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Algorithm for the routes formation of food raw materials procurement on the community territory taking into account the production conditions during emergency situations

Anatoliy M. Tryhuba[1)]
ORCID: https://orcid.org/0000-0001-8014-5661; trianamik@gmail.com. Scopus Author ID: 57205225539
Nazarii Ya. Koval[2)]
ORCID: https://orcid.org/0000-0001-7846-2924; kovaln870@gmail.com. Scopus Author ID: 57216856141
Andrii R. Ratushnyi[2)]
ORCID: https://orcid.org/0000-0003-0768-6466; ratuwnuja@ukr.net
Inna L. Tryhuba[1)]
ORCID: https://orcid.org/0000-0002-5239-5951; trinle@ukr.net. Scopus Author ID: 57210807861
Victor V. Shevchuk[1)]
ORCID: https://orcid.org/0000-0002-8260-2165; shevtyk@meta.ua. Scopus Author ID: 57219890504
[1)] Lviv National University of Nature Management, 1, V. Velikoho, Str. Dublyany, 80381, Ukraine
[2)] Lviv State University of Life Safety, 35, Kleparivska, Str. Lviv, 79000, Ukraine

ABSTRACT

The article concerns the improvement of the ACO (Ant Colony Optimization) ant colony optimization algorithm for the formation of routes of vehicles for the procurement of food raw materials on the territory of the community during emergencies. The purpose of the study is to improve the algorithm for the formation of routes of vehicles for the procurement of food raw materials on the territory of the community during emergencies. The proposed algorithm is based on the classical algorithm of ant colony optimization ACO and, unlike it, takes into account real production conditions during emergencies. The task of the research is to create an algorithm for the formation of effective routes of vehicles for the procurement of food raw materials in the territory of the community during emergencies, as well as its comparison with the classic ACO algorithm for solving various problems of route formation. It was established that the use of the classic algorithm for the optimization of ant colonies ACO, or its known modernizations, does not provide a high-quality solution to the problem of forming routes of vehicles for harvesting food raw materials on the territory of the community during emergencies. This is due to incomplete consideration of specific production conditions. The improved route formation algorithm involves 8 steps and is based on the classic ACO algorithm. In contrast to it, it takes into account real production conditions (damaged sections of the roadway, the presence of partial passage of vehicles, traffic jams caused by an emergency, etc.). The rule of the classic ACO algorithm regarding the selection of the next point in the route using the probabilistic-proportional transition of the k-th ant from the i-th to the j-th node (farm producing food raw materials) is proposed, replaced by one that takes into account the state of production conditions (road surface) between individual nodes. This ensures an increase in accuracy and a decrease in the duration of route formation, as well as an increase in the quality of making appropriate management decisions. The obtained results regarding the comparison of the use of algorithms when solving transport problems with a different number of vertices indicate that the proposed algorithm provides a deviation of the total path in the route, which does not exceed 1%. The proposed algorithm reduces the decision-making time by up to 6% in the presence of up to 50 units of vertices, and by 12...15% in the presence of vertices from 51 to 100 units. The improved vehicle routing algorithm can be used in decision-making support systems to plan the procurement of food raw materials on the territory of the community during emergencies, which will increase their efficiency.

Keywords: Algorithm; formation of routes; provision; food raw materials; Emergency; changing production conditions

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INTRODUCTION

Currently, emergencies are occurring in Ukraine and the world [1]. They will disrupt relationships in food chains. At the same time, several scientific and applied problems arise regarding activities that ensure food security during emergencies. One of these tasks is the formation of effective routes for the procurement of food raw materials in the territory of communities [2, 3], [4, 5]. In this case, the specific production washes of harvesting food raw materials on the territory of the community during emergencies are decisive.

Many scientists have devoted their research to solving the problem of routing the delivery of goods in various production conditions. The ant algorithm ACO, which in its classical form and its known improvements is used to form routes for the delivery of various cargoes, deserves attention [6, 7], [8]. However, despite the advantages of this algorithm, it does not take into account the peculiarities of the production conditions of the procurement of food raw materials on the territory of the community during emergencies.

In particular, the road network during emergencies may be partially damaged, leading to limited vehicle movement, or completely unusable. Vehicles have a limited capacity, which leads to the formation of multiple routes for the collection of food raw materials in the territory of the community during emergencies. This leads to the need to improve the algorithm of forming routes for the procurement of food raw materials on the territory of the community. Improvement of the Ant Colony Optimization (ACO) algorithm will ensure the effective determination of the collection of food raw materials on the territory of the community during emergencies, as well as its use in the relevant information system for making quality management decisions.

LITERATURE ANALYSIS

A large number of scientific works have been devoted to solving the problems of improving cargo delivery processes thanks to the effective formation of routes [9, 10], [11, 12], [13, 14]. Known approaches to solving the problem of discrete optimization of transport processes in logistics systems under various production conditions are mostly imperfect and do not provide unambiguous solutions, as noted in work [15]. Also, the existing methods of planning transport processes do not provide an opportunity to solve large-scale problems and take into account real production conditions during the formation of routes [15].

In article [16], a new algorithm is proposed, which, in contrast to the existing ones, ensures the implementation of discrete optimization of transport processes, taking into account possible options for the formation of vehicle routes based on the analysis of the throughput of individual road sections. According to the author, this method makes it possible to identify road sections with the best conditions for cargo delivery. It eliminates the need to spend a lot of time searching for irrational options for route formation, that is, to reduce the duration of the necessary calculations. However, the use of the method for the formation of food procurement routes in the territory of communities during emergencies is limited. This is because it is based on a linear algorithm that involves solving a system of linear equations of a given dimension.

The ant algorithm ACO, which is used to solve logistic problems of discrete optimization, deserves attention [17]. In its classical form, the ACO algorithm provides a search for a rational route for the movement of ant colonies for a given static graph. At the same time, in the beginning, the agent-ants are located at the junctions of the transport network graph, which in the future simultaneously move on separate branches of the graph. The use of the specified algorithm makes it possible to reduce the duration of calculations.

Scientific works [18, 19] are also known, the authors of which adapt various characteristics for ant agents. This allows for solving a wide range of discrete optimization problems based on taking into account many components of the production conditions of cargo delivery. Conducted studies by scientists using ACO algorithms testify to the expediency of its use for solving discrete optimization problems taking into account many components of production conditions and solving large-scale transport problems [18, 19].

