МАТЕМАТИЧНЕ ТА КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ

MATHEMATICAL AND COMPUTER MODELING

МАТЕМАТИЧЕСКОЕ И КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ

UDC 528.29

METHOD OF SOLUTION OF COMPLEX OPTIMIZATION PROBLEM FOR FORMATION OF COMPONENT COLUMN OF TECHNIQUE AND ROUTE SELECTION OF ITS MOVEMENT BY NON-STATIONARY ROAD NETWORK

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ABSTRACT

Context. Effective solution of a number of application problems related to transportation, as a rule, depends on the solution of two problems: the correct formation of the composition of the column of technique and the successful choice of the route of its movement. Each of the problems is optimization, the methods of solving which are currently being worked out. Theoretical studies of each of the individual problems and their practical applications indicate their interdependence, which has not yet been fully studied. Practical applications necessitate the development of a suitable scientific and methodological apparatus.

Objective. The purpose of this work is development of a method for solving a complex optimization problem of forming a column of vehicles and choosing the route of its movement on a non-stationary road network.

Method. The mathematical model of solving the optimization problem of complex formation of the composition of the column of machinery and the choice of its route of motion is proposed. A heterogeneous set was used to describe the array from which the vehicles were selected. A graph was used to describe the road network. As a criterion for the optimality of the complex problem is the minimization of time spent on moving. The peculiarity of the model is to take into account the possibility of dynamically changing the time weights of edges of the graph when implementing the movement of a column of machinery along the chosen route. Based on the use of this model, a method is proposed, which provides a comprehensive choice of the composition of the column of equipment and optimal routes of its movement on a non-stationary road network.

Results. The article proposes an algorithm that provides the solution of the optimization problem of complex formation of the composition of machinery column and the choice of its route of motion in terms of time-fixed edges that describe the network of roads. The features of application of the proposed algorithm are given. Using the developed software, the choice of technique from an existing inhomogeneous array and the choice of a route on a graph with a non-stationary time weight of edges was investigated. The example shows the imperfection of decisions regarding the complex formation of the column composition and the choice of its optimal route of travel on a non-stationary network of roads obtained using classical methods.

Conclusions. Not taking into account the impact of a possible change in traffic conditions, as evidenced by a change in the time weights of the edges of the graph describing the road network, on the composition of the column of machinery can lead to suboptimality of the obtained solutions using classical methods of forming the composition of the column and finding the shortest route in the graph. The method proposed in this study can be used to obtain the optimum composition of the column and the route, taking into account the change in road conditions during the movement of the column. The obtained results extend the possibilities of the theory of discrete optimization and the theory of graphs.

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KEYWORDS: complexity, optimization problem, graph, non-stationarity, method.

NOMENCLATURE

x_i – symbol of a specific vehicle, $i = \overline{1,n}$;

U_1 – conditional shortening of initial conditions concerning available vehicles from among which the structure of a column of machinery for carrying out transportations of personnel and freights can be formed;

U_2 – conditional shortening of the initial conditions regarding the tactical and technical characteristics of vehicles from the composition of the column;

U_3 – conditional shortening of initial conditions in relation to the studied graph of the road network;

K_1 – conditional shortening of the criterion on the level of technical readiness of equipment from the composition of the column;

K_2 – conditional shortening of the criterion on the number of vehicles in the column;

K_3 – conditional shortening of the criterion on the number of brands of vehicles in the column;

K_4 – conditional shortening of the criterion for the duration of the march;

O_1 – conditional shortening of restrictions on the level of readiness of each vehicle at the stage of formation of the column;

O_2 – conditional shortening of restrictions on the carrying capacity of vehicles;

O_3 – conditional shortening of restrictions on the volume of vehicle bodies;

O_4 – conditional shortening of restrictions on the passenger capacity of vehicles;

O_5 – conditional shortening of restrictions on the consumption of diesel fuel by vehicles from the composition of the column;

O_6 – conditional abbreviation of the restrictions on fuel consumption of one brand by vehicles from a composition of a column;

O_7 – conditional shortening of restrictions on fuel consumption of the second mark by vehicles from the composition of the column;

O_8 – conditional shortening of restrictions on fuel consumption of the third mark by vehicles from the composition of the column;

O_9 – conditional abbreviated designation of restrictions on the power reserve on the motor resource;

O_{10} – conditional abbreviated notation of restrictions on the duration of the march;

O_{11} – conditional shortening of restrictions on the level of readiness of vehicles when they arrive at their destination;

O_{12} – conditional shortening of restrictions on the number of vehicles in the column;

O_{13} – conditional shortening of restrictions on the number of makes of vehicles in the column;

G – designation of the graph corresponding to the road network.

