sciendo

Transport and Telecommunication, 2019, volume 20, no. 2, 142–152
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia
DOI 10.2478/ttj-2019-0013

BUILDING OPTIMAL ROUTES FOR CARGO DELIVERY IN MEGACITIES

Viktor Danchuk [1], Olena Bakulich [2], Vitaliy Svatko [1]

[1] National Transport University, Faculty of Transport and Information Technologies
Kyiv, Ukraine
vdanchuk@ukr.net, vitaliy_svatko@ukr.net
[2] National Transport University, Faculty of Management, Logistics and Tourism
Kyiv, Ukraine
bakulich.elena@gmail.com

The main purpose of the study is to develop a method based on the modified ant algorithm and demonstrate the applicability of its use for building of optimal cargo delivery routes, taking into account the real (non-stationary) dynamics of high-density traffic on the urban road network in megacities. Within the framework of the proposed method the simulation of building optimal routes, by the example of Kiev, was carried out. The results of study indicate the possibility of using the method for the solution to the problems of efficient management of the freight transportation routing process in the conditions of real dynamics of traffic flows (dense traffic, traffic jam, emergency situations, etc.).

Keywords: optimal route; traffic flows; methods of optimization of transport routes; ant algorithm

1. Introduction

Accelerated motorization in the conditions of slow development of the urban road networks (URN) of large cities leads to a sharp increase in the number of vehicles on roads and intensification of traffic. This significantly increases the loading capacity of the transport network, leads to decrease in the velocity of traffic flow, the emergence of traffic congestion. It is known that long congestions on the roads are increasingly the cause of not only temporary, but also economic losses when delivering cargo to consumers in a megacity. This question is especially acute for enterprises that deliver their own goods, for example, small-lot cargo, to consumers without intermediaries, that is, by their own transport. In most segments of the market, the delivery of goods adds to its cost the amount of costs, which in some cases is close to the value of the product itself according to Statistics price of cargo in Ukraine.

Therefore, to a greater extent, the efficiency of the operation of such enterprises is determined by the efficiency of the use of transport logistics. At the same time, the main here is the solution of routing problems using such methods of route optimization that would effectively take into account the real dynamics of traffic flows on the URN.

Thus, the relevance of the study is determined by the need to develop, implement and apply appropriate models, methods and software to optimize and manage the transport process in conditions of unsteady dynamics of traffic flows on the URN. The use of such developments will increase the efficiency of transportation of goods within large cities.

2. Literature Review

As the analysis shows, the classical methods available today to solve the problems of discrete optimization of transport processes occurring in logistics systems are not perfect and do not give unambiguous decisions. In particular, it concerns the optimization of transport routes, which is devoted to a large number of scientific studies (see, for example, Lukinskiy and Dobromirov, 2016; Balasescu S. and Balasescu M., 2014; Qingyou and Zhang, 2015; Prokudin *et al.*, 2016; Goldberg *et al.*, 2005).

A new algorithm is proposed by Knight (2014) that enables an optimization procedure to be performed while simultaneously considering all paths between nodes of the graph taking into account the throughput of each of its edges. This method is based on the representation of a graph in the form of an electrical network, each of which has a certain resistance, which characterizes the corresponding throughput.

The proposed method, in the opinion by Knight (2014), also allows us to focus primarily on computations in the problem areas and high-level structures. This makes it possible to more efficiently use computing time without spending it on solving unimportant issues, but which is associated with cumbersome calculations.

However, a more in-depth analysis of the proposed method by Knight (2014) shows that here the solution of the discrete optimization problem comes to the solution of the problem of a linear algorithm associated with the solution of a corresponding system of linear equations of a certain dimension. Therefore, at least, it remains relevant to find solutions to the systems of equations of the maximum possible dimension for the given resources of computers.

