. The requirements for them are given in Table 1.

When working with the experts, the ethical standards specified in the Guidance note of the European Commission on ethics and data protection (2021) were observed.

Table 1. Requirements for experts involved in the determination

Information	Quantity
Number of experts	Not less than 5
Work experience in positions	from 10 to 14 years
Experts education	higher in the specialty
Work experience	more than 10 years
Auditor's certificate in quality and safety management systems of companies	Yes
Advanced training in risk assessment according to requirements*	Yes

Source: developed by the authors

RESULTS AND DISCUSSION

An example of grain transportation by trucks using four different technologies was considered. Table 2 provides a brief description of the considered transport technologies for grain truck transportation, among which it is necessary to choose the one that will meet the design (target) indicators (Basnak *et al.*, 2020; Touratier-Muller & Jaussaud, 2021). The justification of the transport technology is based on the assumption that grain can be conditionally transported by different types of trucks.

Table 2. Brief description of possible alternative transport technologies (RFT) or grain truck transportation

No.	Transport technology of road freight transport (RFT)		Brief description of transport technology for grain transport
	Name	Designation	
1.	Tarped road train	M_1	Tilted freight road train M1 Freight road train consisting of: seat tractor + tarped semi-trailer. Grain is transported by container loading using "big bags". Loading of cargo into the body of the freight road train is carried out using a forklift.

Continued Table 2.

No.	Transport technology of road freight transport (RFT)		Brief description of transport technology for grain transport
	Name	Designation	
2.	Freight road train with a dump semi-trailer	M_2	Freight road train consisting of: seat tractor + dump semi-trailer with rear unloading. Grain is transported in bulk. Loading of cargo into the body of the freight road train is carried out using elevator equipment of self puring.
3.	Freight road train consisting of: dump truck + dump trailer	M_3	Freight road train consisting of: dump truck + dump trailer with side unloading. Grain is transported in bulk. Cargo is loaded into the body of the freight road train using elevator equipment, of self-pouring.
4.	Specialised container for transporting grain, which is transported by a freight road train consisting of: seat tractor + semi-trailer for transporting containers	M_4	Freight road train consisting of: seat tractor + semi-trailer for transporting containers. Grain is transported by container loading using a container. Cargo is loaded into the container using elevator equipment of self-pouring.

Source: developed by the authors

According to the above algorithm, in the first step, indicators groups names and the indicators of freight road transport technology (Table 3) with the corresponding designations were entered into module 1 of software complex. Then, in module 2, a window appeared in which the experts conducted a pairwise comparison of all previously entered indicators of grain transportation transport technology, based on their influence on each other. After processing the pairwise comparison matrix in module 2, the data were transferred to block 1 of module 4. A normalised fuzzy matrix of direct relationships was constructed in it. Each fuzzy matrix of direct relationships $\tilde{x}^k$ was calculated using fuzzy triangular numbers $\tilde{z}^k_{ij}$ from the matrix $\tilde{z}^k$ based on relations (2) and (4).

Table 3. Indicators catalog of transport technology for grain transportation by road transport

No.	Designation	Group of indicators	Indicator designation	Indicator (factor) name
1.	A_1	Transport factor	A_{11}	Transportation distance, km
			A_{12}	Transport work, tkm
			A_{13}	Transport productivity, t/km
			A_{14}	Cargo preservation during transportation, points (max – 10 points)
			A_{15}	Transport operations performing time, hours
2.	A_2	Operational factor	A_{21}	Cargo volume, tons (vehicle carrying capacity)
			A_{22}	Cargo transportation speed, km/h
			A_{23}	Diesel fuel consumption per 100 km, l/100 km
			A_{24}	Transport process energy intensity, l/km (route length).
			A_{25}	Time spent on transport operations
3.	A_3	Organisational factor	A_{31}	Qualified personnel conducting medical inspection
			A_{32}	Quick registration of accompanying transport documentation
			A_{33}	Efficient process of freight road transportation
			A_{34}	Qualified drivers participating in freight road transportation of grain
			A_{35}	Qualified personnel conducting medical inspection
4.	A_4	Social factor	A_{41}	Driver satisfaction with working conditions at the transport enterprise
			A_{42}	Driver's ability to undergo advanced training (skills)
			A_{43}	Additional leave for the complexity of performing professional duties
			A_{44}	Additional financial payments for the complexity of performing professional duties
			A_{45}	Driver satisfaction with the salary received at the enterprise
5.	A_5	Economic factor	A_{51}	Freight transportation tariff, UAH / ton
			A_{52}	Total cost of all transport operations, UAH
			A_{53}	Cost of transportation, UAH/km
			A_{54}	Profitability, %
			A_{55}	Profit of a motor transport company from transport work, UAH
6.	A_6	Factors related to cargo	A_{61}	Cargo volume, tons
			A_{62}	Productivity of the loading and unloading mechanism, t/h
			A_{63}	Vehicle load capacity utilisation factor
			A_{64}	Adaptability of the vehicle to the transportation of the appropriate cargo type, points (max number – 10 points)
			A_{65}	Reliability (safety) of cargo transportation, points (max number – 10 points)

