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MINIMIZATION OF TRANSPORTATION RISKS IN LOGISTICS BY CHOOSING A CARGO DELIVERY ROUTE WITH THE MINIMAL PROJECTED NUMBER OF ROAD ACCIDENTS

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Запропоновано науково-методичний підхід вибору маршруту з мінімальною прогнозованою кількістю ДТП серед декількох можливих маршрутів, які пов'язують пункти відправлення та призначення, який ґрунтується на трьох кроках: на першому кроці будується орієнтований граф, який включає пункти відправлення, доставки та проміжні пункти, які поєднані ребрами з вказаними відстанями між пунктами; на другому кроці для кожного ребра розраховується прогнозована кількість ДТП, як добуток відстані, яку має проїхати вантажівка дорогою певного регіону на показник ДТП, який розраховано для даного регіону; на третьому кроці визначається маршрут з мінімальною прогнозованою кількістю ДТП.

Особа, яка приймає рішення, може керуватися двома стратегіями: перша стратегія – вибір найкоротшого шляху доставки – при цьому мінімізуються витрати на доставку; друга стратегія – вибір маршруту з мінімальною прогнозованою кількістю ДТП – при цьому мінімізуються показники аварійності. В дослідженні сформульовано задачу багатофакторної оптимізації за відстанню та за прогнозованою кількістю ДТП й запропоновано її Парето-оптимальний розв'язок.

Запропонований метод може бути корисним в діяльності транспортних та логістичних підприємств при обґрунтуванні найбільш безпечних маршрутів з доставки вантажів з урахування важливості мінімізації витрат на доставку.

В програмне забезпечення інтерактивних карт та навігаційних систем входять широко відомі методи визначення найкоротшої відстані, маршруту з найменшим часом, або маршруту з уникненням «заторів». Пропонується розглянути питання щодо додавання алгоритму, який розроблено за запропонованим методом вибору маршруту з мінімальною прогнозованою кількістю ДТП, як одної з альтернатив вибору оптимального маршруту

Ключові слова: прогнозована кількість ДТП, вибір маршруту, доставка вантажів, Парето-оптимальність маршруту, регіональна кластеризація

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1. Introduction

Logistics activities of enterprises imply, among others, the transportation of finished products or components for its fabrication from a supplier to a manufacturer. When transporting a certain cargo, there may occur events that could lead to probable losses and are identified as a risk. Among the many circumstances identified as a risk at cargo transportation, traffic accidents are particularly noted.

After identifying the risk as an event, one should evaluate it. Risk assessment may typically be qualitative or quantitative. Qualitative estimates contain a description of the probability of occurrence of the event based on the scale: high, medium, or low. Or similar characteristic of a loss. Quantitative risk assessments contain calculated probability of occurrence and/or calculated amount of possible losses from its occurrence. For the case of estimating a probability of a road-transport event, one requires statistical reports on traffic in a certain region and the number of road accidents. In the absence of traffic data, it is not possible to estimate the probability of a road accident based on statistical reports. It is also quite difficult to estimate possible losses from a road accident. Therefore, it is appropriate to assess the transportation risks associated with a road accident based on the projected number of road accidents. In this case, it is possible to prevent a road accident by choosing a safer route, which is characterized by the smaller projected number of road accidents. As for the risk assessment of a road accident, then the projected number of road accidents can be used to obtain a qualitative comparison of several routes. Along routes where the projected number of road accidents is less, the probability of a road accident is respectively less. That is, this route has a less risk of a road accident.

Safety of roads in a country is one of the main factors characterizing its development, quality of life of people, and its global competitiveness. Modern freight forwarding and logistics enterprises compete not only in terms of the cost of services rendered, but also in terms of their reliability. That is, the issue of safe delivery of goods is not secondary; in the case of increasing the value of goods, it is the main factor to choose a carrier.

An automobile carrier enterprise typically has several alternatives for choosing the route of goods delivery from a supplier to a customer. Modern approaches to selecting a route among several alternatives are based on choosing a route with the shortest distance that does not warrant the safe delivery of goods. The shortest route may turn to be the most emergency-prone. In this case, an automobile carrier enterprise would save fuel costs, but would jeopardize the lives of people and increase the likelihood of damaging the cargo transported.

Safety of road transportation depends on many factors: road network quality, drivers' compliance with traffic rules, overall traffic, driver's fatigue, serviceability of vehicles, etc. The impact of these factors on traffic safety along a particular route can be assessed based on statistical information about traffic accidents. This information could be used to compile maps that highlight certain territorial units with a high level of road accidents. Such maps may be useful to avoid accidents.

Statistical information about the length of roads in a particular region and the number of traffic accidents makes it possible, based on a certain algorithm, to calculate road accident indicators per km in each of the country's regions, or make use of the country's division into territorial units to form clusters with the high and low road accident indicator. Given the availability of such data, an automobile carrier enterprise could build a route with the minimal projected number of road accidents, which could be somewhat longer by distance, but safer to save a cargo.

The relevance of our research is due to the need to identify the safest routes for cargo delivery by road, as well as to formalize the process of determining the safest routes of cargo delivery in order to automate the above process. Maps with marked risk areas of road accidents might in the future prove to be no less useful than modern navigation systems that help find the shortest path. The software that would be based on information about areas with high and low risk of road accidents should help the driver to choose the safest route.

2. Literature review and problem statement

Logistics, according to definition in [1], is the control over a material flow in order to execute production functions. A material flow is the integration of three logistical functions (functional areas): supply, production support, physical distribution. The transportation of a certain cargo (raw materials, components, or finished products) provides for the supply and physical distribution functions.

The risk management system at an enterprise in a generalized form includes three components [2]: risk identification (detection and recognition); risk assessment (assessment of the probability of danger, forecasting the probable level of losses in terms of cost or natural dimensions), and optimization (development of organizational and technical measures for the prevention of risk in order to regulate and minimize losses). Since the cited work was conceptual in character, transportation risks were not considered.

We first shall consider studies that addressed the identification of transportation risks in logistics. Paper [3] considers logistical risks to be an unexpected, undesirable event, or the cause of this event, which predetermines the lack of a required product or raw material at the time it is needed, the desired quality, at the right place, at the planned price. In the management of a complex logistic system road accidents are considered as one of the components of a logistic risks system. However, the authors focus on the stages of risk mitigation and their prevention, therefore, forecasting road accidents during cargo delivery remained unaddressed. Transportation risks are part of logistical risks and, according to authors of work [4], they arise as a result of inability to ensure the necessary quality of cargo transportation (goods or raw materials) and carry out operations that are not included in the transportation process, but associated with it. The work is conceptual, so the authors do not specify the types of transportation risks and approaches to define them, which, in our opinion, lowers its significance for practical use in the management of logistic risks. Author of paper [5] includes the following in transportation risks: the risk of unnecessary costs when transporting products, caused by the incorrect determination of the most economical path, the risk of delay in supply and the risk of damage to raw materials or materials due to external factors. Under external factors, it is proposed to consider: accidents, repair works, delay of vehicles at customs, etc. Although the paper addresses the issue of determining a freight route, the author does not focus on any quantitative risk assessment of unnecessary expenses from accidents and other external factors.