It should be noted that the proposed method by Knight (2014) is similar to the method of discrete optimization, which is based on the use of self-organizing effects of ant agents (ACO) (Dorigo and Gambardella, 1997) and the classic genetic algorithm (GA) (Glover and Kochenberger, 2003; McCall, 2005; Rejer and Lorenz, 2015). The comparative analysis of ACO and GA points to a number of disadvantages when using a genetic algorithm to solve routing problems. In the works (Chandekar and Jayachandran Pillai, 2017; Ali *et al.,* 2016) are presented results of conducted ACO and GA tests for optimization in the framework of the travelling salesman problem (TSP) of various dimensions. The experimental data obtained showed that the use of ACO provides significantly better results for problems with the number of vertices up to about 100 points. In turn, GA finds better results when solving problems of great dimension (Potvin, 1996). Since the task of delivering small-party cargo within a metropolis contains, as a rule, 10-30 points, then for solving such a class of problems, we consider the most optimal use of the ant algorithm.

However, the classic method of self-organization of an ant colony proposed by Dorigo and Gambardella (1997) suggests the possibility of finding the optimal route for a static graph. Here ants, located at the initial time in the nodes of the graph, also simultaneously move along the edges of the oriented graph. This allows, taking into account the features of this method, to significantly reduce the time of the corresponding calculations. At the same time, the various properties attributed to ant agents enable us to solve a wide class of discrete optimization problems, taking into account many characteristics of the system being studied. Subsequent numerous studies of various physical processes carried out with the use of this method indicate the possibility of its use for solving discrete optimization problems of large dimension (Dorigo and Gambardella, 1997). In particular, it concerns the routing of vehicles on the URN and highways, information flows in computer networks, and so on.

In addition, now the literature presents a large number of modifications ACO (Dorigo *et al*., 1996; Karmakar, 2016; Gambardella and Dorigo, 1995; Bullnheimer *et al.*, 1997; Stutzle and Hoos, 1997; Dorigo and Gambardella, 1997).The majority of the proposed modifications in Dorigo *et al*. (1996); Karmakar (2016); Gambardella and Dorigo (1995); Bullnheimer (1997); Stutzle and Hoos (1997); Dorigo and Gambardella (1997) are known to be used to solve the static salesman problem (TSP), mainly aimed at improving the work of an ant algorithm, increasing the dimension and speed of computing the optimization problem.

On the other hand, the application of the ACO, in our opinion, may be promising for solving problems of optimization of processes occurring in open nonlinear dynamic non-stationary systems. In recent years there has been a rapid development of theoretical concepts, models, methods for describing nonlinear non-equilibrium dissipative processes and phenomena that occur in systems of different physical nature (Puchkovska *et al*., 2005).One of the main approaches used to describe such processes is a synergetic approach based on the principles of self-organization. For example, Puchkovska *et al*., (2005) within the framework of a no equilibrium nonlinear statistical-dynamic model, it is shown that with increasing temperature, due to the effects of self-organization, there is a transition from a single crystal to a rotary crystalline phase in organic molecular crystals. The effects of self-organization of enterprises under the influence of external stochastic and deterministic (discrete sharp, extreme) changes of factors of the nonlinear market environment are considered in the synergistic of Lorentz model proposed by Danchuk and Kravchuk (2013). This approach allows us to correctly describe and predict the time series of the evolution of enterprise activity under the influence of such changes.

As noted above, the ACO is also based on the use of the effects of self-organization of the agents. This determines its applicability to describe the corresponding non-equilibrium, non-stationary processes and phenomena which, among other things, are observed when considering the dynamics of high-density transport flows.

It primarily concerns large cities, the functioning of which is characterized by high dynamics of load, significant changes in the speed of vehicles, the appearance of congestion, etc.