Source: developed by the authors

Then, based on the averaging of normalised matrices calculated from the pairwise comparison matrices, each expert determined the total normalised fuzzy matrix of direct relationships $\tilde{X}$ based on relations (6) and (7). This allowed calculating the total fuzzy matrix of relationships $\tilde{z}_k$. Then, the sum of rows and the sum of columns were calculated, which were transferred to block 2 of module 4. In block 2, the defuzzification process for the vectors of significance and relative position of indicators took place. The defuzzification transformation is given in Table 4, where the ratings of cause-and-effect relationships of transport technology indicators were formed. The names of the first 10 indicators were determined as basic. Their names were transferred to module 2 and visualised by module 3 (Table 5). Also, their names have been transferred to block 3 of module 4.

Table 4. Rating of transport technology indicators based on their mutual influence

Indicator	*D*	*R*	*D+R*	*D-R*	Rating
A_{11}	27.39	26.08	53.47	1.3065	5
A_{12}	27.97	27	54.98	-0.9712	26
A_{13}	27.81	26.96	54.76	-0.8504	23
A_{14}	27.09	25.89	52.98	1.2000	8
A_{15}	26.24	25.45	51.68	-0.7910	20
A_{21}	27.66	26.35	54.01	1.3186	4
A_{22}	27.42	25.99	53.42	1.4318	2
A_{23}	27.13	25.73	52.86	1.3904	3
A_{24}	27.53	26.25	53.78	1.2815	6
A_{25}	27.9	26.63	54.53	1.2753	7
A_{31}	25.95	25.25	51.19	-0.6995	18
A_{32}	26.8	25.89	52.69	-0.9100	24
A_{33}	25.82	25.12	50.94	-0.7034	19
A_{34}	27.47	26.66	54.13	-0.8140	21
A_{35}	26.24	25.62	51.85	-0.6219	16
A_{41}	26.72	25.72	52.44	0.9972	10
A_{42}	28.14	27.67	55.81	-0.4724	15
A_{43}	26.4	25.72	52.12	-0.6776	17
A_{44}	28.22	27.93	56.15	-0.2859	13
A_{45}	26.69	26.89	53.58	-0.2011	11
A_{51}	27.87	26.36	54.23	1.5047	1
A_{52}	27.82	28.04	55.86	-0.2158	12
A_{53}	26.99	27.36	54.35	-0.3678	14
A_{54}	27.19	28.12	55.31	-0.9215	25
A_{55}	27.21	28.33	55.53	-1.1202	27
A_{61}	27.39	28.22	55.61	-0.8263	22
A_{62}	27.32	30.73	58.05	-3.4047	28
A_{63}	27.33	32.38	59.71	-5.0575	29
A_{64}	27.29	35.82	63.11	-8.5354	30
A_{65}	26.95	25.81	52.76	1.1470	9

Note: *D* – is the sum of general fuzzy matrix rows; *R* is the sum of general fuzzy matrix columns; (*D*+*R*) – determines the influence of the indicator on the transportation process; (*D*–*R*) indicates the degree of mutual influence between the indicators

Source: developed by the authors

Table 5. Basic indicators

Rating	Indicators
1	A_{51} Rating for cargo transportation, UAH/ton
2	A_{22} Cargo transportation speed, km/h
3	A_{23} Diesel fuel consumption per 100 km, l/100 km

Continued Table 5 .

Rating	Indicators
4	A_{21} Cargo volume, tons
5	A_{11} Transportation distance, km
6	A_{24} Energy intensity of the transport process, l/km (route length)
7	A_{25} Time spent on transport operations
8	A_{14} Cargo safety during transportation, points (max – 10 points)
9	A_{65} Reliability (safety) of cargo transportation, points
10	A_{41} Driver satisfaction with working conditions at a motor transport enterprise

Source: developed by the authors

The analysis of the results obtained from the determination of transport technologies basic indicators showed that the greatest impact is characteristic of economic attractiveness indicators of freight road transportation of the corresponding type of cargo (rating for grain transportation, fuel consumption, energy intensity of the transport process), operational properties of the vehicle (speed and volume of cargo), and also, several indicators related to safety and the human factor (inspector reliability, satisfaction with working conditions) were highlighted. The determination of the basic indicators allows to proceed to Step 5. The experts entered the values of the basic indicators for each proposed grain transportation technology program (Table 6). Target (reference) basic indicators values related to the motor transport enterprise and will allow to achieve the stated goals were also determined and entered into module 1 (Table 7). Next, data on weighting factors from the specified baseline indicators were generated and entered, which allow obtaining vehicle gray retional coefficients with the specified actual and target (reference) values of baseline indicators for each of the specified technologies.