To assess and prevent transportation risks in logistics, enterprises set up transportation logistics management systems. Most scientific studies propose using specialized software in a transportation logistics management system. To optimize deliveries among manufacturers depending on consumer needs, paper [6] suggests the application of specialized software (Design for Six Sigma), which minimizes the probability of errors related to delayed delivery in warehouse and transport logistics. The authors did not use statistical information about road accidents to determine the safe route, which in our opinion, lowers importance of the proposed software. Study [7] designed a high-quality GPS monitoring algorithm based on the context of concept awareness proposed to be used with real-time intelligent transportation services to integrate changes in the state of integrity of the navigation system. The authors point out that a positioning system becomes an increasingly important requirement to intelligent transportation systems that are based on location, such as electronic toll fees, public transport and traffic control services. And, although predicting the number of possible road accidents along a route can be attributed to intelligent transport services, this issue was disregarded by the study's authors. The issue of trusting GTFS applications data for public transit was addressed in article [8], which proves difference between regular results of measurements of distance and time of travel and data from the program. The authors suggest a way to more accurate measurements of distances, time, and safety of movement. Even though the article deals with the safe component of public transit, the authors failed to consider the issue on choosing a route with the smallest projected number of road accidents. In order to better manage investment in logistics, authors of work [9] propose the structure of logistics management at the enterprise ValLog, based on the Val IT infrastructure. Transportation logistics control elements are included in the proposed structure. However, the authors focused on the issue of managing investment in logistics, so the task of predicting road accidents when choosing a specific route remained unaddressed.

Another field of scientific research into transportation logistics is to minimize accidents on roads by planning a safe infrastructure. The results from studying accidents along the bypass roads in Australia depending on various road parameters [10] showed that the increase in the number of entry lanes, the width of entry, entry radius, traffic volume, the width of the road circulation and speed limitation have positive effects on road safety. On the other hand, an increase in the number of exit lines, exit width, exit radius, central island diameters, and the presence of a fixed object on the central island have a negative impact on safety of routes. The cited study is important in terms of improving traffic safety when building road infrastructure, but issues related to the analysis of road accident statistics along roads of certain territorial units in order to reduce accidents were not considered. A "cargo design" concept was introduced in article [11]. The authors examine information about population density and employment for the four major cities: New York, Los Angeles, Paris, and Seoul, and construct a cargo landscape matrix. Evaluation of convergence and differences between population density and employment is the basis to obtain the landscape of cargo transportation. In our opinion, the consideration of statistical data on road accidents in the examined regions could in a certain way improve the landscape of cargo transportation in terms of its safety component, but this information remained unnoticed by the researchers. Approaches to a multilevel hierarchical system for estimating quality state of a road section were examined in work [12]. The authors constructed a model of weighs of parameters and characteristics of highways for their estimation as a road asset. In our opinion, the quantitative estimation of the projected number of road accidents along the examined roads based on statistical observations could be converted to a certain qualitative assessment, as well as characterize the safety component of a road asset, but this issue was disregarded by the authors. Large-scale transportation infrastructure projects (LSTIP), which emerged from the priority need for fast and convenient transportation of the growing population, as well as the numerous risks associated with them, as well as their features in Europe and Asia, were considered in [13]. The issue of an increase in traffic accidents due to the increase in population was considered in the work, but the authors did not give any quantitative methods for determining the projected number of road accidents.

Another field to explore the issue of reducing accidents on highways is to study the effect of a driver's condition on accidents. Study [14] analyzed the factors affecting the driver's functional state in a traffic jam, as well as the character of their influence. There is a nonlinear mathematical model of the traffic jam influence on the functional condition of a driver. The authors predict the driver's condition and, consequently, the probability of road accidents. A study by authors from Turkey [15] establishes the relationship between accidents involving a vehicle and serious injuries and fatigue, careless behavior, and sleep. A multi-variant logistical regression, obtained from several selective observations, found that excessive speed, fatigue, errors, the Stanford indicator of drowsiness, breach, the use of mobile phones, as well as the Epworth sleepiness scale, were related to injuries in a car crash, after adjusting for ride experience and annual mileage. Data from the cited research make it possible to predict road accidents. In our opinion, considering the statistics of road accident in predicting its occurrence would render the models reported in papers [14, 15] greater reliability; the authors, however, did not consider it. The safety of internationalization of inland road transportation in the European Union is being investigated in [16]. It was determined that the risk of accidents involving heavy cargo vehicles (HGV) varies with a ratio of up to 10 in European countries and that the risk of accidents of foreign HGV is approximately twice as high as that of European HGV. The work determines the risk of road accidents based on research, while information on the number of road accidents from statistical sources is not used. The differentiation of European countries in terms of statistics on road accidents has also remained unaddressed by the authors.

Scientific studies into the choice of a cargo delivery route are typically related to minimizing the costs of delivery or penalties. Thus, paper [17] considers the task on finding optimal routing for a single vehicle with stochastic demand for each customer. The paper constructed an algorithm for dynamic programming in order to determine the optimal routing policy. In our opinion, the issue of optimal routing should include the safety component, but the paper's authors did not take it into consideration. Study [18] addressed the distribution of various types of vehicles for transporting products from a manufacturing enterprise to its warehouses. The issue relates to a limited number of vehicles of different capacities with constant and variable costs, as well as to the mechanism of discounts. The authors proposed a nonlinear mathematical model that minimizes general transportation costs. General transportation costs, in our opinion, are also minimized through a decrease in road accidents involving a vehicle, but the study's authors failed to consider this issue.

Our analysis of scientific works has revealed a certain number of approaches to minimizing accidents during transportation of goods. Most of them do not use road accident statistics to assess the safety component of the route, which, in our opinion, is an important area of scientific research. Based on its results, motor carriers and enterprises would be able, first, to calculate the projected number of road accidents when traveling along different routes, and, second, would obtain a toolset to select a route with the minimal number of projected road accidents. Decision-makers would thus be given an opportunity to choose a route taking into consideration the benefits of cost savings and safety of delivery.

3. The aim and objectives of the study

The aim of this study is to develop a method to minimize the projected number of road accidents when transporting an enterprise's cargoes.

To accomplish the aim, the following tasks have been set:

– to suggest an algorithm for establishing the dependence of road accidents in certain regions of the country on other factors of road traffic and on dividing the regions into clusters with a high and low indicator of road accidents;

– to justify a scientific-methodical approach to determining a route with the minimal projected number of road accidents among several possible routes that connect points of departure and destination;

– to give a solution to the problem of multicriteria optimization on the selection of a route with the smallest distance and minimal projected number of road accidents based on a Pareto-optimal approach.

