

Запропоновано метод побудови раціонального маршруту на основі модифікації мурашиного алгоритму з введенням функції якості, що характеризує реальний стан доріг. Комплексна оцінка потенційних маршрутів враховує практичну пропускну спроможність, реальний стан ділянок маршруту та інтенсивність руху транспортних засобів. Проведено порівняння результатів розрахунків на основі класичного й модифікованого мурашиних алгоритмів

Ключові слова: раціональний маршрут, вантажні автомобільні перевезення, модифікований мурашиний алгоритм, якісний стан доріг, пропускну спроможність ділянок маршруту

Предложен метод построения рационального маршрута на основе модификации муравьиного алгоритма с введением функции качества, характеризующей реальное состояние дорог. Комплексная оценка потенциальных маршрутов учитывает практическую пропускную способность, реальное состояние участков маршрута и интенсивность движения транспортных средств. Проведено сравнение результатов расчетов на основе классического и модифицированного муравьиных алгоритмов

Ключевые слова: рациональный маршрут, грузовые автомобильные перевозки, модифицированный муравьиный алгоритм, качественное состояние дорог, пропускная способность участков маршрута

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DEVELOPING THE METHOD OF RATIONAL TRUCKING ROUTING BASED ON THE MODIFIED ANT ALGORITHM

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1. Introduction

In today's conditions, efficient development of transport is a guarantee of stability and growth of the national economy. However, in difficult economic conditions, particular attention is paid to the problems of logistics as a means of optimizing the activity of transport and logistics enterprises. Implementation of logistic principles enables efficient management of transport potential of enterprises.

Quality of transport services is characterized not only by the cost-effectiveness of deliveries. Efficiency of functioning of the transport service users depends both on the amount of the delivery fares and the aspects of delivery quality such as timeliness, security, etc. In practice, when choosing a delivery option, merely the bulk of the costs associated with

the delivery, namely the transport component is often taken into account [1].

The study of demand for transport services shows that the most important requirement of customers is the timely delivery of goods. It is caused by the desire of many cargo owners to reduce inventories in production and consumption since the costs of maintaining inventories in a number of industries account for more than 20 % per unit of output. Therefore, in rational routing for trucking, a number of parameters that characterize road throughput, traffic intensity, road qualitative state, weather conditions in various road sections, availability of service infrastructure, etc. and materially affect delivery terms and quality should be taken into account. Therefore, development and improvement of the methodology of multiparametric optimization of rational routing the trunk-road freight is a relevant scientific and applied problem.

2. Literature review and problem statement

At present, logistics acts as a scientific line playing an important role in complex automation and rationalization of the process of transportation of goods and passengers. The main objective of logistics is the rational impact on management of material flows to meet the demand of consumers and delivery of goods in exact terms. The concept of logistics is construction of integrated logistics systems from design to waste recycling and processing secondary raw materials.

Therefore, numerous works of well-known scientists are devoted to solution of transport logistics problems. One of the fundamental works in which methodological principles of applying logistic approaches under multicriteria and stochastic conditions are systematized in work [1]. Topical issues of formation of integrated supply chains are presented in [2]. Classification of models and methods used in the theory of transport logistics when planning the trucking routes is given in [3]. Current methods of planning, organizing and managing automobile freight are considered in [4]. Considerable attention is paid to organization of urban transportation of both cargo and passengers. For example, the issue of organization of functioning of the city's transport network was studied, the causes and mechanism of traffic jam formation and the ways of overcoming them were considered in [5]. Particular attention is paid to the issue of optimization of passenger transport. However, the problems of improving transport services and bringing transport services to a higher level of quality are considered insufficiently. When considering transportation problems, it is proposed to evaluate transportation as an integral system, rather than to rank according to criteria [6].

The variety of criteria and constraints in applying the transport problem in various practical fields has led to the emergence of a large number of problems that simulate the freight processes. However, the scientific problem in trucking consists in the lack of effective freight optimizing methods which would take into account limitations of road throughput [7].

At present, most motor transport companies use automated systems for controlling vehicle travel in the route, for example: GPS, Top Route Top Logistic, Yandex Routes. As stated in [8], all of the above programs are alike and differ just in the cost of the licensed product. Greater costs are explained by availability of greater number of functions. However, despite the fact that there are many SCM class software packages, much of the freight management problems remain unresolved.