Table 6. Results of determining indicators by different transport technologies for grain transportation

J-indicator designation	Name of indicators for transport technology	Value of indicators for each transportation technology			
		M_1	M_2	M_3	M_4
	Indicator designation	A_{1i}	A_{2i}	A_{3i}	A_{4i}
1	Cargo transportation rating, UAH / t	2032	1017	1626	1220
2	Cargo transportation speed, km/h	70	90	60	90
3	Diesel fuel consumption per 100 km, l/100 km	40	35	45	35
4	Cargo volume, tons	20	20	20	20
5	Transportation distance, km	455	455	455	455
6	Energy intensity of the transport process, l/km (route length).	0.0879	0.0769	0.0989	0.0769
7	Time spent on loading and unloading operations, hours	0.9	0.5	0.95	0.67
8	Cargo safety during transportation, points (max – 10 points)	10	7	6	10
8	Carrier reliability, points	9	7	7	9
10	Driver satisfaction with working conditions at a motor transport enterprise, points	9	8	9	8

Source: developed by the authors

Table 7. Target (reference) transport process indicators, which are formed from the set goals

Cargo transportation rating, UAH / t k_1	Cargo transportation speed, km/h k_2	Diesel fuel consumption per 100 km l/100 km, k_3	Cargo volume, tons, k_4	Transportation distance, km k_5	Energy intensity of the transport process, l/km (route length), k_6	Time spent on conducting NRR, h, k_7	Cargo preservation during transportation, points (max – 10 points), k_8	Carrier reliability, points k_9	Driver satisfaction with working conditions at motor transport enterprise, points k_{10}
1017	90	35	20	455	0.0769	0.5	10	9	9

Source: developed by the authors

The determination of weight coefficients was carried out by experts, using a scale from 0 to 1, where 0 indicates no effect on cargo delivery time and 1 indicates significant effect. The results of calculating weight coefficients for the above transport technologies are given in Table 8.

Table 8. Results of calculating weight coefficients by basic indicators

Type of transport technology	Cargo transportation rating, UAH / t ξ_{i1}	Cargo transportation speed, km/h ξ_{i2}	Diesel fuel consumption per 100 km l/100 km, ξ_{i3}	Cargo volume, tons, ξ_{i4}	Transportation distance, km ξ_{i5}	Energy intensity of the transport process, l/km (route length), ξ_{i6}	Time spent on conducting NRR, h, ξ_{i7}	Cargo preservation during transportation, points (max – 10 points), ξ_{i8}	Carrier reliability, points ξ_{i9}	Driver satisfaction with working conditions at motor transport enterprise, points ξ_{i10}
M1	0.002	0.778	0.857	1.000	1.000	0.857	0.200	1.000	1.000	1.000
M2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.700	0.778	0.889
M3	0.401	0.667	0.714	1.000	1.000	0.714	0.100	0.600	0.778	1.000
M4	0.800	1.000	1.000	1.000	1.000	1.000	0.660	1.000	1.000	0.889
Average value W	0.250	0.200	0.200	0.050	0.050	0.050	0.050	0.050	0.050	0.050

Source: developed by the authors

At Step 6 in block 3 of module 4, a general matrix is formed for calculating the gray ratio coefficients of the basic indicators by transport technologies for grain transportation according to formulas (8)-(11).

$$K = \begin{bmatrix} 1017 & 90 & 35 & 20 & 455 & 0.0769 & 0.5 & 10 & 9 & 9 \\ 2032 & 70 & 40 & 20 & 455 & 0.0879 & 0.9 & 10 & 9 & 9 \\ 1017 & 90 & 35 & 20 & 455 & 0.0769 & 0.5 & 7 & 7 & 8 \\ 1626 & 60 & 45 & 20 & 455 & 0.0989 & 0.95 & 6 & 7 & 9 \\ 1220 & 90 & 35 & 20 & 455 & 0.0769 & 0.67 & 10 & 9 & 8 \end{bmatrix}.$$

Further, in block 4 of module 4, the calculation was carried out using formula 11 of achievement index of basic indicators relative to target (reference) indicators of transportation technologies.

$$R = E \times W = \begin{bmatrix} 0.002 & 0.778 & 0.857 & 1.000 & 1.000 & 0.857 & 0.778 & 1.000 & 1.000 & 1.000 \\ 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.889 & 0.700 & 0.778 & 0.889 \\ 0.401 & 0.667 & 0.714 & 1.000 & 1.000 & 0.714 & 0.778 & 0.6 & 0.778 & 1.000 \\ 0.800 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.889 \end{bmatrix} \times \begin{bmatrix} 0.25 \\ 0.2 \\ 0.2 \\ 0.05 \\ 0.05 \\ 0.05 \\ 0.05 \\ 0.05 \\ 0.05 \\ 0.05 \\ 0.05 \end{bmatrix} = \begin{bmatrix} 0.63 \\ 0.97 \\ 0.64 \\ 0.93 \end{bmatrix}.$$

Based on the results of the calculations, the above transport technologies for grain transportation were ranked (Table 9).