4. Theoretical aspects of research

4. 1. An algorithm for establishing the dependence of road accidents in certain regions of the country on other factors of road traffic and on dividing the regions into clusters with a high and low indicator of road accidents

Suppose that the possibility of damage to or loss of products during their transportation depends on the quality of roads in a country, serviceability and reliability of rolling stock of transportation enterprises, the mode of transportation and statistics of road accidents compiled in every country. Statistical reporting refers to units within the country's territorial structure. According to international standards of statistics and accounting, information about automobile roads of the country's territorial units is systematically updated in terms of the volume of transported cargoes, cargo turnover, the average distance of transportation of one tone of cargo by motor transport, the length of public roads, etc. Key indicators that we propose to consider are the length of automobile roads within a territorial unit of the country and the number of road accidents over this area for a certain period. Other indicators can be used as variables to form clusters composed of the country's territorial units with a high and low indicator of road accidents. Such clusters are hereafter termed "Regions with a high indicator of road accidents" and "Regions with a low indicator of road accidents".

It is proposed, for each cluster, based on the length of automobile roads and the number of road accidents over a certain period of time, to calculate an indicator of road accidents that would equal the average number of road accidents that could happen per one kilometer of a road within the appropriate cluster in one day.

4. 2. A scientific-methodical approach to determining a route with the minimal projected number of road accidents among several possible routes connecting points of departure and destination

When choosing a route for transportation of goods, an enterprise is typically guided by the approach for minimizing the cost of cargo movement. That is, the shortest route for delivery is optimal. Scientific and methodological approaches to choosing an optimal route of cargo and passenger delivery typically refer to the choice of the shortest path that connects the departure and destination points. Modern software designed to search for the shortest route, the algorithm [19] is used, for example, it is widely applied in the programming and technologies behind the routing protocols OSPF and IS-IS. Another approach, which is proposed, is to choose a route with the minimal projected number of road accidents.

Let us consider approaches to determining the shortest route and a route with the minimal projected number of road accidents. When moving a cargo from point *A* to point *B*, the following cases are possible:

– points *A* and *B* are placed nearby and belong to one of the clusters. For example, both are included in the cluster "Regions with a high indicator of road accidents", or both are included in the cluster "Regions with a low indicator of road accidents";

– at least one of points *A* or *B*, or at least one of possible routes of cargo delivery from point *A* to point *B* includes an element from another cluster.

In the first case, the two approaches (the shortest path and the minimal projected number (of road accidents) yield the same result as the shortest route would have the minimal projected number of road accidents.

Let us consider existing scientific and practical approaches to determining the optimal route of transportation. This task occurs in the case of several alternative options to select a route from point *A* to *B*. A solution is typically found using a directed graph (Fig. 1).

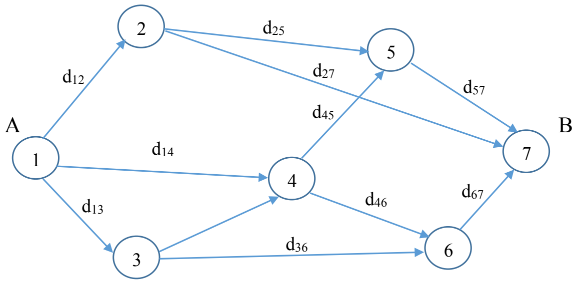

Fig. 1. Example of a road network connecting points *A* and *B*

We denote the distance between adjacent points *i* and *j* in the network through d_{ij}. U_j stands for the length of the shortest route from point 1 to point *j*. For the example shown in Fig. 1, the procedure of finding the route the distance to which from point *A* to *B* would be minimal would end when U_7 is found.

Determining U_7 typically employs using the Dijkstra method [18], which is based on determining the shortest path at each stage from formula

$$U_j = \min_{1 \le i \le j-1} \left\{ U_i + d_{ij} \right\}. \quad (1)$$

For the example in Fig. 1:

$$U_1 = 0;$$

$$U_2 = \min\left\{U_1 + d_{12}\right\};$$

$$U_3 = \min\left\{U_1 + d_{13}\right\};$$

$$U_4 = \min\left\{U_2 + d_{24}, U_1 + d_{14}, U_3 + d_{34}\right\};$$

$$U_5 = \min\left\{U_2 + d_{25}, U_4 + d_{45}\right\};$$

$$U_6 = \min\left\{U_3 + d_{36}, U_4 + d_{46}\right\};$$

$$U_7 = \min\left\{U_2 + d_{27}, U_5 + d_{57}, U_6 + d_{67}\right\}.$$

U_7 for the considered example is the optimal route in terms of length. In the case when all points 1, 2,..., 7 are within the same cluster, the minimal projected number of road accidents $R_{Accident}(\mathrm{AB})$ is determined as the product of the length of the optimal route, U_7, by the indicator of road accidents for the appropriate cluster

$$R_{Accident}(\mathrm{AB}) = U_7 * R_{Accident}\,(\text{appropriate cluster}), \quad (2)$$

where $R_{Accident}(\mathrm{AB})$ is the minimal projected number of road accidents when moving from point *A* to *B*); U_7 is the optimal route in terms of length for the example in Fig. 1, km; $R_{Accident}$ (appropriate cluster) is the indicator of road accidents for the appropriate cluster, which is equal to the projected average number of road accidents per a kilometer of the road, road accident/km.

For a second case, finding a route with the minimal projected number of road accidents, another approach is suggested. The nodal points, which indicate the beginning and end of the motion, as well as to the points that connect or separate roads (in the example shown in Fig. 1, points 1, 2, ..., 7) are to be supplemented with several more nodes. For the case of division into clusters, such nodes are the boundaries of clusters. For example, in the case shown in Fig. 2 and which is a modification of Fig. 1, the route passes through the regions that relate to two different clusters. The line separates two clusters.

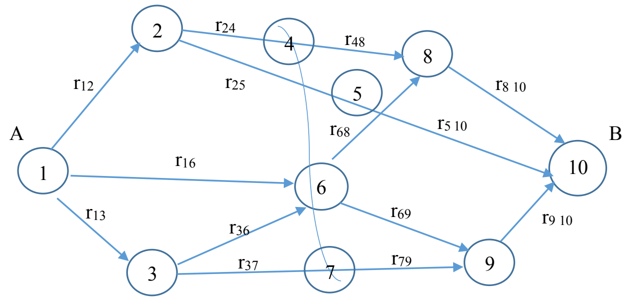

Fig. 2. Example of a road network that connects points *A* and *B* in different clusters

In this case, we propose introducing additional points shared by regions from different clusters. In the example in Fig. 2, these are points 4, 5, and 7. They are not nodal, but it is important to mark them along the way, because they share zones with a different indicator of road accidents.

Along the edges of the graph, we propose denoting not only the distance between vertices but the distance multiplied by the indicator of road accidents in the appropriate cluster. The projected number of road accidents when moving from point *i* to point *j* is denoted via r_{ij}

$$r_{ij}=d_{ij}R_{Accident}(\text{appropriate cluster}), \tag{3}$$

where r_{ij} is the projected number of road accidents along a route that connects points *i* and *j* (road accidents); d_{ij} is the distance between points *i* and *j* (km); $R_{Accident}$(appropriate cluster) is the indicator of road accidents for an appropriate cluster (road accident/km).