However, the existing improvements of the ACO algorithm are mostly intended for solving the problems of forming rational routes under unchanged production conditions and the transport network. At the same time, the formation of routes for the procurement of food raw materials in the territory of communities, taking into account the variability and state of the transport network during emergencies, is quite relevant at the moment.

Scientific work [20] are also known, in which their authors suggest using the ACO algorithm to solve dynamic transport problems. In particular, in [20] it is proposed to use the ACO algorithm for planning transport processes taking into account dynamic emergencies.

All of the above indicates that there is a need to improve the algorithm for the formation of routes for the procurement of raw food materials on the territory of the community, which will take into account changing production conditions. It is they who cause restrictions on the movement of vehicles during emergencies. It should also be taken into account that during emergencies, the movement of vehicles is impossible on certain sections of roads.

FORMULATION OF THE PROBLEM

The formation of routes for the procurement of food raw materials on the territory of the community during emergencies requires the solution of one of the well-known problems of vehicle routing the Collection Route (CR), which belongs to combinatorial optimization. At the same time, the specified task belongs to the tasks of forming routes for the transportation of perishable products. At the same time, the vehicle starts moving from the starting point (food processing plant). They gradually visit the farms of the producers of food raw materials located in the territory of the community. After that, it returns to the starting point (food processing plant).

Many algorithms are used to solve this problem, but some researchers indicate that the ACO ant algorithm is quite effective [6, 7], [8]. However, the use of the ant algorithm in its classical form, or its known improvements, to solve the problems of combinatorial optimization of cargo delivery routes were mainly performed for stable conditions of both a given transport network and a constant environment [7]. At the same time, the transport network was presented in the form of a separate graph, where the distance between the cargo delivery points, and accordingly, the value of the edges was determined by the distance between settlements and the conditions (vehicle type and road condition, which determines the speed of the vehicle) of cargo delivery were set unchanged. This does not correspond to the conditions for harvesting food raw materials on the territory of the community during emergencies, as the road network may be partially damaged, which leads to the limited movement of vehicles, or completely unusable. In addition, a separate vehicle has a limited load, which may be less than the volume of delivery of food raw materials, which causes the formation of several routes for the collection of food raw materials on the territory of the community during emergencies. Taking into account the above-mentioned conditions for the formation of routes for the procurement of food raw materials on the community's territory, there is a need to improve the algorithm for the formation of routes for the procurement of food raw materials on the territory the community.

THE PURPOSE AND THE OBJECTIVES OF THE STUDY

The purpose of the work is to improve the algorithm for the formation of routes of vehicles for harvesting food raw materials on the territory of the community during emergencies, which is based on the classic algorithm ACO and, unlike it, takes into account real production conditions.

To achieve the goal, the following problems must be solved:

– to improve the algorithm for the formation of routes of vehicles for the procurement of food raw materials on the territory of the community during emergencies;

– perform a comparison of the proposed route formation algorithm with the classic ACO algorithm for solving various route formation problems.

RESEARCH METHODS

To achieve the tasks set in the article, we have chosen appropriate methods. In particular, systematic analysis and synthesis to assess the production conditions of food raw materials procurement in the territory of the community during emergencies. The ant algorithm ACO was also used [8], based on which the improvement of the algorithm for the formation of routes for the procurement of food raw materials on the territory of the community was carried out, taking into account real production conditions. To assess the state of the conditions for harvesting food raw materials, we chose the transport network of the Zabolottsivka United Territorial Community (Zolochiv District, Lviv Region).

Based on the use of the Internet resource Google Maps [21], a matrix of distances between farms producing food raw materials and a matrix of vehicle speeds on the transport network of a given community was formed.

Correlation-regression analysis methods were used to compare the proposed route formation algorithm with the classic ACO algorithm for solving various route formation problems.

JUSTIFICATION OF THE SPECIFIC PRODUCTION CONDITIONS OF PROCUREMENT OF FOOD RAW MATERIALS DURING EMERGENCY SITUATIONS

The proposed algorithm for forming routes for the procurement of food raw materials on the territory of the community involves taking into account changing production conditions. They cause restrictions on the movement of vehicles during emergency situations. In particular, there are situations that do not allow the movement of vehicles on certain sections of roads. The transport network can be represented in the form of bidirectional oriented weighted graphs that reflect the production conditions of individual communities. The nodes of these graphs are farms producing food raw materials with a certain point of their collection or processing. The edges that connect the nodes of the graph are the roads by which food raw materials are delivered from producers to the point of their collection or processing. There are weights of edges, the characteristics of which depend on the type of food raw materials (milk, animals for meat, vegetables, etc.), which connect a separate pair of nodes of the graph. These rib weights, depending on the conditions of the problem to be solved, can be represented in the form of distances between farms producing food raw materials, the speed of movement on given sections between separate farms, the duration of the movement

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of vehicles on separate sections of the delivery of food raw materials, the cost of delivering food raw materials on certain sections transport network, etc. (Fig. 1).

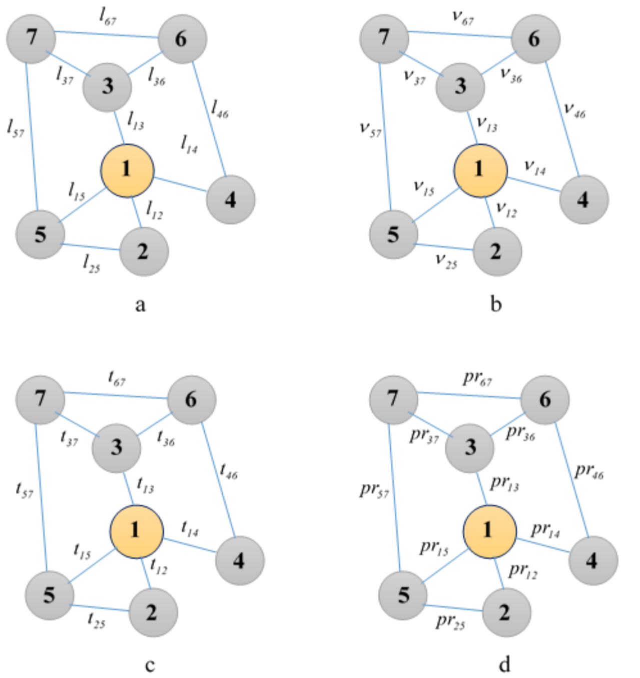

Fig. 1. **Bidirectional-oriented weighted graphs that reflect the production conditions of harvesting food raw materials:**

a – distances between farms producing food raw materials; b – vehicle speed; c – duration of move- ment – of vehicles; d – cost of delivery of food raw materials;