INTRODUCTION

Today the issue of optimization of transport are extremely important in different fields of human activity, in particular, in solving various tasks of logistics. Successful implementation of many transportations depends significantly on the timely arrival of the convoy of vehicles to a specific destination. For the effective transportation of various cargoes by land, various modern vehicle with many features. Prior transportation planning and possible optimization of the composition of the machinery column with a wide range of factors. In the next step required is the solution of the problem of determining the optimal route of the technique column. There is quite an extensive network of roads leads to a significant number of possible routes that combine the place of its disposal destination. This multivariate is observed even at small distances, which need to be overcome. On the choice of the optimal route may essentially influence the dynamics of development of traffic situation. Due to the influence of predicted and stochastic factors, the velocity of the column in separate sections of the route varies significantly. Incorrect consideration of a possible change in road conditions can lead to incorrect formation of the structure of the column of vehicles and the choice of route. And this can ensure the timeliness of the arrival of the column at the destination. Consequently can occur the failure of certain tasks. Therefore, the task of organizing the march (complex solution of component problems) is relevant, and the presence of variability, a large number of factors that should be considered when dealing with it, their complex interactions and influence the result, causes considerable computational complexity of the problem and the need for powerful computational tools and the development of appropriate information technology to solve the problem.

The object of the research is to form the composition of the machinery column and to choose the route of its movement.

The subject of the research is the scientific and methodological apparatus of complex optimization of the composition of the column and the choice of the route of its movement.

The purpose of this work is to develop a method for solving a complex optimization problem of forming a machinery column and choosing the route of its movement on a non-stationary road network.

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1 PROBLEM STATEMENT

Given:

– the aggregate (set) $M = \{x_1; x_2; ...; x_n\}$ of vehicles from which the composition of the column of machinery for the carriage of personnel and cargoes may be formed, (U_1);

– the tactical and technical characteristics of each vehicle of this totality, (U_2).

Also specify a network of roads that connects the departure point (point A) to the destination (point B). The mathematical model of the road network is a marked graph G, whose edge weight is the length of the respective sections of the road, (U_3).

It is necessary to arrange transportation from point A to point B so that:

– the duration of the march was minimal, (K_4);

– coefficient of readiness of each vehicle is not less than the permitted level, (O_1);

– the total capacity of vehicles from the warehouse of the column allowed to carry goods, (O_2);

– the total volume of the bodywork of vehicles from the warehouse allowed to carry the goods, (O_3);

– the total passenger capacity allowed to carry personnel, (O_4);

– the total fuel consumption of vehicles from the convoy did not exceed the amount of fuel available to march by fuel type, (O_5,...,O_8);

– the stock of motorsource was not less than the distance of transportation, (O_9);

– vehicles arrived at point B with readiness not less than specified, (O_{11});

– the number of vehicles in the column was not greater than the specified value, (O_{12});

– the number of vehicle brands in the column was not greater than the specified value, (O_{13}).

However, it should be taken into consideration that during the movement of the column, the motion time along the individual edges can be variable. This condition is determined by the influence on the time of movement along a single edge of different conditions, such as climatic (rain, ice, fog, etc.), man-made (blockage of the roadway, its damage due to flooding of the terrain, etc.), changes in the period of day (day, night), etc.

It should also be taken into consideration that the calculation of the motion time along individual edges can be carried out:

1) at the moments when the column is at a certain vertex of the graph, and the calculation is made at those moments. This is a case where the decision on the further route of traffic is made at the points of branching of roads taking into account the situation due to the condition of individual sections, which changes dynamically and the data on which appear periodically;

2) at the times when the column is at a certain vertex of the graph, and for these moments the initial data on the speed of movement that will take place when the column enters the vertex are known in advance. This is a case where a route decision can be made at the beginning of the traffic, taking into account the well-known situation regarding the state of the roads, which will change dynamically, but the data on which can be taken into account in advance.

2 REVIEW OF THE LITERATURE

The issue of forming the composition of a column of vehicles for the efficient movement of goods has been given attention in a number of works, in particular [1–4].

Thus, in [2] the method of tactical calculations for determining the number of vehicles for transportation of goods took into account the characteristics of cargo, load capacity and speed of movement of vehicles, range of movement, loading time, unloading, refueling, resting drivers between trips (if applicable), as well as the timing of the movement of goods.

The work [3] reflects the issues of predicting the effectiveness of the march of military formation by the reliability of weapons and military equipment, as well as the impact on the march effectiveness of the number of repair units, the technical state of the equipment in terms of reliability, the level of efficiency of repair bodies in carrying out repairs and labor costs restoration of weapons and military equipment.

In [4], a variant of the cargo transportation model for finding the optimal route of transportation of goods from one sender to several consumers is presented in the transport network.

However, in the analyzed works [2–4] the requirements for the formation of the optimum composition of the vehicle column, such as the level of readiness, the stock of motorsource, the number of stamps and samples, the availability of fuel for refueling, etc., were ignored. These requirements were reflected in the author's work [1].

The choice of routes of movement of the transport column for the effective movement of cargos, as well as related problems, was given attention in a number of works, in particular in [5–17].