According to the calculations results, it can be concluded that the best option for the given target indicators will be the transport technology for grain transportation – M_2: a freight road train with a dump semi-trailer (the value of the calculated index value is 0.97). The second place is taken by the transport technology for grain transportation – M4: a specialised container for transporting grain, which is transported by a freight road train consisting of: seat tractor unit + a semi-trailer for transporting containers (the value of the calculated index value is 0.93). The third place is taken by the transport technology for grain transportation – M3: a freight road train consisting of: a dump truck + a dump trailer (the value of the calculated index value is 0.64). The fourth place is taken by the transport technology for grain transportation – M1: a tarped freight road train (container transportation of grain in "big-bag" bags) (the value of the calculated index value is 0.63). Figure 7 shows a ranking diagram of the transport technologies for grain transportation that were considered.

Table 9. Results of determining the best grain transportation technology

Type of transport technology	Achievement index of basic indicators relative to target (reference) indicators of transportation technologies	Percentage of the estimated level of compliance with transportation requirements, %	Rating of transport technologies
M1	0.63	19.8	4
M2	0.97	30.6	1
M3	0.64	20.2	3
M4	0.93	29.4	2
Total:	3.17	100.0	

Source: developed by the authors

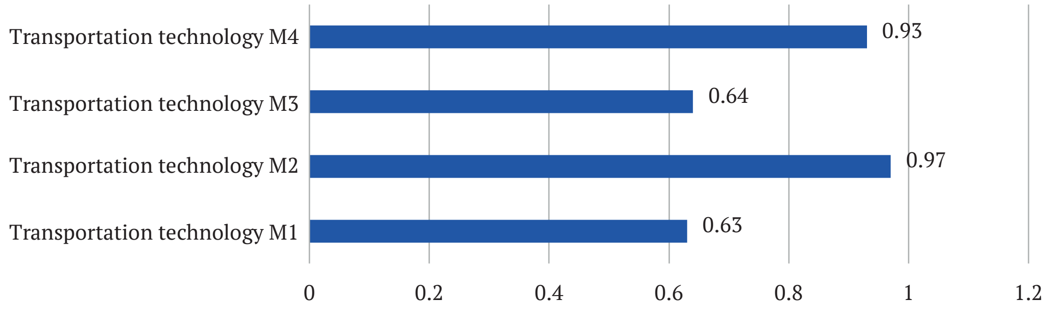


Figure 7. Rating diagram of grain trucking transport technologies

Source: developed by the authors

A software package has been developed for making management decisions regarding the selection of the optimal cargo transportation technology among alternative options. The package consists of four modules: information input, memory, data calculation and output, as well as four blocks: formation of a total matrix of indicator relationships, determination of basic indicators, formation of a gray analysis matrix and selection of the best solution.

The difference of this approach from known methods, in particular the study by K. Čižiūnienė (2022), which was aimed at solving general issues of organising cargo transportation, lies in the combination of two methods: fuzzy DEMATEL and GRA. Such combined use allows to determine the basic indicators characterising the transport technology and, on their basis, selecting the optimal option. The proposed approach ensures the adoption of effective management decisions by comparing the compliance of basic indicators of transport technology with target indicators set in the project of freight road transportation. This corresponds to the priorities of transport industry development and contributes to the introduction of modern information technologies for organising transportation process (Shatilo *et al.,* 2023; Muzylyov *et al.*, 2024; Khomenko *et al.,* 2024).