In particular, Kerner (2004) based on the analysis of relevant experimental data obtained on highways in Germany, England and the United States, B. Kerner developed a theory of three phases of

the dynamics of a transport flow (free flow, synchronized flow, wide moving jam or traffic jam).This theory allows us to explain and predict empirical spatio-temporal dependences of phase transitions from free to dense (synchronized) flow and between resulting structures in a dense traffic flow. Within the framework of this theory, it is considered that the observed effects of phase transitions, hysteresis of velocity changes at these transitions are due to the manifestation of synergistic effects due to the no equilibrium non-stationary dynamics of transport flows in the region of their high density (Haken, 2004).

Now the attention of researchers attracts the problem of using an ant algorithm for solving dynamic transport problems. In particular, Xiaojun *et al.*, (2016) an application of the ACO was proposed for optimization of complex planning processes, with the possibility of taking into account dynamic emergency situations. However, such papers are very rare in the literature nowadays.

The main objective of the study is to develop a method based on a modified ACO and approbate its use for building optimal routes for cargo delivery, taking into account the real (non-stationary) dynamics of high-density traffic streets on the urban road network.

3. Proposed Method

For the development of the method for building the optimal route for the delivery of goods, we represent URN in the form of a two-way oriented weighted graph. At the nodes of such a graph there are points of delivery of the goods (warehouses, supermarkets, etc.) from the consignor with the help of a vehicle moving along the city's URN. The edges connect each pair of nodes of the graph. The weight of the edges is determined depending on the nature of the problem being solved. This can be the distance between points, the average speed or the average time, the cost of delivery by a vehicle in the transport flow in a certain section of the network. The optimization of routes of a vehicle is carried out by means of the ant algorithm within the framework of the TSP.

The classical ACO for discrete route optimization as part of the TSP is presented in Dorigo and Gambardella (1997).

Here, in particular, to determine the probability of a transition of an ant agent between any two nodes is found in accordance with Dorigo and Gambardella (1997) as follows:

$$\begin{cases} P_{ij,k}(t) = \frac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{l\in J_{i,k}}[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}}, j \in J_{i,k}, \\ P_{ij,k}(t) = 0, j \notin J_{i,k} \end{cases} \quad (1)$$

where $\tau_{ij}(t)$ - the amount of pheromone on the edge *(i, j)* at time *t;*

η_{ij} – the visibility that is the heuristic desire of ants to visit the city of *j* if it is in the city *i.* We will assume that visibility is inversely proportional to the distance between cities *i* and *j;*

α, β – are parameters setting the weight of the pheromone trace. When $\alpha=0$ the algorithm degenerates into a greedy algorithm (the closest city will be selected). These parameters were defined $\alpha = 1, \beta = 5$ by Danchuk, V. *et al.* (2017).

In the classical ACO it is not possible to take into account the dynamics of the traffic flow, which affects the finding of the optimal route of cargo delivery. In this regard, it is proposed to apply a modified ACO. The modification of the algorithm, in particular, consists in introducing into the classical ant algorithm function μ_{ij}, which depends on the load of the section URN between the nodes *i* and *j*. It is clear that the larger the load of the section of URN is, the less traffic flow there is. Consequently, the less probability of transition of an ant agent from node *i* to node *j* exists.

In this regard, this function μ_{ij} can be written as follows:

$$\mu_{ij} = \frac{a}{z_{ij}}, \quad (2)$$

where *a* – normalizing multiplier;

Z_{ij} - the load of the URN section between nodes *i* and *j*.

Then (1) can be represented as follows:

$$\begin{cases} P_{ij,k}(t) = \frac{\mu_{ij}[\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{l\in J_{i,k}}\mu_{ij}(t)[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}}, j \in J_{i,k}. \\ P_{ij,k}(t) = 0, j \notin J_{i,k} \end{cases} \quad (3)$$