An approach to choosing the route based on "edgelabels" is given in work [5]. Its use makes it possible to speed up the search for the shortest path by 500 times compared to the standard Dijkstra algorithm over a large graph. In work [6], an algorithm for selecting optimal routes in a multimodal mode of a public transport network is presented. Based on the results of this study, the approach to routing of transit hubs has been adapted to plan public transportation. In the scientific work [7], the method of contraction hierarchy was used to find the shortest path. In the study [8], based on the application of the SHARC algorithm, the possibilities of finding the shortest paths for arbitrary means of transportation in the continental scale transport network were presented. The problem of multimodal route planning has been investigated in

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a scientific paper [9]. In the research [10] a model for estimating traffic delays of vehicles was presented, taking into account arbitrary loads in the process of movement. The study [11] provides route planning for military ground vehicles on the battlefield. An algorithm [12] developed an algorithm for solving the problem of finding the shortest paths in urban public transit routes, taking into account the duration of transplants using the branch and boundary method. In works [13–14], issues of the application of geoinformation technologies in solving logistics tasks in military affairs based on the application of modern ArcGIS information systems [15–17] are explored.

In the author's work [18], the problem of choosing the optimal route of movement of the machinery column of the border commandant rapid response was taken into account, taking into consideration the peculiarities associated with the pre-installation and ensuring the reliability of the initial data based on the use of spline functions [19–21]; mathematical models of the studied problem for three cases (discrete-stochastic, discretely-deterministic and continuous-indefinite) are constructed, which depend on the peculiarities of realization of column motion; Algorithms for choosing the optimal route of movement of the column of border command rapid response command for each possible case are proposed.

However, despite the sufficient attention that was paid to the authors, including the tasks of forming the optimal composition of the column of technique and choosing the route of its movement, the task of organizing a march that organically combines both one and the other of these tasks is not yet completely investigated. This is explained by the imprecision of approaches to solving this problem.

In view of this, the purpose of this work is to develop a method for solving a complex optimization problem of forming the composition of a column of machinery and choosing the route of its movement on a non-stationary road network.

3 MATERIALS AND METHODS

At the physical level, the formulated task of organizing the march consists in the complex solution of two interrelated problems: problem 1 – selection of the appropriate composition of the machinery column; problem 2 – choosing the appropriate route of its movement.

It should be noted that each of problems 1, 2 are solved separately from each other. The corresponding solutions are given in [1, 18].

The problem 1 is solved as a single-criterion optimization problem of the form:

Initial data

$$U_1, U_2, U_3 . \tag{1}$$

Criterion

$$f(K_1, K_2, K_3) \to \min . \tag{2}$$

The system of restrictions:

$$O_1, ..., O_9 . \tag{3}$$

$$O_{10} . \tag{4}$$

In problems (1)–(4), single criterion was obtained by the functional combination of three separate criteria K_1, K_2, K_3, which appeared in the direct formulation of Problem 1, and restriction O_{10} was obtained by transformation of criterion K_4.

The contents of the initial conditions, criteria and restrictions are described in detail in work [1].

The result of solving problem 1 is a set $M_1 = \{x_1; x_2; ...; x_m\}$, whose elements are specific vehicles that are part of the column.

Herewith, $m \le n$ and $M_1 \subset M$.

Problem 2 is solved as a single-criterion optimization problem of the form:

Initial data

$$M_1, U_2, U_3 . \tag{5}$$

Criterion

$$K_4 \to \min . \tag{6}$$

Problems (5)–(6) take into account the variability of the edges of the road network graph, as well as the format of such change – how it occurs, at what moments, at which stage, the dynamic matrixes of the edges are known.

The content of the initial conditions and the criterion of problem 2 are described in detail in work [18].

The result of the solution of problem 2 is the path of motion of the column $V_2 = \{v_1; v_2; ...; v_s\}$ – the set of vertices through which the path of movement must pass.

Herewith, $v_1 = A$, $v_s = B$.

The mathematical model of the problem under study in the following notations can be represented as an optimization problem of the following form:

Initial data

$$U_1, U_2, U_3 . \tag{7}$$

Criterion

$$K_4 \to \min. \tag{8}$$

The system of restrictions

$$O_1, ..., O_9, \tag{9}$$

$$O_{11}, \tag{10}$$

$$O_{12}, \tag{11}$$

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$$O_{13} . \quad (12)$$

Find

$$M_o = \{x_1; x_2; ...; x_r\}, \quad (13)$$

$$V_o = \{v_1; v_2; ...; v_z\} . \quad (14)$$

In Problems (7)–(14), the restriction O_{11} is obtained by converting the criterion K_1, restriction O_{12} – the criterion K_2, restriction O_{13} – criterion K_3 problems (1)–(4), $M_o = \{x_1; x_2; ...; x_r\}$ – the expedient composition of the column of machinery, and $V_o = \{v_1; v_2; ...; v_z\}$ – the expedient route of its motion.

The analysis of problem 1 in the form (1)–(4) and problem 2 in the form (5)–(6) leads to the conclusion that the solution of the studied problem in the form (7)–(14) can be such that $M_o = \{x_1; x_2; ...; x_r\} \neq M_1 = \{x_1; x_2; ...; x_m\}$, $V_o = \{v_1; v_2; ...; v_z\} \neq V_2 = \{v_1; v_2; ...; v_s\}$.