Analysis of the obtained results shows that the proposed software package allows optimising the process of cargo transportation, reducing vehicle downtime, transportation costs and taking into account the shortage of qualified drivers. Similar aspects were considered in the work of M. Kramchaninova *et al.* (2021), where the main emphasis is made on assessing the problems and prospects for the development of railway freight transportation in Ukraine. The authors note that the efficiency of transport logistics largely depends on innovative approaches to transportation management, which confirms the feasibility of using the developed package to select the optimal transportation technology in existing conditions. However, unlike the results of the study by M. Kramchaninova *et al.* (2021), the proposed model focuses on assessing alternative transportation options taking into account the individual requirements of the customer, which provides greater flexibility in management decisions. An important aspect of the study is the possibility of determining an integral indicator of transport technology efficiency, based on multi-criteria analysis. Similar approaches were studied in the work of H.I. Nesterenko *et al.* (2023), which analysed the integration of the transport system of Ukraine into the European transport network. The authors note that for successful entry into the European transport space, it is necessary to implement digital technologies for assessing the efficiency of routes and transportation, which confirms the relevance of using the proposed software package. At the same time, if in the study of H.I. Nesterenko *et al.* (2023) the main emphasis is made on macroeconomic aspects of transport system integration, the results obtained are focused on microeconomic level, offering tools for improving the efficiency of individual carriers. The use of gray relational analysis to determine a complex indicator of transport solutions efficiency, which is a key element of the proposed model, deserves special attention. The study of D. Shmatko *et al.* (2021) also considers the possibilities of optimising rolling stock selection and inventory management, using mathematical modelling to improve logistics decisions. The results obtained are consistent with the conclusions of D. Shmatko *et al.* (2021), as they confirm the effectiveness of mathematical approaches in logistics planning. At the same time, the proposed approach is more flexible, as it allows evaluating different transportation options according to a number of independent criteria, taking into account the specific features of the transport process.

The analysis of the obtained results shows that the proposed software package can be an effective tool not only for choosing the optimal transport technology, but also for predicting fuel consumption during road transportation. Optimisation of fuel consumption is an important task for reducing the cost of logistics processes, which is consistent with the conclusions of T. Škrinjarić & B. Šego (2019). Using fuzzy Dematel to determine the relationships between various factors allows to improve the accuracy of route assessment, which is also noted in the work of T. Škrinjarić (2020).

Unlike traditional methods of vehicle fleet selection, such as queuing theory (Zakeri *et al.,* 2022), object-oriented programming (Fausto *et al.,* 2020) or regression analysis (Onopriienko, 2021), the developed approach offers a multi-criteria analysis that takes into account complex factors and allows finding the most effective solutions according to specific conditions. Additionally, the results correlate with the findings of M. Scorrano *et al.* (2020) and N. Touratier-Muller & J. Jaussaud (2021) as to the impact of transport parameters on overall costs and transportation environmental sustainability.

The obtained results confirm the effectiveness of the proposed software package in selecting the optimal transport technology, which is based on the analysis of ten key indicators, including the speed of cargo delivery and fuel consumption. Similar criteria for assessing the competitiveness of freight transportation were considered in the study by N. Khanna *et al.* (2021), which analysed strategic approaches to the decarbonisation of freight transport. The conclusions obtained in this study are consistent with the results of M. Hu *et al.* (2024), which identified the most effective technology for transporting large-sised cargo. However, in the above works, the main attention was paid to fuel characteristics as the main factor in choosing a transport technology, while in the proposed model this aspect can be taken into account by changing the weight coefficients of the relevant indicators, which allows for more flexible adaptation of the approach to specific conditions.

An important aspect is consumer orientation, since target indicators can be adjusted according to the needs of the customer. A similar approach was considered in the work of C. Cao *et al.* (2021), where an algorithm for selecting a transport technology with the possibility of adjusting weighting coefficients using additional assessment methods was proposed. This is consistent with the concept of fleible logistics process management implemented in this study.

Not only economic feasibility has a significant impact on transport technology choice, but also environmental and social aspects, which are key elements of sustainable regional development (Yan *et al.,* 2024; Pu *et al.,* 2024). Reducing the cost of transportation, environmental load and social losses are important factors that need to be integrated into transport strategies. The obtained results indicate the possibility of further improving the software package by adding risk management modules and expanding the functionality to predict potential threats associated with disruptions to logistics processes.

Thus, the developed software package provides broader opportunities for optimising transport processes, allowing to take into account not only transportation efficiency, but also economic and environmental aspects, which makes it competitive in comparison with other logistics solutions assessing methods. Thus, the conducted study demonstrates the practical effectiveness of the developed methodology in transport technologies selection, confirming its relevance to modern approaches in the field of logistics and sustainable development. The proposed approach provides flexibility in decision-making, allowing to adapt the choice of transport technology to the specific requirements of customers and external conditions. The obtained results indicate using potential of the developed software package to increase the logistics processes efficiency, including reducing costs, optimising resources and increasing the transportation environmental sustainability.

CONCLUSIONS

A software package is proposed for making a management decision to choose the best cargo transportation technology from a set of alternatives, which consists of four modules (information input, memory, calculation and data output) and four blocks located in the calculation module (block 1 for forming a total matrix of indicator relationships, block 2 for determining basic indicators and a block for forming a gray analysis matrix and block 4 for choosing the best solution from a set of alternative solutions) based on the methods: fuzzy Dematel and GRA, which are used to determine basic indicators and based on them, choose the transport technology for grain transportation itself. The software complex implements a seven-Step algorithm: entering groups of indicators, analysing them pairwise, determining basic indicators based on the total matrix of relationships, entering values of basic and reference indicators of grain transportation technologies and weighting factors, constructing gray analysis matrices, determining the index of basic indicators achievement relative to target ones.