R_j stands for the minimal projected number of road accidents when moving from point 1 to point *j*. To find it, we suggest using an approach that is similar to determining the shortest path.

$$R_j = \min_{1\le i\le j-1}\left\{R_i + r_{ij}\right\}, \tag{4}$$

where R_j is the minimal projected number of road accidents when moving from point 1 to point *j*, road accidents; R_i is the projected number of road accidents when moving from point 1 to point *i*, road accidents; r_{ij} is the projected number of road accidents, which connects points *i* and *j*, road accidents.

The minimal projected number of road accidents along the entire route, R_{10}, in this case is denoted $R'_{Accident}(AB)$. The route corresponding to this case is denoted $U'(AB)$.

To transport cargoes, an enterprise can choose two strategies:

– a strategy for the shortest route, that is the choice U(AB);

– a strategy for the minimal forecasted number of road accidents, that is the choice of route $U'(AB)$.

Choosing a strategy of the shortest path implies that all roads that connect points *A* and *B* are the same in quality, that is, the cost of fuel does not change substantially in any way.

Owners of vehicles and cargo owners may be different business entities. Both the owners of cargo and the owners of vehicles can prevent transportation logistics risks by insuring the vehicles – “Comprehensive Cover” and the cargoes – “cargo”. A cargo insurance contract is comprised, as a rule, based on one of three options: covering all transportation logistical risks; liability for a separate accident, or without injury, except for death.

A decision-maker (DM) is not always inclined to choose a strategy of the shortest path. Despite the insurance protection, both the carrier and the cargo owner are likely to be inclined to choose the path with the minimal projected number of road accidents.

Choosing the shortest path or path with the minimal projected number of road accidents is determined, typically, based on what is more important for a DM: to optimize the shipping costs or the reliability of cargo delivery. Choosing one of the two strategies, a strategy of the shortest path or a strategy of the minimal projected number of road accidents, can be regarded by a DM as a finite game of two players with a zero amount, that is as a matrix game. In it, a first player is the DM, a second player is the unpredictability associated with the transportation, and it can also acquire two possible states: a road accident occurred or has not occurred.

Let us consider a first approach to making a decision by a DM: to optimize the cost of cargo delivery. The game can be represented as a cost matrix (Table 1).

Table 1

Cost matrix on selecting a DM’s strategy — enterprise costs

Alternative options for a decision-maker (DM)	Possible transportation states	
	Road accident does not happen	Road accident happens
Shortest path strategy	a_{11}	a_{12}
Strategy of the minimal projected number of road accidents	a_{21}	a_{22}

The matrix elements a_{ij} can express an enterprise’s costs provided that the DM selects the *i* strategy while the transportation process is based on the *j* strategy.

Cost matrix A can be written in the form

$$A=\begin{bmatrix} -U(AB)\cdot p & -\left(U(AB)\cdot p+fine\right) \\ -U'(AB)\cdot p & -\left(U'(AB)\cdot p+fine\right) \end{bmatrix},$$

where all the matrix elements are negative as they characterize the costs of an enterprise, and are calculated as follows:

a_{11} – the length of the shortest route from point *A* to point *B*, U(AB), is multiplied by fuel consumption per a kilometer – p;

a_{12} – certain expenses or a fine shall be added to a_{11}, which an enterprise would incur in case of a road accident, it may be a loss due to downtime, damage, or transferring a cargo to serviceable vehicle, etc.;

a_{21} – the length of a route with the minimal projected number of road accidents, $U'(AB)$, is multiplied by the cost of fuel per a kilometer – p;

a_{22} – certain costs (a fine) shall be added to a_{21} that an enterprise would incur in case of a road accident.

Let us find the lower and upper price of the game in this case:

$$\alpha = \max_i \min_j a_{ij} =$$
$$= \max\left\{-\left(U(AB)\cdot p + fine\right); -\left(U'(AB)\cdot p + fine\right)\right\} =$$
$$= -\left(U(AB)\cdot p + fine\right) - \text{lower price game;}$$

$$\beta = \min_j \max_i a_{ij} =$$
$$= \min\left\{-U(AB)\cdot p; -\left(U(AB)\cdot p + fine\right)\right\} =$$
$$= -\left(U(AB)\cdot p + fine\right) - \text{top game price.}$$

Since α=β, the considered game has a saddle point

$$\gamma = -\left(U(AB)^* p + fine\right),$$

which is the pure price of the game.

Thus, according to the specified terms of the game, an enterprise should adhere to the strategy of the shortest path from point A to point B, then its costs (win) would be $U(\mathrm{AB})\cdot \mathrm{p} + fine$.

Let us consider another case where the matrix elements a_{ij} express the reliability of cargo delivery, that is, the possibility of delivery without road accidents.

Matrix A for the case when the win of an enterprise is the reliability of cargo delivery takes the form

$$A = \begin{bmatrix} 100 - R_{Accident}(AB) & 100 - k\cdot R_{Accident}(AB) \\ 100 - R'_{Accident}(AB) & 100 - k\cdot R^{/}{}_{Accident}(AB) \end{bmatrix},$$

where elements of the matrix are proposed to be calculated as follows:

a_{11} – the reliability of delivery in line with a first strategy, the strategy of choosing the shortest route, equals $100 - R_{Accident}(\mathrm{AB})$ (the projected number of accidents along the shortest route should be subtracted from a much larger number, for example, a hundred);

a_{12} – assumption of an emergency when delivering cargo should significantly reduce the reliability of delivery. Let in this case the reliability be equal to $100 - k\cdot R_{Accident}(\mathrm{AB})$, where k is the importance of reliable delivery for a sender or a recipient, which should be considerably larger than unity, for example, it may equal 10;

a_{21} – the reliability of delivery in line with a second strategy, a strategy of the minimal projected number of road accidents, equals $100 - R'_{Accident}(AB)$;

a_{22} – similarly to a_{12} we obtain $100 - k\cdot R'_{Accident}(AB)$.

Let us find the lower and upper price of the game for these cases:

$$\alpha = \max_i \min_j a_{ij} =$$
$$= \max\left\{100 - k\cdot R_{Accident}(AB); 100 - k\cdot R'_{Accident}(AB)\right\} =$$
$$= 100 - k^* R_{Accident}(AB) - \text{ lower price game;}$$

$$\beta = \min_j \max_i a_{ij} =$$
$$= \min\left\{100 - R'_{Accident}(AB); 100 - k\cdot R'_{Accident}(AB)\right\} =$$
$$= 100 - k\cdot R'_{Accident}(AB) - \text{top game price.}$$

Since α=β, the considered game has a saddle point

$$\gamma = 100 - k\cdot R'_{Accident}(AB),$$

which is the pure price of the game.

Thus, under the specified terms of a second game, an enterprise should adhere to the strategy of the minimal projected number of road accidents; the minimal reliability of delivery is then $100 - k\cdot R'_{Accident}(AB)$.