To solve the problem under study (7)–(14), we consider that the speed of movement of the column along the road network is a key factor that determines the time required to overcome the distance between the start of the route and the destination. Consider a possible approach to its definition. When traveling on the road, this speed is affected by a number of circumstances.

The first factor is the technical speed limitations of the vehicles that are part of the column. The speed of movement of the column may not exceed the minimum of the maximum permissible speeds of movement of the respective vehicles. The approach to determining this velocity can be estimated from [18]. Considering this factor in the model does not cause much difficulty. Let us denote it as $v_{\min kol}$.

The second factor is the speed limits of the road section. For each section of roads of all edges of the graph G the speed limits are determined due to the features of the section (its shape, type of pavement, angle of inclination, etc.). Of course, these restrictions are determined by the appropriate restrictive signs. Limitations of this type can be set as a function of the fraction of distance for each edge of the road graph. In the general case, this limitation may additionally depend on the time (the nature of the coverage may be changed, road works performed, additional restrictive signs may be established), so its consideration is the most difficult. To simplify, until we consider such a time dependence and denote this restriction $v_{ij}(x)$, where: i, j – are the vertices of the graph joined by an edge, x – is the coordinate that determines the position on that edge (varies from 0 to L_{ij} – the length of the corresponding edge).

The third factor is the global impact of weather, or time of day. Adverse weather conditions (heavy rain, snow, fog) or dark time can significantly limit the speed of the column. In particular, such an effect can be significant when combined with low temperatures (ice may occur). Of course, weather influences can also have a local character, then in addition to the time, the location of the column should be additionally taken into account. However, for the sake of simplicity, we will now only consider global weather effects that will only depend on the weather. Let us denote this factor $v_{pog}(t)$.

Given these factors, the speed of the column can be represented by the expression:

$$v_{ij}(t, x) = \min(v_{\min kol}; v_{ij}(x); v_{pog}(t)) . \quad (15)$$

Given the speed (15), you can calculate the passage time of each of the edges that make up the route:

$$t_{ij} = \int_0^{L_{ij}} \frac{1}{v_{ij}(t(x), x)} dx . \quad (16)$$

The complexity of (16) is due to the necessity of taking into account in the integrand the dependence of $t(x)$. This dependence can be taken into account in the calculation (16) in the numerical method as a constant component of T_i (the time of beginning of the passage of the edge *(i, j)*), to which is added the accumulated fraction of integration (16):

$$t(x) = T_i + \int_0^{x} \frac{1}{v_{ij}(t(y), y)} dy . \quad (17)$$

The residual travel time on the route is the sum of the time intervals (16) that are spent moving all the edges of the route

$$T = \sum t_{ij} . \quad (18)$$

The approach taken to determine the speed of the column at any given time and time of the column allows you to go directly to the description of the method of solving the complex optimization problem of the formation of the composition of the column and the choice of the route of its movement under conditions of dynamic change of the situation and taking into account the restrictions of the speed mode.

The method algorithm is proposed as follows.

In the first stage, a set of corteges should be formed that describes all possible routes that connect the starting point to the destination in the road graph (Fig. 1). Thus, to reduce the power of this set and, accordingly, the computational complexity of the problem, options are considered without repetitive passage of nodes.

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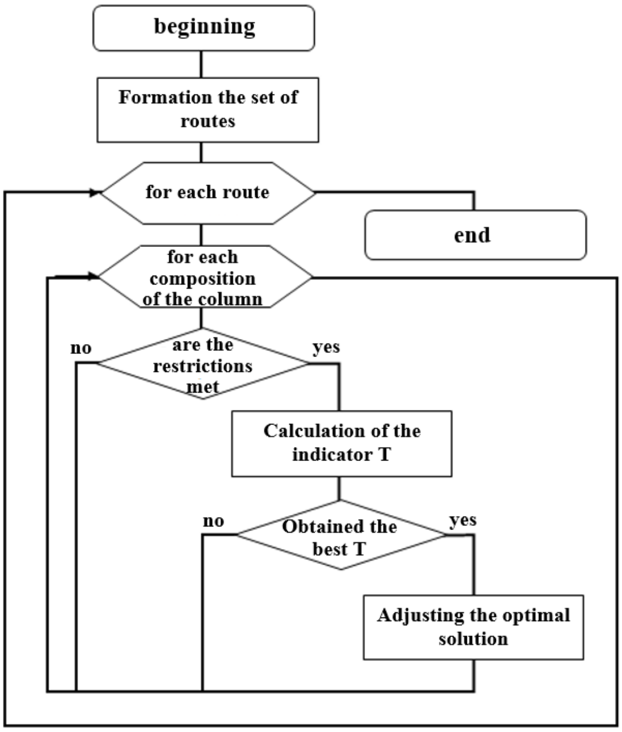

Figure 1 – Structure of the optimization algorithm

The construction of multiple routes without repeated passage of nodes is carried out on the basis of the modified Dijkstra algorithm described in research [18]. Subsequently, for each of these corteges (routes), a search is made of all possible options for constructing a column.