1 – point of collection or processing of food raw materials; 2-7 – farms producing food raw materials

***Source*: compiled by the authors**

Proceeding from the above, based on the mathematical formulation of the transport network for the delivery of food raw materials on the territory of the community, a separate *j*-th node (farms producing food raw materials and its collection or processing point) are connected by a set of edges that represent a part z_j of the network, each i -th section of which is characterized by a separate distance l_{ij} (Fig. 1a), the average speed v_{ij} of movement of the *k*-th type of vehicle (Fig. 1b), the duration t_{ij} of movement of the k -th type of vehicle (Fig. 1c) and the cost pr_{ij} of delivery of food raw materials on certain sections of the transport network (Fig. 1d).

The peculiarity of the production conditions of the procurement of food raw materials during emergencies is that the individual ribs, which are part of the network, have a constant distance, but due to complete damage to the road surface, the passage is impossible, with partial damage to the road surface and traffic jams, each section characterized by its reduced speed of movement of the *k*-th type of vehicle, increasing duration of movement of the *k* -th type of vehicle and increasing cost of delivery of food raw materials on a given section of the transport network.

The peculiarity of the production conditions of the procurement of food raw materials during emergency situations is that the individual edges, which are part z_j of the network, have an invariable distance l_{ij}. However, due to the complete damage to the road surface, it is impossible to drive on them. This is due to partial damage to the road surface and traffic jams. Each specified i -th section is characterized by its reduced speed of movement of the k -th type of vehicle. The increase in the duration t_{ij} of movement of the *k*-th type of vehicle and the increase in the cost pr_{ij} of delivery of food raw materials on a given section of the transport network.

Therefore, the graphs of the distances between farms producing food raw materials (Fig. 1a) and the speed of vehicles (Fig. 1b) are decisive, which determine the derivative graphs of the duration of the movement of vehicles (Fig. 1c) and the cost of food delivery raw materials (Fig. 1d).

Based on the use of the Internet resource Google Maps [21], a matrix of distances M_L^m between farms producing food raw materials and a matrix of vehicle speeds on the transport network of the th rural community is formed. At the same time, in the presence of damage to the road surface, where passage is impossible, the specified sections are removed from the graphs of the transport network.

In the presence of partial damage to the road surface and traffic jams at each section, which is a part z_j of the transport network, a decrease in the speed of movement v_{ij} of the *k*-th type of vehicle is observed. The average speed of the movement of vehicles between the *j*-th settlements of rural communities is taken into account as a variable value on the *i*-th sections, which ensures taking into account the real production conditions on a given section of the transport network. For example, consider the section of the transport network of the Zabolottsivka United Territorial Community (Zolochiv District, Lviv Region) between the settlements of Zabolotsi and Velyn (Fig. 2).

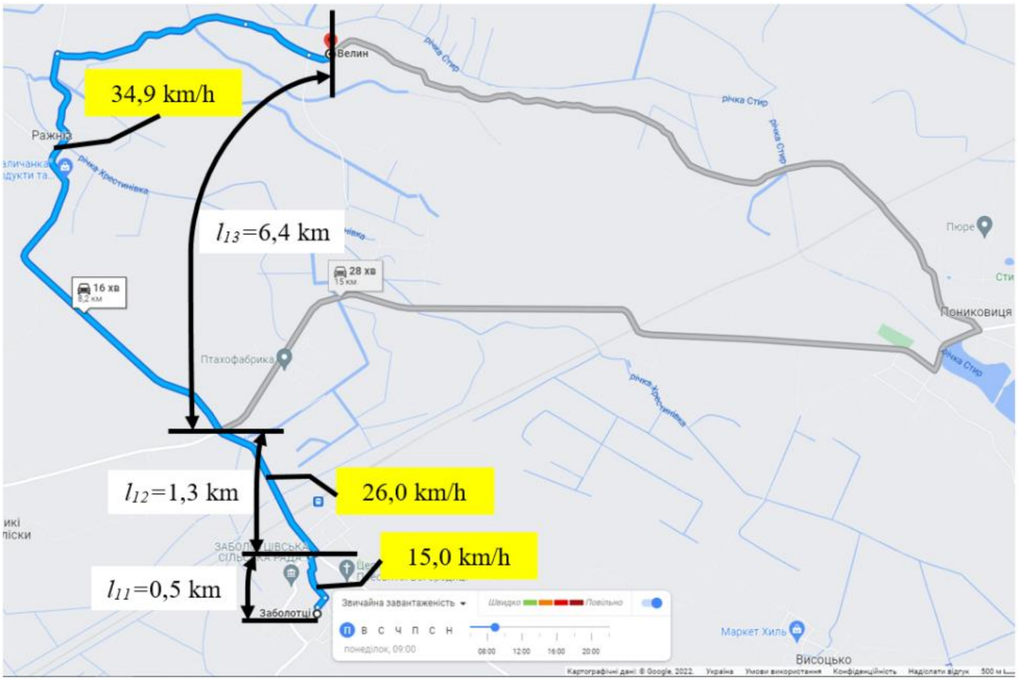

Fig.2. **Determination of the average speed of the vehicle on a section of the transport network of the Zabolottsi united territorial community (Zolochiv District, Lviv Region) between the settlements of Zabolottsi and Velyn**
***Source*: compiled by the authors**

In the given example, we get:

– the distance between settlements

$$l_{ij} = l_{11} + l_{12} + l_{13}, \quad (1)$$

where l_{ij} is total distance traveled by vehicles, km; l_{11}, l_{12}, l_{13} are respectively, the first, second, and third segments of the route traveled by vehicles, km.

$$l_{ij} = 0{,}5 + 1{,}3 + 6{,}4 = 8{,}2 km.$$

– the average duration of vehicle movement between settlements

$$t_{ij} = t_{11} + t_{12} + t_{13}, \quad (2)$$

where t_{ij} is average duration of vehicle movement between settlements, hours; t_{11}, t_{12}, t_{13} – respectively, the duration of the vehicle movement between settlements on the first, second and third segments, hours

$$t_{ij} = 2 + 3 + 11 = 16 min \approx 0{,}26 h.$$

– the average speed of the vehicle between settlements

$$V_{ij}^{c} = \frac{l_{ij}}{t_{ij}}, \quad (3)$$

where V_{ij}^{c} is average speed of vehicle movement between settlements, km/h.

$$V_{ij}^{c} = \frac{8{,}2}{0{,}26} = 30{,}8 km/h.$$

The formation of routes for the procurement of food raw materials in the territory of the community during emergencies is carried out based on solving the VRP (Vehicle Routing Problem).