In addition, according to Lobanov *et al.* (1970), one of the indicators of the state of the transport flow is C_{ij} - the multiplier of traffic velocity of the traffic flow in the section of URN between the points *i* and *j*, calculated by the formula:

$$C_{ij} = \frac{\vartheta_{ijnom}}{\vartheta_{ijfact}}, \quad (4)$$

where ϑ_{ijnom} – nominal value (maximum permissible without violation of traffic rules), the value of the speed of the traffic flow in the section of the URN between the nodes *i* and *j*, km / h;

ϑ_{ijfact} – the actual value of the velocity of the traffic flow in the section of the URN between the points *i* and *j*, km / h. The actual value corresponds to the real velocity value in each section of the URN at a certain point in time and depends on various random factors (congestion, traffic accident, repair of the road, incorrect parking of vehicles, etc.).

Using the value of the coefficient of flow rate of the traffic flow C_{ij} in the section of the UNR, one can find the corresponding value Z_{ij} of the load factor of the corresponding in the section of the UNR, according to Lobanov *et al.* (1970). To do this, we pre-perform the normalization of the value of the coefficient Z to the value of Z_{norm} . Data on the correspondence of the values of the coefficient of traffic flow speed to the coefficient of load in the section of the URN is given by Lobanov *et al.* (1970).

In addition, in order to take into account the real state of the dynamics of the traffic flow and increase the speed of the optimization procedure in the well-known classical ACO, the following modifications were introduced by Danchuk and Svatko (2012):

- Added the opportunity to record the results of optimization of the partly covered way, to calculate the further route when changing the length of the edges during movement. This will make it possible to reconstruct the route when the situation on the URN changes, taken into account the passed points;
- The cyclic movement of the colony has been changed to the asynchronous movement of each ant with a certain speed, which reduces the time of finding the optimal route.

In our view, the use of the ACO presented in this paper allows us to carry out the simulation of optimization of the route in the conditions of the real dynamics of traffic flows on the URN (high density traffic, congestion, etc.), where ant agents as analogues of vehicles move at appropriate speeds. It should be noted that in Danchuk and Svatko (2012), within the framework of such a modification of the method during optimization, the dynamics of changes in the velocity of traffic in the regions of the URN was not taken into account, but only those areas where speed was significantly reduced were excluded.

The application of such a modified method of ACO is carried out under the following assumptions:

1) the type of cargo delivery route - a circular, with gradual delivery of goods;
2) the movement of a dedicated vehicle in all sections of the URN is carried out within the framework of a two-way traffic;
3) there are always alternative routes in each set of n_j-sections of URN, which corresponds to the j-th edge of the graph;
4) any section of the URN between the points *i* and *j* is two-way oriented, that is, the distance between the points *i* and *j* is equal to the distance between the points *j* and *i* $l_{ij} = l_{ji}$;
5) the weight of the cargo transported from the manufacturer to each consumer (supermarket) is not taken into account when optimizing the delivery route;
6) the change in the average travel time and average speed of movement is largely dependent on changes of the driving dynamics modes that do not include stops or delays due to traffic lights signals.

Optimization of the route of vehicles on the URN comes to minimizing the route along the edges of the two-way oriented graph. At the same time, the lengths of the edges correspond to the time of passage between the nodes of ant agents. Accordingly, the optimal length of the route in the graph is the minimum time t of the vehicle's route on the URN. Thus, in our case, the criterion of optimality will be the minimum time of passing the route of cargo delivery.

$$T_{opt} \rightarrow min, \quad (5)$$

where T_{opt} - optimal time of delivery of cargo on the corresponding route.

Consequently, when building the optimal time route of cargo delivery, the information on the actual state of the URN at the time of the route construction is taken into account. At the same time, it is clear that at some limit values of the traffic flow velocity in certain areas of the URN, which correspond to certain levels of load of URN sections, it is possible to reconstruct the vehicle's optimal time route of the traffic on the URN for the delivery of goods to destination points.