Papers [9–12] deal with the development of models, solution of the transport network optimization problems and optimal routing. The study of the model of the logistics system for cargo transportation between Ukraine and Belarus in which it is proposed to take into account the total costs of all participants in the logistics process as a criterion of freight efficiency is presented in [9]. The method for determining the freight scheme based on the multicriteria assessment using expert evaluation of selected qualitative and quantitative criteria is proposed in [10]. A mathematical model for solving a complex multicriteria problem of determining truck backhaul, coordinating the vehicle working schedule and cargo handling is proposed in [11]. Development of the algorithm for designing a system of cargo transportation in conditions

of modern tendencies of transport-logistic support with minimization of total costs is described in [12]. However, to use more effectively these results, one must take into account the actual state of the road network.

The Free Way software product, which simplifies modeling the traffic flows, is proposed for use in paper [13]. Dynamics of speeds in various groups of streets at various times of the day was investigated and the use of labels stored in the database was implemented. However, despite a significant number of scientific works devoted to the study of the traffic flow optimization problems, it is untimely to consider the given problem solved completely.

Today, routing is the key logistics problem. There are numerous methods for solving problems of a discrete type to optimize logistics processes but they do not provide clear solution of the existing problems. Therefore, the search for an optimal solution to the assignment problem has resulted in the use of natural behavioral phenomena, e.g. behavior of an ant colony. Solution of the transport problem based on the algorithm of ant colonies for multimodal freight and the expanded travel salesman problem are given in [14, 15], respectively. In these works, application of the classical ant algorithm is expanded by introduction of parametric indicators and weight coefficients. The use of a hybrid simulated ant algorithm to minimize the total running time of tugs in the port is proposed in [16].

The ant algorithm method can be used both for static models and for dynamic models of combinatorial problems. In any case, optimal solution will be obtained since convergence in this problem is guaranteed but the convergence rate remains uncertain and depends on many factors.

Methods for solving problems based on the classical ant algorithm are quite competitive compared to other heuristic methods. Combined effective optimization based on the algorithms involving several local search algorithms is presented in [17]. According to the authors, this approach provides satisfactory scalability and is competitive compared to other meta-heuristic algorithms. The search for a solution to the problems of combinatorial optimization is considered in [18] where a new modification of the ant colony algorithm of the adaptive local search method is proposed.

The scope of solving the applied problems based on the ant algorithm is quite wide. Application of the ant algorithm for planning multiprofile operations in production systems is given in [19, 20]. A multi-purpose programming model for optimizing an import crude oil transportation network based on the use of genetic and ant algorithms is given in [21].

In practice, to facilitate calculations of roadway throughput, the mixed traffic flow is reduced by coefficients to a homogeneous flow, usually car flow. However, this approach does not take into account dynamic dimensions of the car [22, 23].

Improvement of the methods based on the classical ant algorithm, modification of the algorithm itself allows to obtain more precise solutions of multicomponent problems in various spheres of production activity. However, in developing rational road transportation routes, insufficient attention is paid to taking into consideration qualitative characteristics of roads. Taking into account condition of road sections and their throughput is necessary in logistics routing in order to avoid traffic in the road sections with a hindered or partially impossible traffic.

3. The aim and objectives of the study

The study objective was to formulate a method for a rational truck freight routing between the departure and destination points based on a modified ant algorithm.

In accordance with this objective, the following tasks were set:

- substantiate lines of modification of the ant algorithm;
- form the function of quality of the freight process based on studying the state of individual sections and determining their theoretical throughput in the designed routes;
- compare effectiveness of classical and modified algorithms on an example of optimal routing between the departure and destination points.

4. Formation of the method for rational routing of the road freight

Routing is an iterative process that combines the synthesis procedures when developing and analyzing the already formed design solutions. The state of the problem of structural analysis in design and logistics is given in [24].

The problem of freight routing belongs to the class of the problems of spatial-temporal synthesis and is one of the most difficult to solve.

Consideration of a large number of parameters characterizing the system of cargo delivery, stochasticity, uncertainty and variability of many of them necessitates the use of heuristic algorithms.

Approaches to solution of the problems of structural synthesis are divided into two groups: the use of intellectual methods, mainly these are expert methods, and application of discrete optimization methods.

The presence of qualitative variables among the controlled parameters necessitates search for solutions in nonmetrizable spaces. This often leads to the need for quasi-optimal solutions based on evolutionary methods [25]. Evolutionary algorithms use the principles of adaptation of living organisms to the environment conditions in the process of their evolution.

Groups of evolutionary methods such as genetic methods (Genetic Algorithms, GA); methods of crowd behavior (Particle Swarm Optimization, PSO) and ant colony (Ant Colony Optimization, ACO) were further developed.