4. 3. Solving the problem of multicriteria optimization on selecting a route with the smallest distance and the minimal projected number of road accidents based on a Pareto-optimal approach

When choosing one of two alternatives: the shortest route or a route with the minimal projected number of road accidents, it is important that a DM should understand not only the importance of each of them, but the ratio of key characteristics of these alternatives as well (Table 2).

Table 2

Ratio of key characteristics of alternatives for a transportation route selection

Alternative options for a decision-maker (DM)	Key features of alternatives	
	Delivery path length	Projected number of road accidents
Shortest path strategy	$U(AB)$	$R_{Accident}(\mathrm{AB})$
Strategy of the minimal projected number of road accidents	$U'(AB)$	$R'_{Accident}(\mathrm{AB})$

It is clear that, based on key characteristics, the following ratios would always hold:

$$U(AB) < U'(AB); \quad R'_{Accident}(AB) < R_{Accident}(AB).$$

For a decision-maker, it is important which sign can be put between the ratio of the projected number of road accidents $R_{Accident}(AB)/R'_{Accident}(AB)$ and the ratio of distances $U'(AB)/U(AB)$. Three cases are possible:

$$\frac{R_{Accident}(AB)}{R'_{Accident}(AB)} = \frac{U'(AB)}{U(AB)}.$$

In the first case, the estimated number of road accidents along the shortest route relates to the minimal estimated number of road accidents along the corresponding route in the same manner as the distance of the route with the minimal projected number of road accidents to the shortest distance. In this case, there is no reasoned advantage of one of two strategies for a DM.

$$\frac{R_{Accident}(AB)}{R'_{Accident}(AB)} > \frac{U'(AB)}{U(AB)}.$$

In the second case, choosing the shortest route is not justified. A decision maker should be inclined to choose a route with the minimal projected number of road accidents, since in this case the increase in fuel costs could significantly increase the reliability of delivery.

$$\frac{R_{Accident}(AB)}{R'_{Accident}(AB)} < \frac{U'(AB)}{U(AB)}.$$

In the third case, a decision maker should be inclined to choose the shortest route, as the cost of fuel for an enterprise, when choosing a route with the minimal forecasted number of road accidents, far exceeds the benefits of the increased reliability of delivery.

A DM choosing a route for cargo delivery can strive to minimize both the length of the route and the projected number of road accidents. In this case, the task on choosing the optimal route can be considered as a multi-criterion optimization based on two criteria: a path length and the estimated number of road accidents.

As already mentioned, the shortest route and a route with the minimal projected number of road accidents can coincide, but, typically, a route with the minimal projected number of road accidents is not shorter than the route with the smallest distance. In the case when these two criteria have different solutions, this problem has no a common solution. Therefore, in this case, we propose finding the Pareto-optimal solutions.

Suppose that one connects points A and B via n routes u_i, $i=1,..., n$, each route u_i is matched with the projected number of road accidents, r_i. Then the Pareto- optimal solution is a solution to the problem

$$F_{\alpha,\beta}(u,r) = \alpha u + \beta r \to \min, \tag{5}$$

where α, β are coefficients, with $\alpha+\beta=1$; u is the length of a specific route path, km; r is the projected number of road accidents along a particular route, road accident.

The magnitude α and β are chosen by a DM for his/her own reasons. There are three possible options:

– if there is no advantage for any alternative, that is equally important are both the shortest way and the minimal projected number of road accidents, then $\alpha=\beta=0.5$;

– if it is more important for a DM to choose the shortest path, then $\alpha>\beta$;

– if the priority is the choice of a route with the minimal projected number of road accidents, then $\alpha<\beta$.

For example, in the summer and early autumn months it would be more important for a DM to choose the shortest route because roads are typically in good condition during this period. In contrast, in winter and spring, a DM may prefer the route along which the projected number of road accidents is minimal.

To select the Pareto-optimal solution, a DM should compile a table (Table 3), which gives all possible routes for cargo transportation with a corresponding projected number of road accidents.

For different combinations of pairs α and β, one finds a single minimal Pareto-optimal value

$$F_{\alpha,\beta}(u,r) = \alpha u + \beta r \to \min.$$

In the last column of Table 3 one selects the minimal value corresponding to a specific combination of α and β and is a Pareto- optimal solution.

Table 3

Solving a multicriteria problem using a Pareto approach

Route No.	u	r	$\alpha u + \beta r$
1	u_1	r_1	$\alpha u_1 + \beta r_1$
2	u_2	r_2	$\alpha u_2 + \beta r_2$
...	...	...	...
i	u_i	r_i	$\alpha u_i + \beta r_i$
...	...	...	...
n	u_n	r_n	$\alpha u_n + \beta r_n$

5. Verification of a route selection method based on the minimal projected number of road accidents

The proposed method was verified in determining a route with the minimal projected number of road accidents using a network of motor roads in Ukraine as an example. At the first stage, we considered a situation related to the statistics on road accidents in the regions of the country, as well as other indicators of automobile roads, based on which we clustered the regions of the country.

According to data from the State Statistics Committee of Ukraine, the largest number of road accidents in 2017 occurred in Odesa oblast (14,609 road accidents), followed by Kharkiv oblast (12,029 road accidents), Lviv and Kyiv oblasts (11,576 and 11,530 road accidents, respectively) (Table 4).

Correlation matrix was built (Table 5) based on data from Table 4.

Based on Table 5, the average correlation relationship can be established between the number of road accidents and cargo turnover (0.67), as well as between the number of road accidents and the length of automobile roads (0.57). The average transportation distance of one ton has an average correlation to cargo turnover (0.48).

Using a cluster analysis, we grouped the regions of Ukraine in order to identify groups with the larger or less indicators of road accidents. Let us find the optimal number of groups from data in Table 4, except for the variable "Average transportation distance of one ton of cargoes". Based on a hierarchical cluster analysis using the Ward's method of clustering, performed by employing the software SPSS Statistics 21, we conclude that the optimal quantity is two clusters. That is confirmed by the plan of agglomeration of a cluster analysis dendrogram (Fig. 3).

A characteristic for each cluster is derived using a k-means method (Table 6).

The first cluster contains 19 oblasts (Table 7). The transportation of cargoes along the roads of oblasts within this cluster is 33.45 mln. tons per year on average, which is almost three times less than that in a second one. The average cargo turnover in this cluster is 2.26 times smaller than that in a second one (1,857.49 million t·km versus 4,195.3 million t·km). The average length of public roads in the oblasts of this cluster is 1.4 times less than that in the regions of a second cluster. The average number of road accidents in the oblasts of this cluster is 3.9 times lower than that in a second cluster.