In such a search, the system of restrictions (9)–(12) is checked. Those columns that do not have this constraint system are not considered.

It should be noted that the implementation of individual restrictions is affected by the length of the route under consideration. This is one of the factors that link the two parts of the complex optimization problem under study.

For each variant of construction of the column, the resulting maximum speed of its motion is determined by the formula (15), as the speed of the vehicle with the worst speed capabilities that is included in its column.

Taking into account this speed and other factors, formulas (16)–(18) determine the time required to overcome the route by the investigated composition of the column. According to criterion (8) of minimum time, the best combination of route and column composition is chosen, which is the desired solution.

4 EXPERIMENTS

For the purpose of algorithmic-software implementation of the method described above, appropriate software was developed. The XML format (Fig. 2–3) was used for the convenience of describing the output data (vehicle fleet and road network).

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        <point l="10" v="100" />
        <point l="15" v="40" />
        <point l="20" v="80" />
    </rebro>
    <rebro x="A" y="C" vaga="81,7">
        <point l="0" v="60" />
        <point l="11" v="100" />
        <point l="26" v="80" />
        <point l="45" v="40" />
        <point l="63" v="80" />
        <point l="75" v="60" />
    </rebro>

  </graph>
</head>
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Figure 2 – Fragments of file of road network description

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```

Figure 3 – Vehicle fleet description file

The experimental studies considered the network of roads described by the graph shown in Fig. 4. This graph shows the weight of the edges that describes the lengths of the corresponding road fragments.

Fig. 4 shows the location from which the column (node A) and destination (node H) leave. Using the modified Dijkstra algorithm to find the shortest route allows you to determine the optimum distance for the ABEH route with a total length of 251.7 km.

However, when traveling on a network of roads at different speeds, the shortest route will not always provide the minimum amount of time spent traveling.

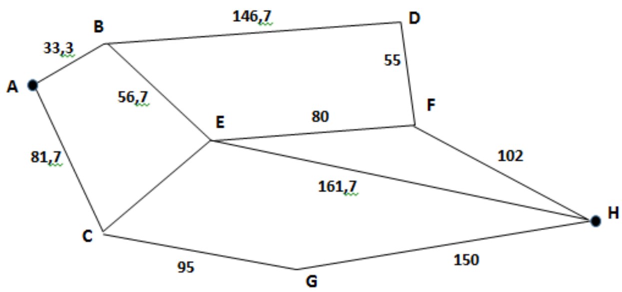

Figure 4 – Road network graph

5 RESULTS

We will evaluate the results of determining the optimal composition of the column in combination with optimizing the route of its movement from point A to point H. In the first stage, we will determine the essential requirements for the transportation of people and cargo. To accomplish this, a large list of vehicles with significant restrictions on the maximum speed of movement had to be used in the formation of the column (Fig. 5).

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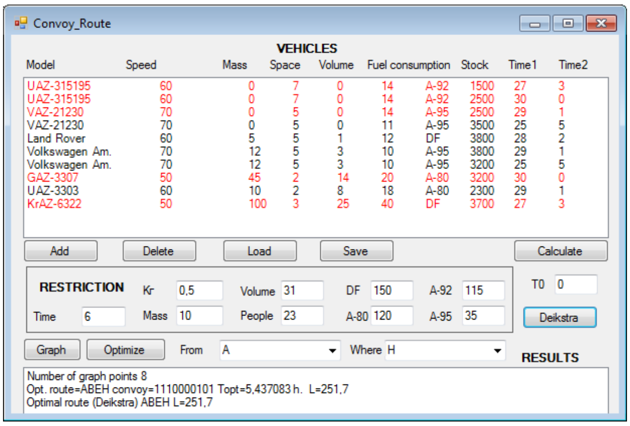