Application of the evolutionary approach involves:

- 1) formation of a plurality of controlled parameters (X);
- 2) development of a model and algorithm for determining the function of purpose ($F(X)$);
- 3) development of algorithmic realization of evolutionary methods.

Because of the proximity and statistical nature of these methods, the main line of studies is obtaining of a more efficient algorithm, both in terms of accuracy and laboriousness.

There is a known variant of the ant algorithm (classical), which is used in applied problems to determine transition probabilities taking the form [26].

$$\begin{cases} P_{ij,k}(t) = \frac{[\tau_{ij}(t)]^\alpha [\mu_{ij}(t)]^\beta}{\sum [\tau_{ij}(t)]^\alpha [\mu_{ij}(t)]^\beta} \cdot 100\%, j \in J_{i,k}, \\ P_{ij,k}(t) = 0, j \notin J_{i,k}, \end{cases} \quad (1)$$

where τ_{ij} is the number of pheromones on the edge (i, j) representing how “more desirable” was one or another way in the previous iterations and how it changes with each iteration; μ_{ij} is visibility which is inversely proportional to the distance L_{ij} between points i and j ; α, β are parameters that specify importance to the pheromone trace and visibility. At $\alpha=0$, the closest point is chosen ignoring each time the experience of predecessors. When $\beta=0$, only experience of the predecessors is taken into account and the distance between the points in the route is completely ignored.

When rational routing is made, it is important to look for options that most effectively use the actual state of the transport infrastructure and ensure fulfillment of special freight conditions. Therefore, it is necessary to consider operational condition of the road sections, their throughput and the traffic volume when developing efficient transportation routes. In addition, each road section is characterized by the following parameters:

- the number of lanes in one direction;
- the roadway condition;
- the traffic flow structure;
- the distance between the route points.

Therefore, for constructing rational road routes, it is proposed to apply a modified method of the ant algorithm by introducing a function of quality $\epsilon_{ij}(t)$, which characterizes the state of roads in each section of the route between the points and is defined as follows:

$$\epsilon_{ij}(t) = \omega_{ij}(t) \cdot R_{ij}(t), \quad (2)$$

where $\omega_{ij}(t)$ is a membership function that characterizes roadway condition in the road section; $R_{ij}(t)$ is expert estimation of throughput of the route sections (the coefficient characterizing throughput of the road section with the probability of emergence of vehicles of diverse types); t is the iteration number in execution of the ant algorithm.

The complexity of formalizing the roadway condition in individual sections of the route requires the use of the apparatus of fuzzy sets for approximate reasoning and fuzzy logic [1]. The complexity of obtaining the function of membership $\omega_{ij}(t)$ for assessing the roadway condition consists in that it is impossible to quantify important indicators, that is, to obtain a formalized estimate.

To formalize description, the roadway condition was estimated by appropriate coefficients:

- $\omega_{ij}=0.5$ at unsatisfactory state of the road where there are ruts, potholes or partially missing asphalt road covering;
- $\omega_{ij}=0.75$ at a partially satisfactory state of the road where hillocks, small potholes, etc. occur rarely;
- $\omega_{ij}=1$ at a satisfactory condition of the road section.

To obtain an expert estimate of throughput of individual sections $R_{ij}(t)$ of the route, it is proposed:

- 1) determine theoretical throughput of each of the road sections taking into account the probability of appearance of vehicles of diverse types in it according to formula [27]

$$P_{ij}(t) = s_{ij}(t) \cdot V_{ij}(t) \cdot q_{ij}(t), \quad (3)$$

where $s_{ij}(t)$ is the coefficient depending on loading of the opposite lane in a certain section of the route between points i and j ($s_{ij}=1.3$ at a low loading of the opposite lane;

$s_{ij}=1$ at a uniform traffic distribution outside the lanes; $s_{ij}=0.99$ at a high loading of the opposite lane); $V_{ij}(t)$ is average speed at the considered section (km/hr); $q_{ij}(t)$ is the maximum traffic density in the considered section (vehicle/km):

$$q_{ij} = \frac{L}{l_{calc}},$$

where L is the length of the section under consideration; l_{calc} is the interval between vehicles.