Table 4

Source data for grouping (clustering) the regions of Ukraine in 2017 [20]

Regions	Transportation of cargoes by vehicles, per region, mln tons	Turnover of motor transport, per region, mln. tkm	Average transportation distance of one ton of cargoes by vehicles, per region, km	Length of motor roads in general use, per region, thousand km	Number of road accidents, cases
Ukraine	1,121.7	62,296.8	56	163.1	162,526
Vinnyts′ka	27.8	1,672.7	60	9.5	3,223
Volyns′ka	13.0	2,401.7	185	6.2	3,132
Dnipropetrovs′ka	328.1	4,815.6	15	9.2	11,203
Donets′ka	105.1	2,367.3	23	8.1	3,534
Zhytomyrs′ka	43.4	990.9	23	8.5	4,158
Zakarpat·s′ka	8.7	5,285.6	604	3.3	2,874
Zaporiz′ka	30.4	1,522.8	50	7.0	5,923
Ivano-Frankivs′ka	20.2	1,690.9	84	4.1	2,935
Kyyivs′ka	48.9	4,191.6	86	8.6	11,530
Kirovohrads′ka	45.8	1,470.5	32	6.3	1,612
Luhans′ka	4.9	477.2	98	5.9	839
L′vivs′ka	23.2	4,604.1	198	8.4	11,576
Mykolayivs′ka	20.5	14,66.5	72	4.8	3,865
Odes′ka	24.1	2,886.9	120	8.3	14,609
Poltavs′ka	173.0	2,563.0	15	8.9	4,083
Rivnens′ka	19.2	2,270.0	118	5.1	2,386
Sums′ka	12.6	765.8	61	7.2	1,853
Ternopil′s′ka	16.7	1,321.9	79	5.0	2,325
Kharkivs′ka	32.4	4,478.3	138	9.6	12,029
Khersons′ka	13.4	1,353.5	101	5.0	3,593
Khmel′nyts′ka	32.2	2,151.3	67	7.2	3,249
Cherkas′ka	30.1	3,074.6	102	6.2	4,064
Chernivets′ka	6.9	1,272.3	185	2.9	2,564
Chernihivs′ka	11.7	1,173.8	100	7.7	2,728

Table 5

Correlation matrix of indicators for the regions of Ukraine in 2017

Indicators of the country's motor roads	Cargo transportation	Cargo turnover	Average transportation distance of one ton of cargoes	Length of motor roads in general use	Number of road accidents
Cargo transportation	1	0.38	–0.33	0.45	0.32
Turnover of cargoes	0.38	1	0.48	0.27	0.67
Average transportation distance of one ton of cargoes	–0.33	0.48	1	–0.47	–0.02
Length of motor roads in general use	0.45	0.27	–0.47	1	0.57
Number of road accidents	0.32	0.67	–0.02	0.57	1

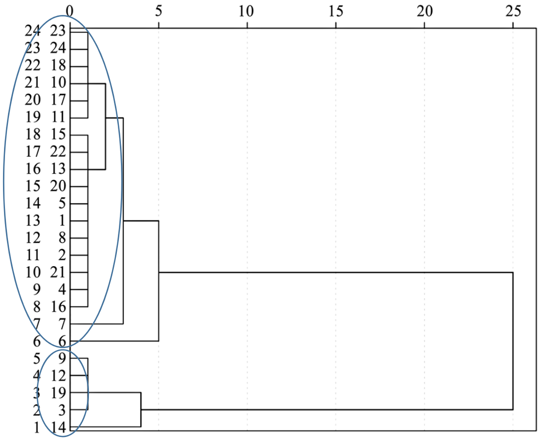

Fig. 3. Dendrogram of the Ward's method of cluster analysis

Table 6

Resulting cluster centers of cluster analysis

Mean values	Cluster	
	1	2
Cargo transportation	33.45	91.34
Cargo turnover	1,857.49	4,195.30
Length of motor roads in general use	6.26	8.82
Number of road accidents	3,102.11	12,189.40

Table 7

Number of observations in each cluster

Cluster	1	19,000
	2	5,000
Valid		24,000
Missed		0.000

We term the first cluster "*Regions with a low indicator of road accidents*". It includes nineteen oblasts: Vinnyts′ka, Volyns′ka, Donets′ka, Zhytomyrs′ka, Zakarpat·s′ka, Zaporiz′ka, Ivano-Frankivs′ka, Kirovohrads′ka, Luhans′ka, Mykolayivs′ka, Poltavs′ka, Rivnens′ka, Sums′ka, Ternopil′s′ka, Khersons′ka, Khmel′nyts′ka, Cherkas′ka, Chernivets′ka, Chernihivs′ka.

The second cluster is termed "*Regions with a high indicator of road accidents*". It includes five oblasts: Dnipropetrovs′ka, Kyyivs′ka, L′vivs′ka, Odes′ka ta Kharkivs′ka (Fig. 4).

The probability of a road accident for a motor vehicle moving along the roads of regions from a second cluster is much higher than that for a first cluster. We propose calculating the indicator of road accidents in each cluster obtained as the ratio of the average number of road accidents over a year (AVNUM_road_accidents) to the average length of public roads (AVLEN_public_roads) divided by the number of days in the year. That is, an indicator of road accidents corresponds in terms of value to the average number of road accidents per a km of roads over one day and is calculated from formula:

For a first cluster, the indicator of road accidents is

$$R_{road\ accidents}= =\text{AVNUM\_road\_accidents}/\text{AVLEN\_public\_roads}/365. \quad (6)$$

$$R_{road\ accidents}\ (\text{I cluster})= =3102.11/6260/365=0.0014\ \text{road\_accidents/km}. \quad (7)$$

For a second cluster, the indicator of road accidents is:

$$R_{road\ accidents}\ (\text{II cluster})=12189.4/8820/365= =0.0037\ \text{road\_accidents/km}. \quad (8)$$

As shown by (7), (8), the frequency of road accidents along the public roads within a second cluster is almost three times higher than that on the roads of a first one.

From data in Table 5, we drew conclusions, based on the coefficients of correlation, about a substantial relation between the number of road accidents over a year and cargo turnover (r=0.67). In contrast, when planning motion of vehicles along the roads of the country, it is proposed to use an indicator of the length of automobile roads of general purpose, which is weaker related to the number of road accidents (r=0.57), but which is more convenient for calculations in problems on determining the optimal route for cargo delivery. To calculate the projected number of road accidents when choosing a specific route, we propose multiplying the distance planned to travel along roads in the regions from a first cluster by the indicator of road accidents for regions from a first cluster, and multiplying the distance planned to travel along roads in the regions from a second cluster by the indicator of road accidents for regions from a second cluster; and then add these two products.

One can use an approach that does not require a cluster analysis to determine the predicted number of road accidents when moving along roads of general purpose within a certain region. For this purpose, based on data from Table 4, it is proposed to derive indicators of road accidents for each individual region from formula (6) without averaging the values. That is, the number of road accidents per year is divided by the length of general-purpose roads and the number of days over a year. By following the approach, we would compile a table of road accidents in 2017 for each region separately (Table 8).

This approach is more detailed in determining the predicted number of road accidents along a particular route and requires more laborious calculations.

At the second stage, the choice of a route with the minimal predicted number of road accidents is selected for a particular task on moving a cargo.