Figure 5 – Optimization result with significant constraints

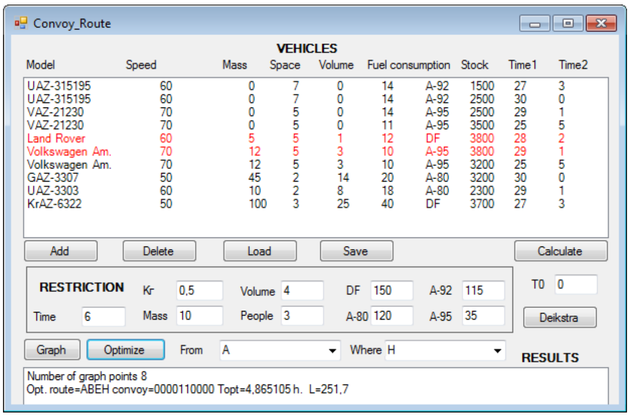

Figure 6 – Optimization result with moderate constraints

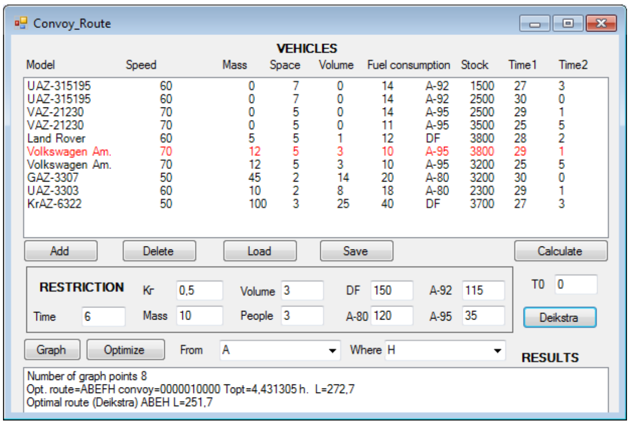

Figure 7 – Optimization result with slight constraints

With such a convoy structure, restrictions on the maximum vehicle speed (50 km/h) make it impossible to realize the high-speed potential of the roads themselves. Therefore, the route obtained is the same as the shortest route obtained using the Dijkstra algorithm. The weakening of the requirements for the carriage of people and the volume of cargo reduces the composition of the column and improves its speed from 50 km/h to 60 km/h (Fig. 6).

Improving the speed of the column leads to an improvement in the optimization score. Travel time decreased from 5.44 h to 4.87 h. However, with such an increase in the average speed of the route (from 46 km/h to 52 km/h), the route itself has not changed.

With further weakening of the traffic requirements as a result of the optimization, the column remains the only vehicle that has the best speed characteristics and which meets the other requirements for the composition of the column (Fig. 7).

With this composition of the column and improving its speed characteristics (up to 70 km/h), there is a further reduction of time to 4.43 hours. However, the most interesting part is the change of route, which becomes different from the shortest. This change is explained by the fact that when moving from node E to node H, although the length of the edge {EN} is smaller than the section {EFH}, but the speed of movement on this edge is less. At the low possible speed of movement of the column, this advantage of the road section {EFH} was not realized (Fig. 5–6). However, when it is increased to 70 km/h, this variant of the route leads to an improvement in the time frame for optimization. And despite the increase in the distance of the route from 251.7 km to 272.7 km, by increasing the average speed to 61.6 km/h, the resulting time was reduced to an optimum value of 4.43 h.

Let us now study the impact on the result of solving the complex optimization problem of reducing the speed of movement of the column due to the worsening weather conditions. To this end, the program implemented speed limits from 10 to 12 hours to 20 km/h. The *T0* parameter is used to set the start time of the column exit.

Consider the impact of this factor in the formation of columns for transportation of 3 people and cargo volume of 3 m3. With such restrictions, as shown above, the column is formed of 1 car. We carry out the solution of the optimization problem when changing the parameter *“T0”* from 4 to 12 hours (Fig. 8).

According to the calculation results, for the initial time of 4 and 5 hours the results are identical and coincide with the 0 hour variant (Fig. 7). This is explained by the fact that it takes 4.43 hours to move the column and therefore the factor of influence of weather conditions is excluded (the column arrives at destination till 10 o’clock). However, for the initial time of 6 hours, it begins to be partially affected, and the restriction of the speed of the last sections of the route leads to an increase in the time to move almost one hour.

Most interesting is the effect of this factor at the departure time of the column at 7 and 8 o’clock. Speed limitation at the final stage of the movement eliminates the benefits of detours at {EFH}, where good speed is ensured. Therefore, the shortest route is optimal. At the departure of the column from 9 to 11 o’clock, the speed limitation is carried out at the initial sections of the route and the route {ABEFH} becomes optimal again. However, different periods of time from 5.09 to 5.8 hours are spent to overcome it. The last optimization option in Figure 8 corresponds to a 12-hour departure time when the weathering

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effect is complete. Therefore, the result obtained is the same as the variants for T0 values: 0, 4 and 5 hours.

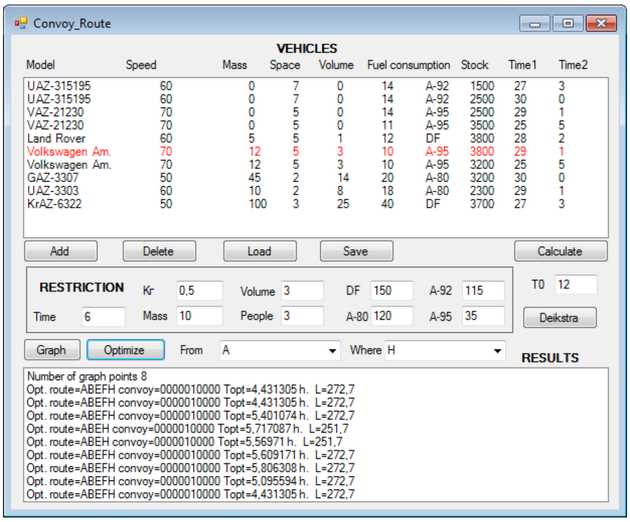

Figure 8 – Optimization result when the initial column departure time changes

Consider also the column option with moderate constraints that determine the formation of a column of two cars. Fig. 9 shows the optimization results for *T0* values from 4 to 12 hours. Similar to the previous variant, the initial two cases show no influence of the speed limits (the column manages to pass the route before the negative influence of the weather conditions begins).