To calculate the parameter l_{calc} , formula [27] is used:

$$l_{calc} = \rho_c^2 l_{cc} + \rho_c \rho_l l_{cl} + \rho_c \rho_t l_{ct} + \rho_l \rho_c l_{lc} + \rho_l^2 l_{ll} + \rho_l \rho_t l_{lt} + \rho_t \rho_c l_{tc} + \rho_t \rho_l l_{tl} + \rho_t^2 l_{tt}, \quad (4)$$

where ρ_c, ρ_l, ρ_t is the actual probability of appearance of a car, a lorry and a tractor vehicle, respectively (determined by statistical data or by the traffic composition); l_{ct}, l_{cl}, l_{tl} are the intervals between vehicles of diverse types taking into account their length (Table 1, [27]).

Table 1

Calculation intervals between vehicles of different types

Type of the next vehicle in the traffic	Vehicle type		
	cars	lorries	tractor vehicles
cars	7.3	9.3	13.2
lorries	9.0	9.7	14.1
tractor vehicles	13.0	14.2	17.3

The average speed of vehicles is determined by the data on the condition of individual road sections taking into account the number of lanes.

2) based on the theoretical estimation of throughput of each of the road sections, an expert estimate is found and the expert coefficients R_{ij} are determined (Table 2).

Table 2

Expert estimation of throughput of the route sections

Item No.	Throughput, P_{ij} , vehicle/hr	Expert opinion, R_{ij}
1	0–300	0.15
2	300–600	0.3
3	600–900	0.45
4	900–1,200	0.6
5	1,200–1,500	0.75
6	≥ 1500	1

Taking into account the above considerations, the following modified model of the ant algorithm with introduction of the quality function $\epsilon_{ij}(t)$ is proposed to determine the probability of choosing a route:

$$\begin{cases} P_{ij,k}(t) = \frac{\epsilon_{ij}(t) [\tau_{ij}(t)]^\alpha [\mu_{ij}(t)]^\beta}{\sum_{l \in J_{i,k}} \epsilon_{ij}(t) [\tau_{ij}(t)]^\alpha [\mu_{ij}(t)]^\beta} \cdot 100\%, J \in J_{i,k}, \\ P_{ij,k}(t) = 0, j \notin J_{i,k}. \end{cases} \quad (5)$$

Concerning the main indicators, the algorithm for implementing the proposed model uses the classical probabilistic-proportional rule. However, the probability of passage of each section of the route will be different for each ant.

Next, the amount of pheromone that will be deposited by the ant after the passage of each section of the route is determined. The classical formula which determines the amount of pheromone after each iteration, has the form:

$$\Delta\tau_{ij,k}(t) = \begin{cases} \frac{Q}{L_k(t)}, & \text{if } (i, j) \in T_k(t), \\ 0, & \text{if } (i, j) \notin T_k(t), \end{cases} \quad (6)$$

where $T_k(t)$ is the route passed by the ant k in the iteration t ; $L_k(t)$ is the length of this route; Q is an adjustable parameter with its value chosen of the same order as the order of the optimal route length.

Let us assume that pheromone on the routes is renewing after each iteration according to the classical formula [26] taking into account the parameter of pheromone evaporation. The parameter of pheromone evaporation is indicated by ρ and the range of ρ values is within $[0, 1]$.

Then, the rule of pheromone renewal takes the form:

$$\tau_{ij}(t+1) = (1-\rho) \cdot \tau_{ij}(t) + \Delta\tau_{ij}(t), \quad (7)$$

$$\Delta\tau_{ij}(t) = \sum_{k=1}^m \Delta\tau_{ij,k}(t),$$

where m is the number of ants in the colony.

At $\rho=0$, the colony will take into account all routes, including those that are completely ineffective. In this case, it will be very difficult to reach the optimal route.

In the case of $\rho=1$, the ant remembers the experience of only his predecessor and the experience of other ants is completely ignored. Again, there is a high probability that ants will go admittedly the wrong way.

Then, with respect to the criteria introduced, the economic-mathematical model of route optimization takes the form:

$$\begin{cases} \sum_{i=1}^n \sum_{j=1}^n L_{ij} \rightarrow \min \\ 0 \leq \omega_{ij} \leq 1; \\ 0 \leq \alpha \leq 1; \\ 0 \leq \beta \leq 1; \\ 0 \leq \rho \leq 1; \\ Q_{\min} \leq Q \leq Q_{\max}; \\ 0 \leq R_{ij} \leq 1. \end{cases} \quad (8)$$

At the beginning of the calculation, the amount of pheromone is assumed to be equal to a small positive number τ_0 . The total number of ants remains unchanged during execution of the entire algorithm.

To elaborate solutions of the optimization problem (8), the results of statistical analysis and expert opinions are used based on available sources of information, Internet materials, etc.