The main criteria by which routes are optimized are the total distance l_{ij} covered using transport, the average speed of delivery of food raw materials, the duration v_{ij} of delivery of food raw materials, and the cost pr_{ij} of delivery of food raw materials using the *k*-th type of vehicles. The choice of criteria depends both on the requirements for the delivery of food raw materials and on the production conditions of transportation, which are caused by the action of emergencies. At the same time, the condition is accepted that vehicles leave the point of collection or processing of food raw materials, go around producers' farms, and return to them with cargo.

ALGORITHM FOR THE FORMATION OF ROUTES OF VEHICLES FOR PROCUREMENT OF FOOD RAW MATERIALS

It is proposed to use the ant algorithm to create routes for harvesting food raw materials on the territory of the community and take into account real conditions during emergency situations. It is also called the ACO [22, 23], [24]. We have improved the classic ant colony algorithm to take into account real conditions during emergency situations.

In particular, it is suggested to use the following rules of behavior of ants:

1) ants remember a separate jth node (farms producing food raw materials) and can be visited only once. At the same time, a list of visited *j*-th nodes of the transport network graph is formed for each ant, which is included in the list of prohibitions against visiting them. There is a set of farms producing food raw materials $C=\{1,...,n\}$, which can be visited by the available vehicles from the available set $K=\{1,...,k\}$. For each *k*-th vehicle located in the ith node (farm producing food raw materials), there is a set of J_{ik} available for visiting *j*-th nodes (farms producing food raw materials);

2) ants are characterized by a given visibility η_{ij} and voluntarily choose which of the *j*-th nodes of the transport network graph (a farm producing food raw materials) they want to visit if they are in the *i*-th node.

At the same time, it is assumed that the visibility is:

$$\eta_{ij}=\frac{1}{l_{ij}}, \quad (4)$$

where l_{ij} – distance between the *i*-th and *j*-th nodes (farms producing food raw materials), km.;

3) ants are characterized by the ability to recognize the smell due to the feeling of traces of pheromone η_{ij}, which gives them the opportunity to overcome the distance between the *i*-th and *j*-th nodes (farms producing food raw materials), taking into account the experience of other ants who have already passed this way. At the same time, the amount of pheromone on the edge between the *i*-th and *j*-th nodes (farms producing food raw materials) at a given time t is $\tau_{ij}(t)$;

4) it is proposed to replace the unambiguous cyclic type of movement of the ant colony with a possible variable type of movement of each ant with a given speed of its movement;

5) it is ensured that the obtained results of the optimization of the part of the traveled path are recorded on a separate section of the network after visiting the j-th nodes (farms of producers of food raw materials);

6) it is possible to perform changes and calculations of the route for changes in production conditions, which are set by the length of the edge of the graph of the transport network for the delivery of food raw materials (speed, duration, cost, etc.) during the execution of the route;

7) the rule of the classic ACO algorithm regarding the selection of the next farm producing food raw materials using the probability-proportional transition of the *k*-th ant from the *i*-th to the *j*-th node (farm producing food raw materials):

$$\begin{cases} P_{ij,k}(t)=\dfrac{\left[\tau_{ij}(t)\right]^{\alpha}\cdot\left[\eta_{ij}\right]^{\beta}}{\sum\limits_{l\in J_{i,k}}\left[\tau_{il}(t)\right]^{\alpha}\cdot\left[\eta_{il}\right]^{\beta}},\ j\in J_{i,k} \\ P_{ij,k}(t)=0,\ j\notin J_{i,k} \end{cases}, \quad (5)$$

8) it is proposed to replace (5) with a probabilistic-proportional rule for choosing the next farm of the producer of food raw materials, which takes into account the state of production conditions (road surface) between individual nodes *i*,*j* and is written by the following expression:

$$\begin{cases} P_{ij,k}(t)=\dfrac{rc_{ij}\cdot\left[\tau_{ij}(t)\right]^{a}\cdot\left[\eta_{ij}\right]^{b}}{\sum\limits_{l\in J_{i,k}}rc_{ij}\cdot\left[\tau_{il}(t)\right]^{a}\cdot\left[\eta_{il}\right]^{b}},\ j\in J_{i,k} \\ P_{ij,k}(t)=0,\ j\notin J_{i,k} \end{cases}, \quad (6)$$

where a,b are the corresponding parameters characterizing the relative importance of the amount of pheromone and the distance during the selection of the next *j*-th node (farm of the producer of food raw materi; rc_{ij} is indicator of the state of production conditions (road surface) between individual nodes *i*,*j*; τ_{ij},η_{ij} is correspondence of the amount of pheromone and the distance indicator on the edge connecting the *i*-th node to the *j*-th node (farms producing food raw materials).

The indicator rc_{ij} of the state of production conditions (road surface) between individual nodes *i*,*j* can take on three values:

$-rc_{ij}=0$ – movement from the *i*-th to the *j*-th node (farms producing food raw materials) is impossible due to the unusability of the road surface, which was damaged during an emergency;

$-rc_{ij}=1$ – nothing prevents the movement from the *i*-th to the *j*-th node (farms producing food raw materials). In this case, the indicator of the state of production conditions can be neglected;

– $0<rc_{ij}<1$ – the movement of the i-th to the j-th node (farms producing food raw materials) is possible with a decrease in the speed of transportation of food raw materials, which is associated with a partially damaged road surface or complicated traffic due to traffic jams caused by the occurrence of an emergency.