As a result, the best transport technology for transporting grain was selected to meet the target (reference) indicators of the motor transport enterprise according to the following indicators: cargo transportation raiting; cargo transportation speed; diesel fuel consumption per 100 km; cargo volume; transportation distance; energy intensity of the transport process; time spent on loading and unloading operations; cargo safety during transportation; carrier reliability; driver satisfaction with working conditions. According to the calculations results, the transport technology for transporting grain from a freight truck with a dump semi-trailer best meets the target indicators. The dependence of the basic indicators of the transport technology for transporting cargo and the target indicators of the motor transport enterprise was established, which allows improving the algorithm for making a management decision to choose an effective transportation technology from a set of alternative ones.

Further research will be aimed at developing the possibilities of integrating the software complex with existing transport logistics systems used in logistics terminals. This will allow for automated data exchange, increase the efficiency of route planning, and optimise grain loading and unloading processes.

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None.

REFERENCES

[1] Basnak, P., Giesen, R., & Muñoz, J.C. (2020). Technology choices in public transport planning: A classification framework. *Research in Transportation Economics*, 83, article number 100901. doi: 10.1016/j.retrec.2020.100901.

[2] Bazaluk, O., Pavlychenko, A., Yavorska, O., Nesterova, O., Cheberiachko, S., Deryugin, O., & Lozynskyi, V. (2024). Improving the risk management process in quality management systems of higher education. *Scientific Reports*, 14, article number 3977. doi: 10.1038/s41598-024-53455-9.

[3] Cao, C., Su, Y., & Zheng, Q. (2021). Impact of policy incentives on technological innovation and diffusion within the new-energy vehicle industry: An ecosystem approach. *Technology Analysis & Strategic Management*. doi: 10.1080/09537325.2024.2306648.

[4] Čižiūnienė, K. (2022). Information systems in freight transportation. In *Development of smart context-aware services for cargo transportation*. *International series in operations research & management science* (vol. 330, pp. 285-299). Cham: Springer. doi: 10.1007/978-3-031-07199-7_13.

[5] Dulebenets, M.A. (2021). An adaptive polyploid memetic algorithm for scheduling trucks at a cross-docking terminal. *Information Sciences*, 565, 390-421. doi: 10.1016/j.ins.2021.02.039.

[6] Essghaier, F., Allaoui, H., & Goncalves, G. (2021). Truck to door assignment in a shared cross-dock under uncertainty. *Expert Systems with Applications*, 182, article number 114889. doi: 10.1016/j.eswa.2021.114889.

[7] European Commission. (n.d.). Identifying serious and complex ethics issues in EU-funded research. *Horizon Europe guidelines*. Retrieved from https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/guidelines-on-serious-and-complex-cases_he_en.pdf.

[8] Fausto, F., Reyna-Orta, A., Cuevas, E., Andrade, Á.G., & Perez-Cisneros, M. (2020). From ants to whales: Metaheuristics for all tastes. *Artificial Intelligence Review*, 53, 753-810. doi: 10.1007/s10462-018-09676-2.

[9] Feng, M., & Cheng, Y. (2021). Solving truck-cargo matching for drop-and-pull transport with genetic algorithm based on demand-capacity fitness. *Alexandria Engineering Journal*, 60(1), 61-72. doi: 10.1016/j.aej.2020.05.015.

[10] Guidance note of the European Commission on ethics and data protection. (2021). Retrieved from http://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/ethics-and-data-protection_he_en.pdf.

[11] Gustavo, C.B., Seimetz Chagas, R.D., Silva, V.A., Peres Vianna, I.G., Longhi, R.P., Ribas, P.C., & Ferreira Filho, V.J.M. (2021). A solution framework for the integrated problem of cargo assignment, fleet sizing, and delivery planning in offshore logistics. *Computers & Industrial Engineering*, 161, article number 107653. doi: 10.1016/j.cie.2021.107653.

[12] Hu, M., Wu, X., Yuan, Y., & Xu, C. (2024). Competitive analysis of heavy trucks with five types of fuels under different scenarios – a case study of China. *Energies*, 17(16), article number 3936. doi: 10.3390/en17163936.