Suppose that it is necessary to dispatch a cargo from the State enterprise Kharkiv Machine-Building Plant "FED" (DP HMZ "FKD") to Zhytomyr Machine-Building Plant. We shall schematically represent a logistic task of transporting the cargo from point A (the city of Kharkiv) to point C (the city of Zhytomyr) (Fig. 5).

Fig. 4. Clusters of Ukraine's regions with the low and high indicators of road accidents

Table 8

Estimation of road accident indicators for regions of Ukraine

Region	Road accident indicator/km	Region	Road accident indicator/km
Vinnyts'ka	0,0009	Mykolayivs'ka	0.0022
Volyns'ka	0.0014	Odes'ka	0.0048
Dnipropetrovs'ka	0.0033	Poltavs'ka	0.0013
Donets'ka	0.0012	Rivnens'ka	0.0013
Zhytomyrs'ka	0.0013	Sums'ka	0.0007
Zakarpat-s'ka	0.0024	Ternopil's'ka	0.0013
Zaporiz'ka	0.0023	Kharkivs'ka	0.0034
Ivano-Frankivs'ka	0.0020	Khersons'ka	0.0020
Kyyivs'ka	0.0037	Khmel'nyts'ka	0.0012
Kirovohrads'ka	0.0007	Cherkas'ka	0.0018
Luhans'ka	0.0004	Chernivets'ka	0.0024
L'vivs'ka	0.0038	Chernihivs'ka	0.0010

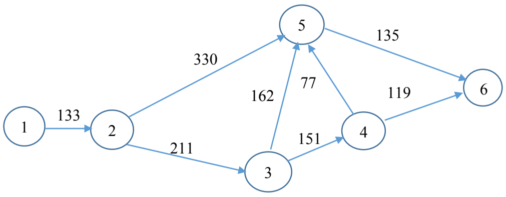

Fig. 5. Map of routes that connect points A and C: 1 – Kharkiv, 2 – Poltava, 3 – Cherkassy, 4 – Bila Tserkva, 5 – Kyiv, 6 – Zhytomyr

Let us consider a first route selection strategy with the smallest distance from point *A* to point *C*. To determine U_6, we find the shortest path at each stage from formula

$$U_j = \min_{1\le i\le j-1}\{U_i + d_{ij}\};$$

$$U_1 = 0;$$

$$U_2 = U_1 + d_{12} = 133, U_3 = U_2 + d_{23} = 133 + 211 = 344;$$

$$U_4 = U_3 + d_{34} = 344 + 151 = 495;$$

$$U_5 = \min\{U_2 + d_{25}, U_3 + d_{35}, U_4 + d_{45}\} = \\ = \min\{463, 506, 572\} = 463;$$

$$U_6 = \min\{U_4 + d_{46}, U_5 + d_{56}\} = \min\{598, 614\} = 598.$$

The route of the smallest length is 1, 2, 5, 6, or Kharkiv, Poltava, Kyiv, Zhytomyr. Its length is 598 km.

According to a second strategy, the choice of a route with the minimal projected number of road accidents, there are two possible approaches: cluster-based and regional. Both approaches require adding the intermediate points to the map at which there is a boundary that divides the regions through which the road passes. Under a cluster-based approach, two regions – Kyiv and Kharkiv – belong to the regions with a high indicator of road accidents, other points relate to the cluster with a low indicator of road accidents (Fig. 6).

Following a cluster-based approach, we shall calculate for the edges of the graph that connect its vertices the predicted number of road accidents along the route. Boundaries of regions with a high indicator of road accidents are outlined and highlighted in orange in Fig. 6.

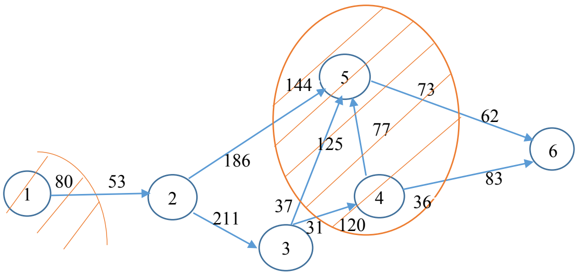

Fig. 6. Map of routes connecting points A and C: 1 – Kharkiv, 2 – Poltava, 3 – Cherkassy, 4 – Bila Tserkva, 5 – Kyiv, 6 – Zhytomyr

The indicator of road accidents for regions from a first cluster is 0.0014 road accident/km, for a second one, 0.0037 road accident/km. Thus, we obtain:

r_{12}=80·0.0037+53·0.0014=0.3702 road accidents;

r_{23}=211·0.0014=0.2954 road accidents;

r_{25}=144·0.0037+186·0.0014=0.7932 road accidents;

r_{34}=120·0.0037+31·0.0014=0.4874 road accidents;

r_{35}=125·0.0037+37·0.0014=0.7932 road accidents;

r_{45}=77·0.0037=0.2849 road accidents;

r_{46}=73·0.0037+62·0.0014=0.3569 road accidents;

r_{56}=36·0.0037+83·0.0014=0.2494 road accidents.

To find the minimal projected number of road accidents, we shall use the approach similar to determining the shortest path:

$$R_j = \min_{1\le i\le j-1}\{R_i + r_{ij}\};$$

$$R_1 = 0;$$

$$R_2 = R_1 + r_{12} = 0.3702;$$

$$R_3 = R_2 + r_{23} = 0.3702 + 0.2954 = 0.6655;$$

$$R_4 = R_3 + r_{34} = 0.6655 + 0.4874 = 1.1529;$$

$$R_5 = \min\{R_2 + r_{25},\ R_3 + r_{35},\ R_4 + r_{45}\} = \\ = \min\{1.1634; 1.4587; 1.4378\} = 1.1634;$$

$$R_6 = \min\{R_4 + r_{46}, R_5 + R_{56}\} = \\ = \min\{1.4098; 1.4128\} = 1.4098.$$

The route, which has the minimal projected number of road accidents, is 1, 2, 5, 6, or Kharkiv, Poltava, Kyiv, Zhytomyr. Its length is 614 km. The projected number of road accidents along this route is 1.4098, which is the minimal projected number of road accidents among all routes. An alternative route of the smallest length of 598 km has a projected number of road accidents of 1.4128.

Here are the data in the above terms:

$U(AB)$=598 km;

$U'(AB)=614$ km;

$R_{Accident}(AB)=1.4098$ road accident;

$R^{/}_{Accident}(AB)=1.4128$ road accidents.

Calculate ratios

$$\frac{U'(AB)}{U(AB)}=\frac{614}{598}=1.027$$

and

$$\frac{R_{Accident}(AB)}{R^{'}_{Accident}(AB)}=\frac{1.4128}{1.4098}=1.002.$$

As one can see, in this case, a third case of the ratio holds, that is

$$\frac{R_{Accident}(AB)}{R^{'}_{Accident}(AB)}<\frac{U'(AB)}{U(AB)}.$$

A decision maker should be inclined to choose the shortest path, because the cost of fuel for an enterprise, when choosing a route with the minimal projected number of road accidents, exceeds the benefits from the increased delivery reliability.