Under the condition $0<rc_{ij}<1$, which characterizes the case of partial damage to the road surface or traffic complications due to traffic jams, the indicator rc_{ij} of the state of production conditions is determined by the expression:

$$rc_{ij}=\frac{V_{ij}^{c}}{V_{ij}^{n}}, \tag{7}$$

where V_{ij}^{c} is average speed of movement from the *i*-th to the *j*-th node (farm producing food raw materials), km/h; V_{ij}^{n} is predicted speed of movement from the *i*-th to the *j*-th node (farm producing food raw materials), taking into account cases of partial damage to the road surface or traffic complications due to traffic jams, km/h.

If the condition *a=0* is accepted, then the algorithm degenerates and becomes a greedy algorithm that chooses the nearest farm producing food raw materials. The parameters *a,b* characterizing the relative importance of the amount of pheromone and the distance during the selection of the next *j*-th node (farm of the producer of food raw materials) are determined on the basis of the relevant experiments.

To update the pheromone trail, first of all, a simulation of pheromone evaporation is carried out, after which the trail is updated depending on the obtained result.

The formula is used to simulate the evaporation of pheromone:

$$\tau_{ij}=(1-\rho)\cdot\tau_{ij}+\sigma, \tag{8}$$

where ρ is parameter characterizing the intensity of pheromone evaporation; σ – the parameter that ensures the lowest concentration of pheromone on the edge between the i-th and j-th nodes (farms producing food raw materials), which has an arbitrarily small quantitative value.

On the edge between the *i*-th and *j*-th nodes (farms producing food raw materials), the amount of pheromone for a separate route is set:

$$\Delta T_{ij,k}=\begin{cases}\frac{O}{L_k},(i,j)\in T_k\\ O,(i,j)\notin T_k\end{cases}, \tag{9}$$

where O is parameter that displays the optimal length of all routes.

At the same time, on the edge of the *i*-th and *j*-th nodes (farms producing food raw materials), the total amount of pheromone can be determined by the formula:

$$\Delta T_{ij}=\sum_{k=1}^{m}\Delta T_{ij,k}, \tag{10}$$

where m is the number of ants in a separate colony.

So, taking into account the above, the amount of pheromone is determined by the formula:

$$\tau_{ij}=(1-p)\cdot\tau_{ij}+\sigma+\tau_{ij}, \tag{11}$$

In the future, during our research, we will use values $\alpha=1,\beta=5$, which were determined on the basis of the relevant experiments. In addition, this is confirmed by studies [25, 26], [27].

The proposed algorithm for forming routes for the procurement of food raw materials in the territory of the community, taking into account the production conditions during emergencies, which is based on the algorithm of ant colony optimization ACO, makes it possible to take into account real production conditions (damaged sections of the transport lane, the presence of a partialossibility traffic, traffic jams caused by an emergency, etc.). At the same time, ant agents, which are analogues of vehicles, move in given production conditions with permissible speeds, which determine the time of stay on the routes, the cost of delivery of food raw materials, etc.

The proposed improvement of the algorithm takes into account the case $rc_{ij}=0$, which reflects the impossible movement from the *i*-th and *j*-th nodes (farms producing food raw materials) due to the unusability of the road surface, which is damaged during an emergency situation, which makes it impossible to spend additional time on the delivery of food raw materials due to high-quality route planning.

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Under the condition $\sum Q > q_k$ that the total amount of food raw materials in the farms exceeds the load of the vehicle, the distribution and fixing of routes by means of vehicles is carried out.

On the basis of the above, we built a block diagram of an improved algorithm for the formation of routes for the procurement of food raw materials on the territory of the community, taking into account the production conditions during emergency situations (Fig. 3).