[13] Hu, X., Guo, J., & Zhang, Y. (2019). Optimal strategies for the yard truck scheduling in container terminal with the consideration of container clusters. *Computers & Industrial Engineering*, 137, 106083. doi: 10.1016/j.cie.2019.106083

[14] Khanna, N., Lu, H., Fridley, D., & Zhou, N. (2021). Near and long-term perspectives on strategies to decarbonize China's heavy-duty trucks through 2050. *Scientific Reports*, 11(1), article number 20414. doi: 10.1038/s41598-021-99715-w.

[15] Khomenko, Yu., Matsiuk, V., Okorokov, A., & Gorobchenko, O. (2024). Development of a simulation model of grain delivery in global supply chains. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 20(5), 21-35. doi: 10.31548/dopovidi/5.2024.21.

[16] Kim, H., & Kim, H. (2020). Integrated model for morphological analysis and named entity recognition based on label attention networks in Korean. *Applied Sciences*, 10(11), article number 3740. doi: 10.3390/app10113740.

[17] Kramchaninova, M., Kasatkina, M., & Masalova, T. (2021). Current state, issues and evolution horizons of railway cargo services in Ukraine. *Problems and Prospects of Economics and Management*, 3(15), 63-70.

[18] Lu, N., Liu, S., Du, J., Fang, Z., Dong, W., Tao, L., & Yang, Y. (2023). Grey relational analysis model with cross-sequences and its application in evaluating air quality index. *Expert Systems with Applications*, 233, article number 120910. doi: 10.1016/j.eswa.2023.120910.

[19] Lyu, Z., Pons, D., Chen, J., & Zhang, Y. (2022). Developing a stochastic two-tier architecture for modelling last-mile delivery and implementing in discrete-event simulation. *Systems*, 10(6), article number 214. doi: 10.3390/systems10060214.

[20] Muzylyov, D., Medvediev, I., & Pavlenko, O. (2024). Risk factor assessment in agricultural supply chain by fuzzy logic. *IOP Conference Series: Earth and Environmental Science*, 1376, article number 012038. doi: 10.1088/1755-1315/1376/1/012038.

[21] Nesterenko, H.I., Muzykin, M.I., Strelko, O.H., Bibik, S.I., & Aleksieieva, A.O. (2023). Analysis of possibilities for integrating the transport system of Ukraine into the European transport network. *Systems and Technologies*, 66(2), 97-107. doi: 10.32782/2521-6643-2023.2-66.11.

[22] Onopriienko, D. (2021). Management of support of sustainable development of the enterprise. *Economics Finances Law*, 6(1), 33-36. doi: 10.37634/efp.2021.6(1).7.

[23] Pečený, L., Meško, P., Kampf, R., & Gašparík, J. (2020). Optimisation in transport and logistic processes. *Transportation Research Procedia*, 44, 15-22. doi: 10.1016/j.trpro.2020.02.003

[24] Pu, Y.-H., Dejaegere, Q., Svensson, M., & Verhelst, S. (2024). Renewable methanol as a fuel for heavy-duty engines: A review of technologies enabling single-fuel solutions. *Energies*, 17(7), article number 1719. doi: 10.3390/en17071719.

[25] Quan, J., Bo, Z., & Dai, L. (2018). Green supplier selection for process industries using weighted grey incidence decision model. *Complexity*, 2018, article number 4631670. doi: 10.1155/2018/4631670.

[26] Scorrano, M., Danielis, R., & Giansoldati, M. (2020). Dissecting the total cost of ownership of fully electric cars in Italy: The impact of annual distance travelled, home charging and urban driving. *Research in Transportation Economics*, 80, article number 100799. doi: 10.1016/j.retrec.2019.100799.

[27] Sénquiz-Díaz, C. (2021). The effect of transport and logistics on trade facilitation and trade: A PLS-SEM approach. *Economics*, 9(2), 11-24. doi: 10.2478/eoik-2021-0021.

[28] Shatilo, O., Derevianko, O., Boichenko, K., Shevchuk, N., & Magdaliuk, O. (2023). Strategic development of motor transport enterprises' innovative processes in Ukraine. *Journal of Eastern European and Central Asian Research*, 10(7), 940-955. doi: 10.15549/jeecar.v10i7.1326.

[29] Shmatko, D., Averyanov, V., Korobochka, A., & Sasov, A. (2021). Comprehensive solution to the problem of rolling stock choice and inventory management. *Mathematical Modeling*, 1(44), 76-82. doi: 10.31319/2519-8106.1(44)2021.235975.

[30] Skovron, I., Dorosh, A., Demchenko, Y., Bolvanovska, T., & Malashkin, V. (2020). The efficiency improvement of groupage cargo delivery by road transport. *Transport Systems and Transportation Technologies*, 20, 36-44. doi: 10.15802/tstt2020/217400.