5. Results obtained in the studies of the choice of a rational automobile freight route

To check effectiveness of the proposed approach, consider the problem of choice of a rational freight route between the cities of Odesa and Dnipro. Possible routes from the starting point to the end-point and back and the length of individual sections were determined using the Google Map resource. Using its Street View mode and analyzing the information found on the Avtostrada: The Current State of Ukrainian Roads Internet site [25], roadway quality on established routes was estimated (Table 3). Sections of the road network chosen for routing between Odesa and Dnipro are shown in Fig. 1. For numerical experiments, potential routes were divided into items with names and numbers: 1 – Dnipro; 2 – turn to Znamyanka; 3 – Kryvy Rih; 4 – Dniprovski Khvyli; 5 – Znamyanka; 6 – Nikopol; 7 – Maryanske; 8 – Kropyvnytsky; 9 – turn to Vozsiyatske; 10 – Kherson; 11 – Vozsiyatske; 12 – Mykolaiv; 13 – turn to Voznesensk; 14 – Voznesensk; 15 – turn to Odesa; 16 – Odesa. The corresponding model of the graph of the calculated polygon of the transport network is shown in Fig. 2.

The results of calculations, formal description of the roadway quality and the final value of ϵ_{ij} coefficient are given in Table 3.

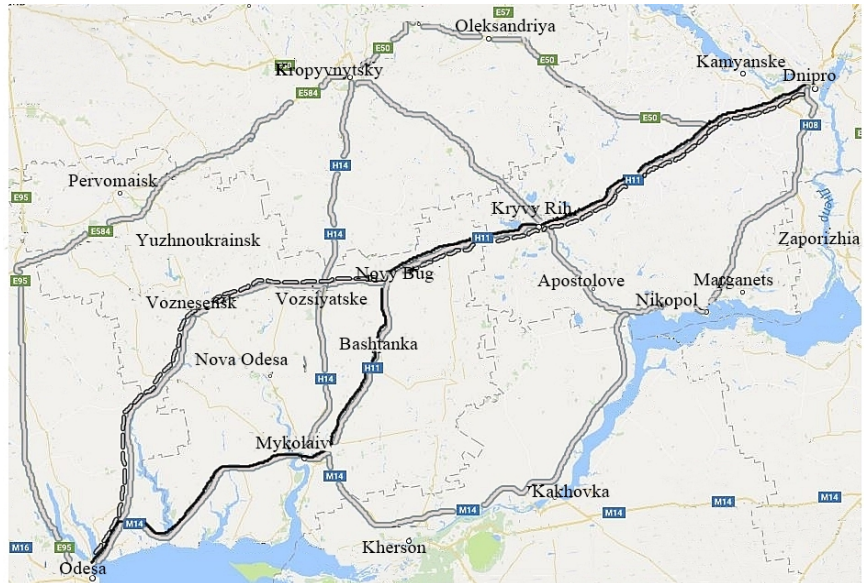


Fig. 1. Mapping of the routes where: — — a network of possible routes; — — the route in implementation of the classical ant algorithm; - - - - the route when applying a modified ant algorithm

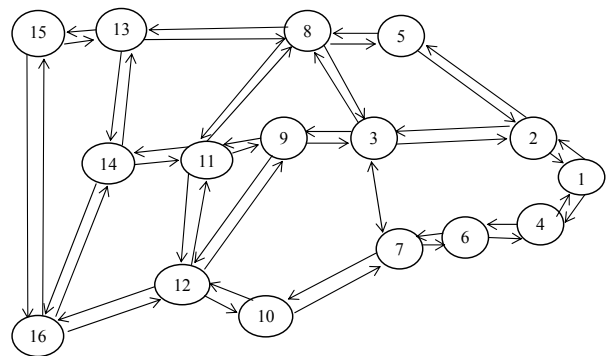


Fig. 2. Graph of routes in the road network between the cities of Dnipro (1) and Odesa (16)

Table 3

Results of calculations of the coefficient of influence on the probability of the route choosing