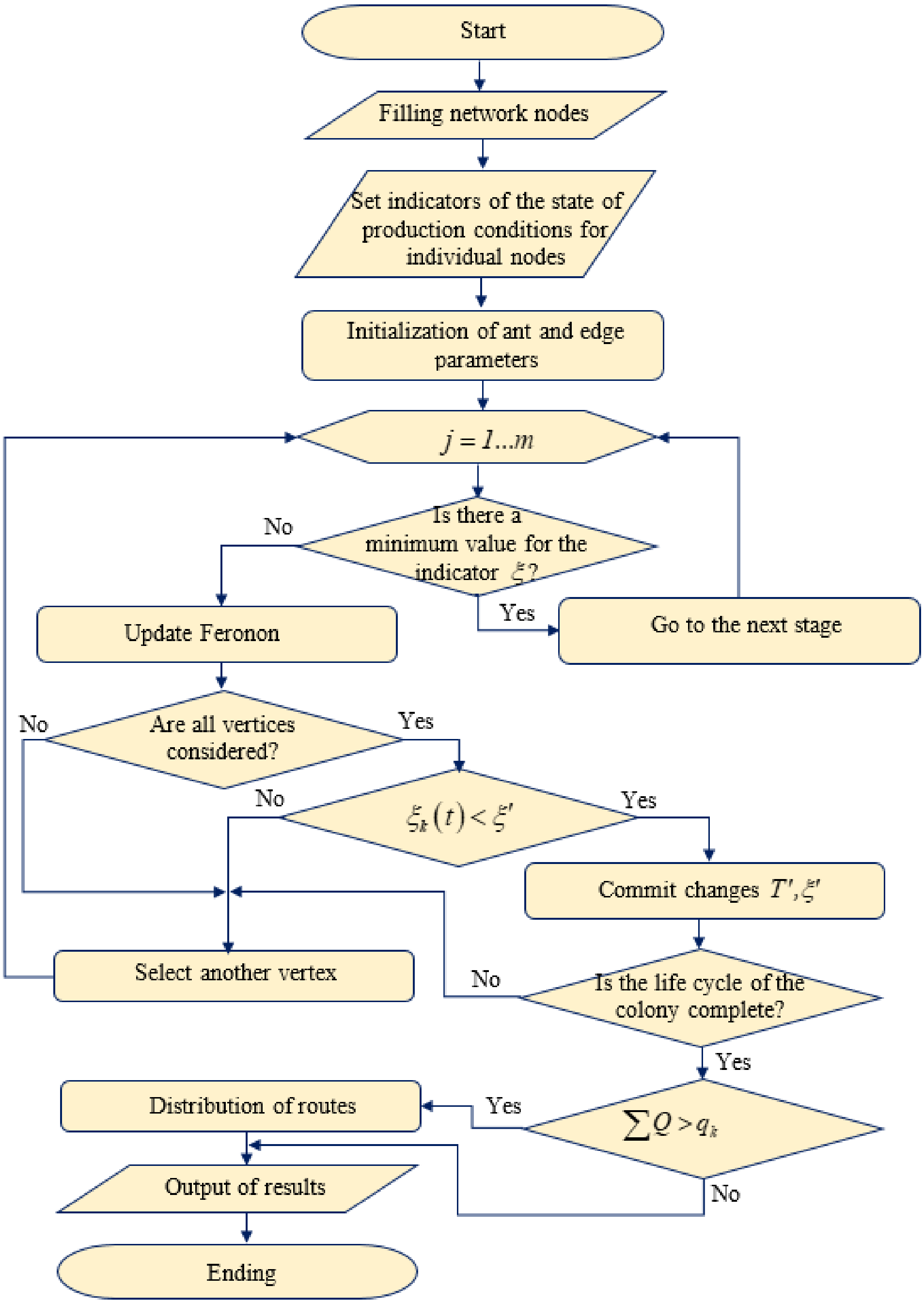

Fig.3. **Block diagram of the improved algorithm for the formation of routes for the procurement of food raw materials in the territory of the community, taking into account the production conditions during emergencies:**

ξ **is the indicator of choosing a rational option (path, time, cost, etc.);**

T', ξ' **are respectively, the current route and its indicators;**

m **is the number of ants (agents) in the colony**

***Source*: compiled by the authors**

When using the algorithm for the formation of routes for the procurement of food raw materials on the territory of the community, taking into account the production conditions during emergency situations, the following conditions were adopted [28, 29], [30, 31], [32]:

– the number of vertices (farms producing food raw materials) on the graph is equal to the number of ants that start moving from different vertices;

– the intensity of the pheromone, which is present on individual ribs before the start of the movement of ants from the i-th to the j-th node (farm producing food raw materials) is the same;

– at the beginning, for an individual ant, the nearest vertex is chosen (farm producing food raw materials), and the following stages are performed using expression (6).

The improved algorithm for forming routes for the procurement of food raw materials on the territory of the community, taking into account production conditions during emergency situations, provides:

1) Entering (downloading) initial data in the form of a matrix of basic indicators (distances, time, cost, etc.) characterizing the process of filling network nodes;

2) Entering indicators of the state of production conditions for individual *j*-th nodes (farms of producers of food raw materials) that have damage to the road surface or traffic complications due to traffic jams during emergency situations;

3) Initialization of parameters of ants and edges *a*,*b* from the *i*-th to the *j*-th node (farms producing food raw materials);

4) Placement of agents in separate randomly selected *j*-th nodes (farms producing food raw materials) without coincidences;

5) Execution of the movement cycle of the ant colony, which involves finding a rational route according to the given indicator ξ. In case of damage to the road surface or traffic complications due to traffic jams during emergencies, the pre-created route is rebuilt and this applies only to the part of the route that has not been completed;

6) The current circular route and its indicators are fixed T', ξ'.

7) The condition $\sum Q > q_k$ is checked, that the total amount of food raw materials in farms exceeds the load of the vehicle, if it is fulfilled, then the distribution and fixing of routes by means of vehicles is carried out, if not, then the route is fixed for one vehicle;

8) The results of finding rational routes T' and their indicators ξ' are derived ξ'.

COMPARISON OF THE PROPOSED ROUTE FORMATION ALGORITHM WITH THE CLASSIC ACO ALGORITHM

We performed a comparison of the results of route determination based on the traveled path L' obtained using the classic ACO algorithm and the improved algorithm for forming routes for the procurement of food raw materials in the territory of the community, taking into account production conditions during emergencies. The obtained results of the conducted research are presented in Table 1 and Fig. 4.

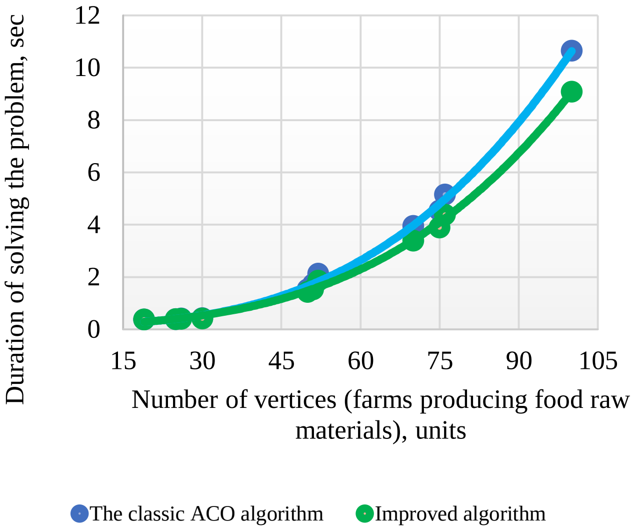

Fig.4. **The dependence of the duration of route determination on the number of vertices using the classic ACO algorithm and the improved algorithm for the formation of routes for the procurement of food raw materials in the territory of the community**
***Source*: compiled by the authors**

The obtained results regarding the use of the classic ACO algorithm and the improved algorithm for forming routes for harvesting food raw materials in the territory of the community indicate that the proposed algorithm provides a deviation that does not exceed 1% for the total path in the route. With regard to the duration of obtaining a management decision, the proposed algorithm ensures its reduction in the presence of vertices up to 50 units – up to 6 %, and in the presence of vertices from 51 to 100 units - by 12...15 %.

Table 1. **Comparison of the results obtained using the classic ACO algorithm and the improved algorithm for the formation of routes for the procurement of food raw materials in the territory of the community**

Task	The number of vertices, n, unit	The best option is a known value L', km	The classic ACO algorithm		Improved algorithm		Deviation, %	
			L', km	t, sec	L', km	t, sec	L', km	t, sec
Els 19	19	532	532	0.37	532	0.37	0	0
R208.25	25	332	332	0.38	332	0.38	0	0
Bur 26a	26	280	280	0.41	280	0.4	0	2
Oliver 30	30	423	423	0.42	422	0.41	0.24	2
Eilon 50	50	428	428	1.52	427	1.43	0.23	6
Eil 51	51	429	429	1.72	427	1.52	0.47	12
Berlin 52	52	755	755	2.13	755	1.85	0.00	13
St 70	70	681	681	3.95	680	3.38	0.15	14
Eilon 75	75	548	548	4.54	543	3.89	0.91	14
Eil 76	76	551	551	5.15	546	4.38	0.91	15
KroA 100	100	21452	21452	10.65	21392	9.08	0.28	15

***Source*: compiled by the authors**

The obtained results regarding the improved algorithm indicate that the formation of routes using it during the harvesting of food raw materials in the territory of the community gives quite accurate results. In particular, the improved algorithm ensures the appropriate accuracy and reduction in the duration of route formation, which is the basis for improving the quality of making relevant management decisions. It is advisable to use the proposed algorithm to determine a rational scenario for the execution of works on the procurement of food raw materials on the territory of the community during emergency situations.