It is interesting to change the optimal route for *T0* 6 and 9 hours. All variants affected by negative conditions are subject to greater travel time values.

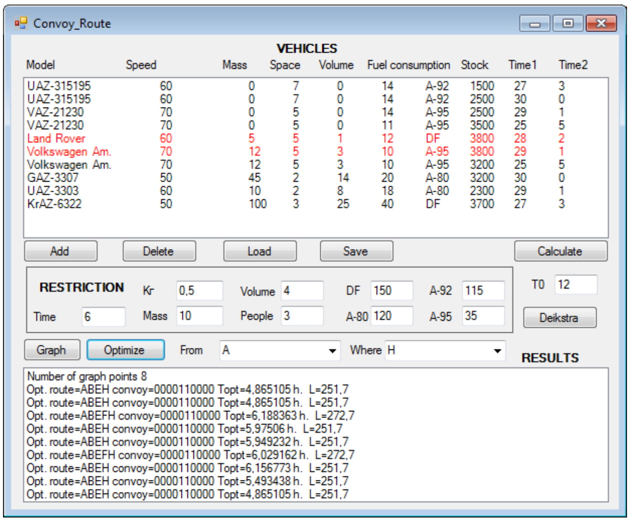

Figure 9 – Changing the route for a column of 2 vehicles

6 DISCUSSION

The method of solving the complex optimization problem of forming a column of machinery and choosing the route of its movement on a non-stationary road network proposed in this study allows to take into account the initial conditions and restrictions on the level of readiness of each vehicle at the stage of forming a column, load capacity, body volume and passenger capacity of vehicles, consumption of different types of fuel by vehicles from the composition of the column, the reserve of the course on motor resources, duration of march, the level of readiness of transport which means at the moment of arrival at the destination, the number of vehicles and their brands a part of the column that best approximates the studied problem to real conditions.

However, although the proposed method allows to solve the problem under study, the question of choosing a sampling step in the study of the mathematical model and quantitative assessment of the reliability of the obtained results remain relevant. In order to predict the impact of changes in road conditions on the movement of the column, it is advisable to consider the use of artificial intelligence methods, in particular, neural networks.

CONCLUSIONS

Thus, the task of organizing the march, which provides a complex solution to the problems of forming the composition of the column of machinery and choosing the route of its movement, is set out in the work, as well as its mathematical model is formed.

Taking into account the peculiarities of the model, which are determined by the influence of stochastic factors, the method of complex choice of composition of the column of technique and the optimal route of its movement is proposed. Algorithmic software is also formed, which takes into account a considerable part of the features of the model.

The study looks at an example of using the proposed method for a fragment of the horn network and shows a significant relationship between the two partial problems, which is amplified by the increase in the influence of the hundred-host factor.

The application of the proposed method can allow avoiding unreasonable decisions when organizing movements.

The scientific novelty of the obtained results lies in the formalization of the problem of complex search for the composition of the column of vehicles and the route of its movement, taking into account the dynamics of the change of the road situation, the structure of the corresponding mathematical model and the method of its solving. The results of computational experiments confirmed the interdependence of partial problems of the studied complex problem. The proposed scientific and methodological apparatus expands on the scientific toolkit of the theory of discrete optimization and the theory of graphs.

The practical significance of the obtained results is to increase the efficiency of logistic transportations by optimizing the composition of the column of machinery and routes of its movement. The software-algorithmic implementation of the proposed method allows to expand the functionality of the respective software and hardware complexes.

The prospects for further research are to investigate the effectiveness of the proposed mathematical model. It is also promising to explore the possibility of using artificial intelligence methods to predict the development of road conditions.

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МЕТОД РОЗВ'ЯЗАННЯ КОМПЛЕКСНОЇ ОПТИМІЗАЦІЙНОЇ ЗАДАЧІ ФОРМУВАННЯ СКЛАДУ КОЛОНИ ТЕХНІКИ ТА ВИБОРУ МАРШРУТУ ЇЇ РУХУ ПО НЕСТАЦІОНАРНІЙ МЕРЕЖІ ДОРІГ

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АНОТАЦІЯ

Актуальність. Ефективне вирішення ряду прикладних задач, що стосуються перевезень, як правило, залежить від розв'язання двох задач: коректного формування складу колони техніки та вдалого вибору маршруту її руху. Кожна із задач є оптимізаційною, методи вирішення яких на даний час опрацьовані. Теоретичні дослідження кожної з окремих задач і їх практичні застосування вказують на їх взаємозалежність і взаємообумовленість, що ще не до кінця вивчено. Практичні застосування обумовлюють необхідність розвитку відповідного науково-методичного апарату.

Мета. Метою роботи є розробка методу розв'язання комплексної оптимізаційної задачі формування складу колони техніки та вибору маршруту її руху по нестаціонарній мережі доріг.