Item number	Point names	P_{ij} , vehicle/hr	Coefficient R_{ij}	Road state	ω_{ij}	ϵ_{ij}
1	2	3	5	6	7	8
1	Dnipro – turn to Znamyanka (1–2)	304	0.3	Partially satisfactory	0.75	0.23
2	Turn to Znamyanka – Znamyanka (2–5)	945	0.6	Unsatisfactory, large number of pit holes	0.5	0.3
3	Dnipro – Dniprovi Khvyli (1–4)	345	0.3	Satisfactory	1	0.3
4	Turn to Znamyanka – Kryvy Rih (2–3)	744	0.45	Partially satisfactory: pit holes	0.75	0.34
5	Dniprovi Khvyli – Nikopol (4–6)	416	0.3	Unsatisfactory: ruts, pit holes	0.5	0.15
6	Znamyanka – Kropyvnytsky (5–8)	241	0.15	Satisfactory	1	0.15
7	Nikopol – Maryanske (6–7)	252	0.15	Partially satisfactory	0.75	0.13
8	Kryvy Rih – turn to Vozsiyatske (3–9)	308	0.3	Unsatisfactory: road bed is absent in places	0.5	0.15
9	Kropyvnytsky – Vozsiyatske (8–11)	252	0.15	Unsatisfactory: pit holes	0.5	0.08
10	Kryvy Rih – Maryanske (3–7)	443	0.3	Partially satisfactory: pit holes	0.75	0.23
11	Maryanske – Kherson (7–10)	1125	0.6	Partially satisfactory: pit holes	0.75	0.45

1	2	3	4	5	6	7
12	Turn to Vozsiyatske – Vozsiyatske (9–11)	325	0.3	Satisfactory	1	0.3
13	Vozsiyatske – Mykolaiv (11–12)	510	0.45	Unsatisfactory: pit holes	0,5	0,23
14	Turn to Vozsiyatske – Mykolaiv (9–12)	405	0.3	Unsatisfactory: pit holes	0.5	0.15
15	Kherson – Mykolaiv (10–12)	502	0.3	Satisfactory	1	0.3
16	Kropyvnytsky – turn to Voznesensk (8–13)	705	0.45	Unsatisfactory	0.5	0.23
17	Turn to Voznesensk – Voznesensk (13–14)	400	0.3	Unsatisfactory	1	0.3
18	Kryvy Rih – Kropyvnytsky (3–8)	825	0.45	Partially satisfactory: pit holes, ruts	0.75	0.34
19	Vozsiyatske – Voznesensk (11–14)	364	0.3	Partially satisfactory: pit holes, ruts	0.75	0.23
20	Voznesensk – Odesa (14–16)	826	0.45	Partially satisfactory: pit holes, ruts	0.75	0.34
21	Turn to Voznesensk (E548) – turn to Odesa (13–15)	420	0.3	Unsatisfactory: pit holes, ruts	0.5	0.15
22	Turn to Odesa – Odesa (15–16)	994	0.6	Satisfactory	1	0.6
23	Mykolaiv – Odesa (12–16)	969	0.6	Partially satisfactory	0.75	0.45

The route optimization based on classical and modified algorithms has been implemented in the MATLAB programming environment.

The economic-mathematical model takes the following form:

$$\sum_{i=1}^n \sum_{j=1}^n L_{ij} \rightarrow \min;$$

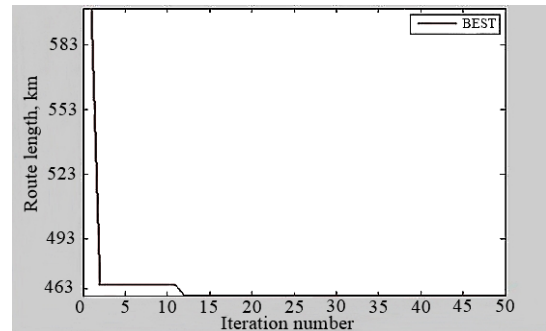
$$\begin{cases} 0,5 \leq \omega_{ij} \leq 1; \\ 0,5 \leq \alpha \leq 1; \\ 0,5 \leq \beta \leq 1; \\ 0 \leq \rho \leq 1; \\ 400 \leq Q \leq 500; \\ 0,15 \leq R_{ij} \leq 1. \end{cases}$$

Initial parameters were taken the same, namely:

- number of vehicles passing in one iteration: 5 units;
- maximum number of iterations: 50;
- Q parameter: 450;
- $\alpha = \beta = 1$;
- the initial pheromone level: $\tau_0 = 1$;
- the pheromone evaporation coefficient $\rho = 0.3$.

The results of calculating the optimal route based on the classical ant algorithm are shown in Fig. 3. According to the results of application of the classical algorithm, it was determined that the obtained route passes through points 1 – 2 – 3 – 9 – 12 – 16, Fig. 1. When the classical algorithm was applied, the same result was obtained in the opposite direction.