DISCUSSION OF THE RESULTS

Planning the delivery of food raw materials on the territory of the community during emergencies requires solving the problem of routing vehicles CR (The Collection Route). It belongs to the tasks of routes for the transportation of perishable products, where the vehicle starts moving from the starting point (food processing plant), gradually goes around farms producing food raw materials located in the territory of a given community, and returns to the starting point (food processing plant). Among the existing algorithms, the ant algorithm ACO is quite effective [8]. However, the use of the ant algorithm in its classical form, or in its known improvements, does not provide a high-quality solution to the problem of forming routes of vehicles for the procurement of food raw materials in the territory of the community during emergencies. This is due to incomplete consideration of specific production conditions.

A feature of the production conditions for the procurement of food raw materials during emergencies is that individual ribs, which represent the z_j part of the network, have a constant distance of l_{ij}.

However, it should be taken into account that with complete damage to the road surface, passage is impossible, with partial damage to the road surface and traffic jams, each i-th section is characterized by its reduced speed v_{ij} of movement of the k-th type of vehicle, increasing duration t_{ij} of movement of the k-th type of vehicle and by the increasing cost pr_{ij} of the delivery of food raw materials on a given section of the transport network. In addition, a separate vehicle has a limited load, which may be less than the volume of delivery of food raw materials, which causes the formation of several routes for the collection of food raw materials on the territory of the community during emergency situations. Taking into account the above-mentioned conditions for the formation of routes for the procurement of food raw materials on the territory of the community, there is a need to improve the algorithm for the formation of routes for the procurement of food raw materials on the territory of the community.

In accordance with this, we have substantiated the specific production conditions for harvesting food raw materials during emergency situations, which is the basis of the improved route determination method. In particular, rule (5) of the classic ACO algorithm regarding the selection of the next farm producing food raw materials using the probability-proportional transition of the *k*-th ant from the *i*-th to the *j*-th node (farm producing food raw materials) is proposed to be replaced with a probabilistic-proportional rule for selecting the next of the producer of food raw materials, which takes into account the state of production conditions (road surface) between individual nodes *i,j* and is written by the following expression (6).

The improved route formation algorithm involves the implementation of 8 steps and is based on the classic ACO algorithm, and, unlike it, takes into account real production conditions (damaged sections of the roadway, the presence of partial passage of vehicles, traffic jams caused the emergency, etc.). This ensures an increase in accuracy and a decrease in the duration of route formation, as well as an increase in the quality of making appropriate management decisions.

The obtained results regarding the comparison of the use of algorithms when solving different problems with a different number of vertices indicate that the proposed algorithm provides a deviation of the total path in the route, which does not exceed 1 %. The proposed algorithm reduces the decision-making time by up to 6% in the presence of up to 50 units of vertices, and by 12 ... 15 % in the presence of vertices from 51 to 100 units.

The proposed vehicle routing algorithm can be used in decision support systems for planning the procurement of food raw materials in the community during emergencies, which will increase their efficiency.

CONCLUSIONS

The improved algorithm for forming the routes of vehicles for harvesting food raw materials in the territory of the community during emergencies involves the implementation of 8 steps and is based on the classic algorithm of ant colony optimization ACO. Unlike the existing one, it takes into account real production conditions, which ensures an increase in accuracy, a decrease in the duration of route formation, and an increase in the quality of management decision-making.

The comparison of the proposed route formation algorithm with the classic ACO algorithm for solving various route formation problems shows that the proposed algorithm provides a deviation that does not exceed 1 % of the total path in the route. The proposed algorithm reduces the decision-making time by up to 6% in the presence of up to 50 units of vertices, and by 12...15 % in the presence of vertices from 51 to 100 units.

FUTURE WORK

Further research requires the design of a decision support system for planning the procurement of food raw materials on the territory of the community during emergencies, which will be based on an improved algorithm for the formation of vehicle routes.

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Алгоритм формування маршрутів заготівлі продовольчої сировини на території громади з урахуванням виробничих умов під час надзвичайних ситуацій

Тригуба Анатолій Миколайович[1)]
ORCID: https://orcid.org/0000-0001-8014-5661; trianamik@gmail.com. Scopus Author ID: 57205225539
Коваль Назарій Ярославович[2)]
ORCID: https://orcid.org/0000-0001-7846-2924; kovaln870@gmail.com. Scopus Author ID: 57216856141
Ратушний Андрій Романович[2)]
ORCID: https://orcid.org/0000-0003-0768-6466; ratuwnuja@ukr.net
Тригуба Інна Леонтіївна[1)]
ORCID: https://orcid.org/0000-0002-5239-5951; trinle@ukr.net. Scopus Author ID: 57210807861
Шевчук Віктор Володимирович[1)]
ORCID: https://orcid.org/0000-0002-8260-2165; shevtyk@meta.ua. Scopus Author ID: 57219890504
[1)] Львівський національний університет природокористування, вул. В. Великого, 1. Дубляни, 80381, Україна
[2)] Львівський державний університет безпеки життєдіяльності, вул. Клепарівська, 35. Львів,79000, Україна