[31] Škrinjarić, T. (2020). Dynamic portfolio optimization based on grey relational analysis approach. *Expert Systems with Applications*, 147, article number 113207. doi: 10.1016/j.eswa.2020.113207

[32] Škrinjarić, T., & Šego, B. (2019). Using grey incidence analysis approach in portfolio selection. *International Journal of Financial Studies*, 7(1), article number 1. doi: 10.3390/ijfs7010001.

[33] Touratier-Muller, N., & Jaussaud, J. (2021). Development of road freight transport indicators focused on sustainability to assist shippers: An analysis conducted in France through the FRET 21 Programme. *Sustainability*, 13(17), article number 9641. doi: 10.3390/su13179641.

[34] Tsopa, V., Cheberiachko, S., Yavorska, O., Deryugin, O., Litvinova, Y., & Lantukh, D. (2024a). Justification of the choice of measures to reduce logistics risks in the transportation of cargo. *Proceedings of 28th international scientific conference "Transport means 2024"* (pp. 547-552). Kaunas: Kaunas University of Technology. doi: 10.5755/e01.2351-7034.2024.

[35] Tsopa, V., Nehrii, T., Cheberiachko, S., Litvinova, Ya., Deryugin, O., & Horoshko, N. (2024b). Improving the risk assessment process of road accidents involving trucks. *Transactions on Transport Sciences*, 15(3), 4-11. doi: 10.5507/tots.2024.011.

[36] Vickerman, R. (2024). The transport problem: The need for consistent policies on pricing and investment. *Transport Policy*, 149, 49-58. doi: 10.1016/j.tranpol.2024.02.009.

[37] Wang, Q., Zhang, R., Lv, S., & Wang, Y. (2021). Open-pit mine truck fuel consumption pattern and application based on multi-dimensional features and XGBoost. *Sustainable Energy Technologies and Assessments*, 43, article number 100977. doi: 10.1016/j.seta.2020.100977.

[38] Yan, X., Zheng, W., Wei, Y., & Yan, Z. (2024). Current status and economic analysis of green hydrogen energy industry chain. *Processes*, 12(2), article number 315. doi: 10.3390/pr12020315.

[39] Zakeri, S., Chatterjee, P., Cheikhrouhou, N., & Konstantas, D. (2022). Ranking based on optimal points and win-loss-draw multi-criteria decision-making with application to supplier evaluation problem. *Expert Systems with Applications*, 191, article number 116258. doi: 10.1016/j.eswa.2021.116258.

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Програмний комплекс з вибору транспортної технології перевезення зерна вантажним автомобільним транспортом

Анотація. Метою роботи було розробити програмний комплекс для прийняття управлінського рішення для вибору транспортної технології перевезення зерна автомобільним транспортом із множини альтернатив. Для досягнення поставленої мети використано метод морфологічного аналізу, який заснований на підборі можливих рішень для окремих частин завдання. Запропоновано програмний комплекс для прийняття управлінського рішення із множини альтернатив, який складався з чотирьох модулів та чотирьох блоків. В його основі знаходились два метода: fuzzy Decision Making Trial and Evaluation Laboratory (далі – fuzzy Dematel) і сірого реляційного аналізу (далі – GRA), які використовувалися для визначення базових показників та на їх основі вибір самої транспортної технології перевезення зерна. В програмному комплексі реалізовано алгоритм з восьми кроків: вводу груп показників, їх попарному аналізу, визначення базових показників на основі сумарної матриці зав'язків, вводу значень базових та еталонних показників транспортних технологій перевезення зерна та вагових коефіцієнтів, побудови матриць сірого аналізу, визначення індексу досягнення базових показників відносно цільових. В результаті обрано кращу транспортну технологію вантажних автомобільних перевезень зерна до цільових (еталонних) показників автотранспортного підприємства за наступними показниками: тариф на транспортування вантажу; швидкість транспортування вантажу; витрата дизельного палива на 100 км; обсяг вантажу; відстань транспортування; енергоємність транспортного процесу; час, який витрачений на проведення навантажувально-розвантажувальних робіт; збереження вантажу при транспортуванні; надійність перевізника; задоволеність водієм умовами праці. За результатами проведених розрахунків зазначено, що найкраще задовольняє цільовим показникам транспортна технологія перевезення зерна – вантажним автопотягом з самоскидним напівпричепом. Встановлено залежності базових показників транспортної технології перевезення вантажу і цільовими автотранспортного підприємства, що дозволяє вдосконалити алгоритм прийняття управлінського рішення з вибору ефективної транспортної технології перевезення із сукупності альтернативних. Запропонований процес вибору кращого рішення із сукупності альтернативних може використовуватися в організаціях, які здійснюють вибір кращої технології вантажних автомобільних перевезень сипких вантажів – зерна

Ключові слова: транспортна технологія, метод fuzzy Dematel, метод сірого реляційного аналізу, цільові показники, еталоні показники. управлінські рішення