The results of calculating the optimal route based on the modified ant algorithm are shown in Fig. 4. According to the results of application of the modified ant algorithm, it was determined that the route passes through points: 1 – 2 – 3 – 9 – 11 – 14 – 16 (Fig. 1). The result of optimizing the route in the opposite direction when applying the modified ant algorithm is the same.



(9) Fig. 3. Result of route optimization based on the classical ant algorithm

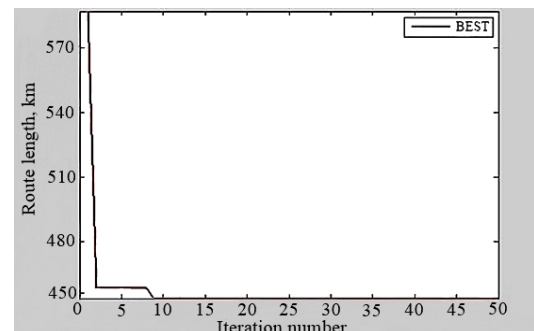


Fig. 4. Result of optimizing the route based on the modified ant algorithm

A comparative analysis of the constructed optimal routes based on classical and modified ant algorithms shown in Fig. 5 shows that the use of the modified algorithm enables a better optimal solution ($L=449.3$ km vs. 461.3 km) in less iterations (9 vs. 12). The obtained optimal solutions are highlighted with markers with no filling.

Analysis of influence of parameters α , β and Q on quality of the solution obtained showed the following.

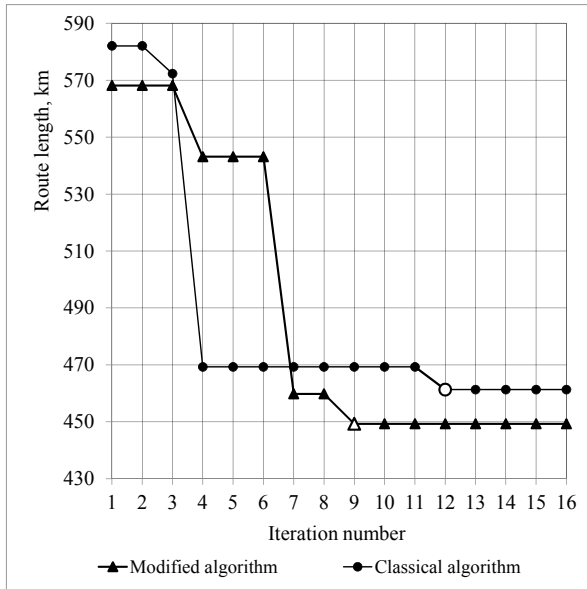


Fig. 5. Comparison of optimized routes based on the classical and modified ant algorithm

In the first test, parameters β and Q remained unchanged and influence of the α parameter on the search quality L was studied (Table 4). The following parameters did not change in all calculations: the number of vehicles per iteration, the number of iterations and the coefficient of pheromone evaporation.

Table 4

Influence of the α parameter on quality of search for the route length L

Parameter α	0.5	1	1.5	2	2.5	3	3.5	4
Iteration number	7	9	11	4	4	4	9	7
Time, s	0.16	0.11	0.13	0.13	0.14	0.14	0.14	0.13
L , km	449.3	449.3	459.8	557.65	557.8	587.8	627.5	627.5

In the second test, influence of the β parameter on the solution quality obtained under the same conditions was checked while parameters α and Q remained unchanged (Table 5).

Table 5

Influence of the β parameter on quality of the search for the length of route L

Parameter β	0.5	1	1.5	2	2.5	3	3.5	4
Iteration number	13	6	11	10	11	10	3	8
Time, s	0.11	0.11	0.14	0.14	0.12	0.13	0.15	0.14
L , km	459.3	449.3	449.3	459.8	459.8	557.65	557.8	557.8

In the third test, $\alpha=\beta=1$ was taken, and the Q indicator changed. The test results are presented in Table 6.

Table 6

Influence of parameter Q on the quality of search of the route length L

Parameter Q	400	425	450	475	500	525	550
Iteration number	5	11	14	6	12	11	10
Time, s	0.16	0.19	0.14	0.15	0.13	0.14	0.14
L , km	449.3	449.3	449.3	449.3	557.65	567.8	557.8

Based on the analysis of the obtained indicators, it can be seen that the Q parameter for this problem should not exceed the value of 475.

6. Discussion of the results obtained in the study of rational freight routing based on the modified ant algorithm

In determining effectiveness of the proposed function of quality which adjusts the probability of choosing the travel direction, the main idea was to find optimal route in terms of length which would avoid with a maximum probability the road sections with an unsatisfactory roadway condition.