Метод. У роботі запропонована математична модель розв'язування оптимізаційної задачі комплексного формування складу колони техніки та вибору її маршруту руху. Для опису масиву, з якого здійснюється вибір транспортних засобів, використано неоднорідну множину. Для опису мережі доріг використаний граф. В якості критерію оптимальності комплексної задачі виступає мінімізація часу, який витрачається на переміщення. Особливістю моделі є врахування у ній можливості динамічної зміни часових ваг ребер графу при реалізації переміщення колони техніки по обраному маршруту. На основі використання даної моделі запропоновано метод, який забезпечує комплексний вибір складу колони техніки та оптимальних маршрутів її руху на нестаціонарній мережі доріг.

Результати. У статті запропоновано алгоритм, що забезпечує розв'язування оптимізаційної задачі комплексного формування складу колони техніки та вибору її маршруту руху в умовах нефіксованої в часі ваги ребер, які описують мережу доріг. Наведено особливості застосування запропонованого алгоритму. З використанням розробленого програмного забезпечення досліджено варіант вибору техніки з наявного неоднорідного масиву та вибору маршруту на графі з нестаціонарною часовою вагою ребер. На прикладі показано недосконалість рішень щодо комплексного формування складу колони та вибору її оптимального маршруту руху на нестаціонарній мережі доріг, отриманих з використанням класичних методів.

Висновки. Неврахування впливу можливої зміни дорожньої обстановки, що проявляється зміною в часі часових ваг ребер графа, який описує мережу доріг, на склад колони техніки може призвести до неоптимальності отримуваних рішень з використанням класичних методів формування складу колони та пошуку найкоротшого маршруту в графі. Для отримання оптимального складу колони та маршруту з урахуванням зміни в часі дорожньої обстановки при русі колони, можна використати запропонований у даному дослідженні метод. Отримані результати розширюють можливості теорії дискретної оптимізації і теорії графів.

КЛЮЧОВІ СЛОВА: комплексність, оптимізаційна задача, граф, нестаціонарність, метод.

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МЕТОД РЕШЕНИЯ КОМПЛЕКСНОЙ ОПТИМИЗАЦИОННОЙ ЗАДАЧИ ФОРМИРОВАНИЯ СОСТАВА КОЛОННЫ ТЕХНИКИ И ВЫБОРА МАРШРУТА ЕЕ ДВИЖЕНИЯ ПО НЕСТАЦИОНАРНОЙ СЕТИ ДОРОГ

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АННОТАЦИЯ

Актуальность. Эффективное решение ряда прикладных задач, касающихся перевозок, как правило, зависит от решения двух задач: корректного формирования состава колонны техники и удачного выбора маршрута ее движения. Каждая из задач является оптимизационной, методы решения которых в настоящее время определены. Теоретические исследования каждой из отдельных задач и их практические применения указывают на их взаимозависимость и взаимообусловленность, что еще не до конца изучено. Практические применения обусловливают необходимость развития соответствующего научно-методического аппарата.

Цель. Целью работы является разработка метода решения комплексной оптимизационной задачи формирования состава колонны техники и выбора маршрута ее движения по нестационарной сети дорог.

Метод. В работе предложена математическая модель решения оптимизационной задачи комплексного формирования состава колонны техники и выбора ее маршрута движения. Для описания массива, с которого осуществляется выбор транспортных средств, использовано неоднородное множество. Для описания сети дорог использован граф. В качестве критерия оптимальности комплексной задачи выступает минимизация времени, которое тратится на перемещение. Особенностью модели является учет в ней возможности динамического изменения временного веса ребер графа при реализации перемещения колонны техники по выбранному маршруту. На основе использования данной модели предложен метод, который обеспечивает комплексный выбор состава колонны техники и оптимальных маршрутов ее движения по нестационарной сети дорог.

Результаты. В статье предложен алгоритм, обеспечивающий решение оптимизационной задачи комплексного формирования состава колонны техники и выбора ее маршрута движения в условиях нефиксированного во времени веса ребер, которые описывают сеть дорог. Приведены особенности применения предложенного алгоритма. С использованием разработанного программного обеспечения исследовано вариант выбора техники из имеющегося неоднородного массива и выбора маршрута на графе с нестационарным временным весом ребер. На примере показано несовершенство решений комплексно-

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го формирования состава колонны и выбора ее оптимального маршрута движения на нестационарной сети дорог, полученных с использованием классических методов.

Выводы. Неучет влияния возможного изменения дорожной обстановки, что проявляется изменением во времени временного веса ребер графа, которое описывает сеть дорог, на состав колонны техники может привести к неоптимальности получаемых решений с использованием классических методов формирования состава колонны и поиска кратчайшего маршрута в графе. Для получения оптимального состава колонны и маршрута с учетом изменения во времени дорожной обстановки при движении колонны, можно использовать предлагаемый в данном исследовании метод. Полученные результаты расширяют возможности теории дискретной оптимизации и теории графов.

КЛЮЧЕВЫЕ СЛОВА: комплексность, оптимизационная задача, граф, нестационарность, метод.

ЛІТЕРАТУРА / ЛИТЕРАТУРА

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