АНОТАЦІЯ

Стаття стосується удосконалення алгоритму оптимізації мурашинних колоній ACO (Ant Colony Optimization) для формування маршрутів транспортних засобів заготівлі продовольчої сировини на території громади під час надзвичайних ситуацій. Метою дослідження є вдосконалення алгоритму формування маршрутів транспортних засобів заготівлі продовольчої сировини на території громади під час надзвичайних ситуацій. Запропонований алгоритм базується на класичному алгоритмі оптимізації мурашиних колоній (ACO) (Ant Colony Optimization) та на відміну від нього враховує реальні виробничі умови під час надзвичайних ситуацій. Завданням дослідження є створення алгоритму для формування ефективних маршрутів транспортних засобів заготівлі продовольчої сировини на території громади під час надзвичайних ситуацій, а також його порівняння із класичним алгоритмом ACO для вирішення різних задач формування маршрутів. Встановлено, що використання класичного алгоритму оптимізації мурашиних колоній ACO, або ж відомих його модернізацій, не забезпечує якісного вирішення задачі формування маршрутів транспортних засобів заготівлі продовольчої сировини на території громади під час надзвичайних ситуацій. Це повязано із неповним врахування специфічних виробничих умов. Встановлено, виробничі умови заготівлі продовольчої сировини під час надзвичайних ситуацій, мають свої особливості. Зокрема, мережа доріг під час надзвичайний ситуацій може бути частково пошкодженою, що зумовлює обмежений рух транспортних засобів, або вцілому непридатною до використання. Транспортні засоби мають обмежену вантажність, що зумовлює формування множини маршрутів збору продовольчої сировини на території громади під час надзвичайних ситуацій. Це зумовлює потребу удосконалення алгоритму формування маршрутів заготівлі продовольчої сировини на території громади. У статті здійснено обґрунтування специфічних виробничих умов заготівлі продовольчої сировини під час надзвичайних ситуацій, характеристики яких лежать в основі удосконаленого методу визначення маршрутів. Удосконалений алгоритм формування маршрутів передбачає виконання 8 кроків та базується на класичному алгоритмі оптимізації мурашиних колоній (ACO) (Ant Colony Optimization). На відміну від нього враховує реальні виробничі умови (пошкоджені ділянки транспортного полотна, наявність часткової можливості проїзду транспортних засобів, затори викликані надзвичайною ситуацією тощо). Запропоновано правило класичного алгоритму ACO стосовно вибору наступного пункту у маршруті із використанням імовірнісно-пропорційного переходу *k*-ої мурахи із *i*-го у *j*-й вузол (господарство виробник продовольчої сировини), замінити на таке, що враховує стан виробничих умов (дорожнього полотна) між окремими вузлами. Це забезпечує підвищення точності та зниження тривалості формування маршрутів, а також підвищення якості прийняття відповідних управлінських рішень. Отримані результати щодо порівняння використання алгоритмів під час розвязання транспортних задач із різною кількістю вершин свідчать про те, що запропонований алгоритм забезпечує відхилення за сумарним шляхом у маршруті, яке не перевищує 1 %. Запропонований алгоритм забезпечує скорочення тривалості прийняття рішення за наявності до 50 одиниць вершин – до 6 %, а за наявності вершин від 51 до 100 одиниць – 12…15 %. Удосконалений алгоритм формування маршрутів транспортних засобів можна використовувати у системах підтримки прийняття рішень для планування заготівлі продовольчої сировини на території громади під час надзвичайних ситуацій, що підвищить їх ефективність.

Ключові слова: алгоритм; формування маршрутів; заготівля; продовольча сировина; надзвичайні ситуації; мінливі виробничі умови

ABOUT THE AUTHORS

Anatoliy M. Tryhuba - Doctor of Engineering Sciences, Professor, Head of the Department of Information Technology.
Lviv National University of Nature Management, 1, V. Velikoho Str. Dublyany, 80381, Ukraine
ORCID: https://orcid.org/0000-0001-8014-5661; trianamik@gmail.com. Scopus Author ID: 57205225539
***Research field*:** Modeling and designing of intelligent information systems; management of programs and project portfolios; computational intelligence

Тригуба Анатолій Миколайович - доктор технічних наук, професор, завідувач кафедри Інформаційних технологій.
Львівський національний університет природокористування, вул. В. Великого, 1. Дубляни, 80381, Україна

Nazarii Ya. Koval - Adjunct, Department of Information Technologies and Electronic Communications Systems.
Lviv State University of Life Safety, 35,. Kleparivska, Str. Lviv, 79000, Ukraine
ORCID: https://orcid.org/0000-0001-7846-2924; kovaln870@gmail.com. Scopus Author ID: 57216856141
***Research field*:** Design of information systems and technologies; machine learning; civil protection of the population

Коваль Назарій Ярославович – ад'юнкт, кафедра Інформаційних технологій та систем електронних комунікацій.
Львівський державний університет безпеки життєдіяльності, вул. Клепарівська, 35. Львів, 79000, Україна

Andrii R. Ratushnyi - Adjunct, Department of Information Technologies and Electronic Communications Systems.
Lviv State University of Life Safety, 35, Kleparivska, Str. Lviv, 79000, Ukraine
ORCID: https://orcid.org/0000-0003-0768-6466; ratuwnuja@ukr.net.
Research field: Design of information systems and technologies; machine learning; civil protection of the population

Ратушний Андрій Романович – ад'юнкт, кафедра Інформаційних технологій та систем електронних комунікацій.
Львівський державний університет безпеки життєдіяльності, вул. Клепарівська, 35. Львів, 79000, Україна

Inna L. Tryhuba - Candidate of Agricultural Sciences, Associate Professor, Associate Professor of the Department of Genetics, Breeding and Plant Protection. Lviv National University of Nature Management, 1, V. Velikoho, Str. Dublyany, 80381, Ukraine
ORCID: https://orcid.org/0000-0002-5239-5951; trianamik@gmail.com. Scopus Author ID: 57210807861
Research field: Modeling and designing of intelligent information systems; management of programs and project portfolios; computational intelligence

Тригуба Інна Леонтіївна – кандидат сільськогосподарських наук, доцент, доцент кафедри Генетики, селекції та захисту рослин. Львівський національний університет природокористування, вул. В. Великого, 1.
Дубляни, 80381, Україна

Viktor V. Shevchuk – Candidate of Engineering Sciences, Associate Professor, Head of the Department of Automobiles and Tractors. Lviv National University of Nature Management, 1, V. Velikoho Str. Dublyany, 80381, Ukraine
ORCID: https://orcid.org/0000-0002-8260-2165; shevtyk@meta.ua. Scopus Author ID: 57219890504
***Research field*:** Study of operational properties of vehicles; formation of the type and basic parameters of cars in agriculture

Шевчук Віктор Володимирович – кандидат технічних наук, доцент, завідувач кафедри Автомобілів і тракторів.
Львівський національний університет природокористування, вул. В. Великого, 1. Дубляни, 80381, Україна