When implementing the classic algorithm, a route was constructed through the city of Kryvy Rih and the city of Mykolaiv along the way usually chosen by the vast majority of cargo carriers. However, quality of the roadbed in the sections from the city of Kryvy Rih to the city of Mykolaiv is in a rather bad condition, roadway is absent in places, there are ruts and deep potholes. Partly these sections undergo repair works.

When routing based on the modified ant algorithm, the section of the road from point 9 (turn to village of Vozsiyatske) to point 12 (Mykolaiv city) was not included in the route. This is because that among the two options, the further route with a better road surface was chosen since $\epsilon_{9-11}=0.3$ and $\epsilon_{9-12}=0.15$. Consequently, the probability of choosing section 9-11 is twice as large.

Comparing the results, we can draw the following conclusions:

- software implementation on the basis of the modified ant algorithm has shown that taking into account the introduced coefficient ϵ_{ij} , routing is made not solely by orienting on the length of the route section from point to point but also by taking into account condition of the roadway and practical throughput of the corresponding road section;

- the route obtained on the basis of the modified ant algorithm is shorter (449.3 km) compared with that obtained by using the classical algorithm (461.3 km);

- the route based on the modified ant algorithm was obtained in 9 iterations compared with the solution based on the classical algorithm in 12 iterations.

Comparison of the search time has given the following results:

- the result obtained using the classical algorithm: calculation in the forward direction took 0,10 s and 0,11 s in the reverse direction;

- the result obtained using the modified algorithm: calculation in the forward direction took 0.11 s and 0,10 s in the reverse direction.

Certainly, the difference is not significant enough for such small scales but when calculating higher values, the difference is noticeable. However, when implementing the classical and the modified ant algorithms, the solution search time is correlative in terms of speed.

Data analysis of Table 4 shows that the indicator α is better to take in the range from 0.5 to 1 for this problem.

Analyzing the data in Table 5, we can say that the best solutions are obtained when the parameter β takes values from 0.5 to 1.5.

Analysis of the results (Table 6) shows that the Q indicator should be taken approximately of the same order as the length of the optimal route. In this case, the limits from 400 to 475 fully meet these conditions. The only difference is that the smaller the indicator, the longer the search for the optimal route will be. This is because of taking into account additional transportation conditions which are given in in the optimization model (9).

It should also be noted that effectiveness of the proposed method is reduced in the case of a small number of route variants.

The most promising line of study is analysis of the way of choosing parameters for adjustable algorithms. Choice of the ant algorithm parameters significantly influences effectiveness of its application and therefore scientists are actively working out various methods for adapting parameters of heuristic algorithms [28].

Introduction of additional parameters into the model of ant algorithm through the quality function enables improvement of its efficiency and expansion of possibilities for taking into account additional conditions of transportation: road relief, existing service infrastructure, emergence of extreme traffic situations, climatic conditions, etc.

The results obtained in the work can later be used in decision support systems for management in the process of rational routing. The proposed methodological approach may be useful in solving the synthesis problem since it will enable consideration of complicated and changing conditions of practical realization, in particular, in a real-time mode.

7. Conclusions

1. The proposed method of a rational road freight routing based on a modified ant algorithm enables a comprehensive assessment of potential freight routes taking into account practical throughput, traffic intensity, route length, road surface condition.

2. Introduction of the function of quality of performing the transportation process has allowed us to form a modified model of the ant algorithm which takes into account the actual state of roads in a rational routing of motor freight. Practical application of the proposed method provides a comprehensive assessment of potential transportation routes taking into consideration the route length, condition of the roadway and practical throughput.

3. A function of quality of the transportation process was formed. Formalization of the roadbed condition in separate sections of the route was carried out with the use of the fuzzy set apparatus for describing the membership function. Condition of the road surface was estimated on the basis of empirical data and reduced to corresponding coefficients characterizing various qualitative road states. Determination of the theoretical and practical throughput of individual sections of the route was carried out taking into account the probability of occurrence of vehicles of various types in the path with the reduction to corresponding expert coefficients.

4. Comparison of effectiveness of the classical and modified ant algorithm was carried out on the example of optimal routing from the point of departure to the point of destination. Analysis of the current condition of roads in Ukraine was conducted on the example of a road network between Odesa and Dnipro. The study has shown that when routing the road freight, it is necessary to identify the road sections not suitable for transportation. Implementation of classical and modified algorithms proved effectiveness of the proposed approach and has made it possible to determine the route that avoids road sections with unsatisfactory road condition.

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