Let us compile a table to determine a Pareto-optimal solution (Table 9).

Table 9

Determining a Pareto-optimal solution

Route No.	u	r	$0.3u+0.7r$	$0.8u+0.2r$
1 (1, 2, 5, 6)	598	1.4128	180.39	478.68
2 (1, 2, 3, 4, 6)	614	1.4098	185.19	491.48
3 (1, 2, 3, 5, 6)	641	1.4588	193.32	513.09
4 (1, 2, 3, 4, 5, 6)	707	1.6873	213.28	565.94

In the first case, more important to a DM is the minimal projected number of road accidents, so the search for a minimum is carried out based on criterion $0.3u+0.7r$. In the second case, more important to a DM is to determine a route of the smallest length, so the search for a minimum is based on criterion $0.8u+0.2r$. As shown by Table 9, in both cases, the first route would be optimal, with the smallest distance between the points of departure and destination.

6. Discussion of results of applying a method for selecting a route with the minimal projected number of road accidents

The algorithm of clustering territorial units in the country in terms of indicators of road accidents is based on defining the groups of regions with similar indicators of statistical reporting, including: the volume of cargoes transported, cargo turnover, the length of total roads in public use, the number of road accidents. Based on the results from verifying the algorithm using motor roads in the regions of Ukraine as an example, we identified two groups of regions: the group of "Regions with a high indicator of road accidents" includes five oblasts where the indicator of road accidents (the number of road accidents per a km) was three times higher than that in a second group of nineteen oblasts "Regions with a low indicator of road accidents". This can be explained, first of all, by the fact that regions with a high indicator of road accidents include oblast centers – the city millionaires in terms of population. The cities-millionaires are characterized by more intense traffic and higher cargo turnover, but the ratio of the average number of road accidents for the regions from a first cluster to the regions from a second cluster significantly exceeds all other ratios. Therefore, the division of territorial units into groups with the low and high risk of road accidents could improve road safety, which is a practical result of the current study.

The scientific result of our work is the substantiation of a scientific and methodical approach to determining a route with the minimal projected number of road accidents among several possible routes connecting points of departure and destination. The projected number of road accidents for each possible route of cargo transportation is calculated from a formula in which the distance traveled by a vehicle in a particular cluster is multiplied by the indicator of this cluster's road accidents. Thus, for each route, one can derive a projected indicator of road accidents and choose a route where its value is minimal based on the method that is similar to choosing the shortest path. Based on the results of approbation, a route with the minimal projected number of road accidents was determined, which turned out to be 16 km longer than the route of the minimal distance. Such results are explained by that, according to the results from the cost matrix for the choice of an enterprise's strategy in case of minimal expenses the strategy that would always be of advantage is the shortest path strategy, and in the case of maximum reliability the strategy that always prevails is choosing a route with the minimal projected number of road accidents.

Solving a multicriteria optimization problem on choosing a route of the smallest distance and with the minimal projected number of road accidents based on a Pareto-optimal approach makes it possible for a decision maker to choose a route taking into consideration two approaches: the minimal projected number of road accidents and the shortest route. Depending on which approach is more important, it is given the appropriate weight; a value is calculated for the objective function for all possible routes. The approbation has revealed that the route having the smallest distance is Pareto-optimal both in terms of the smallest distance and the minimal projected number of road accidents. This result can be explained by that the shortest route and a route with the smallest projected number of road accidents differ insignificantly both in terms of distance and the number of road accidents.

In contrast to other studies stating that accidents on roads depend on traffic intensity, a driver's fatigue, the nationality of a driver, the number of traffic lanes, etc., the proposed method is based on the indicators derived from statistical reports that rules out any subjective assumptions and assessments, and renders it specific benefits. It is also important that in the proposed method a decision maker, when choosing a route, may always compare the ratio of the projected number of road accidents along the routes of the smallest distance and the lowest number of road accidents to the ratio of distances along these routes and make a decision on price and safety benefits, as well as determine the route based on a Pareto-optimal approach.

Thus, our solving the tasks set for the study provides a toolset for using statistical information on road accidents in order to choose a safe route, that is, the route with the smallest projected number of road accidents. By clustering the territorial units based on indicators of road accidents, a researcher receives a map of regions in which this indicator is high and low. When planning a route for cargo deliveryn, the researcher is given an opportunity to calculate the projected number of road accidents along each route and choose the safest one.

Practical implementation of the proposed method has certain limitations. In general, they are associated with the availability of statistical data on road accidents for certain territorial units. It is possible to apply the method when data on the length of motor roads within a certain territorial unit and the number of road accidents are available. The method does not consider any other factors that affect road accidents.

The disadvantage of the study is its rather general approaches to dividing territorial units into regions with the high and low indicators of road accidents. Such a division was carried out based on the information provided by statistical reports. Statistical reporting treats an oblast as a whole, which may influence the accuracy of an indicator for road accidents given differences in road quality, traffic, number of lanes, etc. More detailed reports on road accident statistics, for example for certain areas or roads, would make it possible to more accurately calculate an indicator of road accidents.

In the future, to improve the method for choosing a route with the minimal projected number of road accidents, data on the road accident statistics should be supplemented with data on planned road works, traffic, and road quality along certain routes. That would make it possible to consider more factors that should prevent road accidents or reduce their probability.

7. Conclusions

1. We have proposed an algorithm for dividing territorial units of the country into clusters termed "Regions with a low indicator of road accidents" and "Regions with a high indicator of road accidents". The approach is based on data from the statistics of road accidents and indicators that characterize the roads of territorial units in the country. Our verification of the algorithm based on a cluster analysis of the country's territorial units using a Ward's method for a particular example has produced two groups of territorial units. Average indicators of the number of road accidents in a first group were three times lower than those in a second group. For each cluster, it has been proposed to calculate an indicator of road accidents, which is determined as the ratio of the average number of road accidents per year to the average length of roads and the number of days in the current year. That is, an indicator of road accidents is the number of road accidents that could occur when moving a motor transportation unit along a kilometer of roads within an appropriate cluster over a day.

2. The scientific-methodological approach to selecting a route with the minimal projected number of road accidents is based on determining, for each edge in the directed graph that reflects all possible routes of cargo delivery from the point of departure to the point of destination, the corresponding projected number of road accidents, which is calculated as the product of the length of the edge in km by the indicator of road accidents for the appropriate cluster (road accidents/km). For each intermediate point, one chooses a route with the minimal projected number of road accidents by analogy to choosing a route of minimal distance. For our example, a route with the minimal projected number of road accidents was 16 km longer than the route with the minimal distance between the point of departure and the delivery point.

3. We have stated the problem of multicriteria optimization for the case when a decision maker has certain preferences for the choice of a route with the smallest distance and the choice of a route with the minimal projected number of road accidents. It has been proposed that the solution to this problem should be a minimum of the criterion of two-factor optimization, calculated based on all possible routes. In our case, the optimal route both in terms of length and the minimal projected number of road accidents was the same route.

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