4. Forming Questionnaires and Data Collection. Case Study from Kyiv

For the approbation of the proposed method of building the optimal route of cargo delivery, data on the distance between the points of delivery in Kyiv city (Fig. 1) and the average traffic velocities in the corresponding sections of the URN were used Routing service Google map and Video surveillance resource for road network in Kiev. A fragment in the URN of Kyiv was presented as a two-way oriented weighted graph.

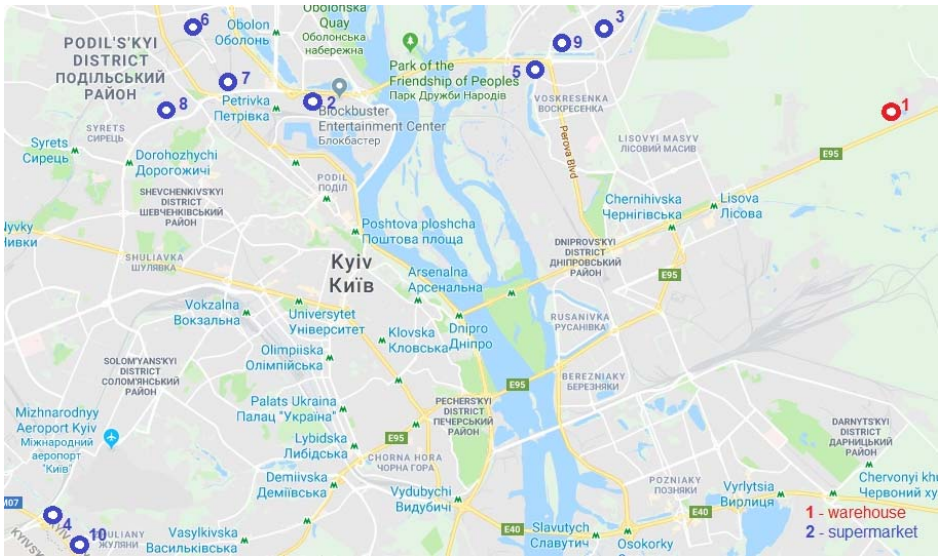


Figure 1. Scheme of the location of cargo delivery points in the URN of Kyiv.
Point 1 – distribution center (warehouse of delivery of goods); points (2– 10) – points of delivery of goods (supermarkets, etc.)

The corresponding simulation studies on the construction of the optimal route are performed according to the proposed method for 10 nodes that determine the delivery points of the cargo. The passage time of each section of the URN is calculated as the ratio of the length of the route to the average traffic flow velocity in this section. Length or times of travel on the corresponding route were chosen as the parameters of optimization.

Table 1. Data on the distance and the actual speed of movement between the points of delivery of the goods on the URN of Kyiv (Routing service Google map and Video surveillance resource for road network in Kiev)

Points between objects		The value of the velocities of traffic flow between the points, km / h									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Value of distances between points, km	**1**	0	54	49	44	47	44	45	25	15	32
	2	17	0	38	55	51	52	53	48	46	55
	3	16	15	0	49	56	38	45	58	38	36
	4	28	20	16	0	52	49	53	55	43	57
	5	17	5	10	25	0	55	58	50	41	43
	6	23	6	21	21	11	0	42	49	47	57
	7	19	2	17	18	7	3	0	55	59	54
	8	25	23	14	2	28	24	21	0	44	49
	9	15	8	13	28	3	14	10	31	0	53
	10	32	15	22	6	20	16	13	7	23	0

** Under the main diagonal are the distances between any two delivery points, and above the main diagonal of the matrix - the actual speed of the vehicle between them*

4.1. Building of the optimal route for the delivery of cargo on the URN of Kyiv without taking into account the change in the speed of traffic flows. Results and discussion

This section presents the results of simulation researches of the processes of building the optimal route provided the average velocities are unchanged in the URN areas. At the same time, for calculations,

data on the distance and average velocities in the regions of URN were presented in Table 1. The results of these calculations are shown in Figure 2 for 10 nodes respectively.

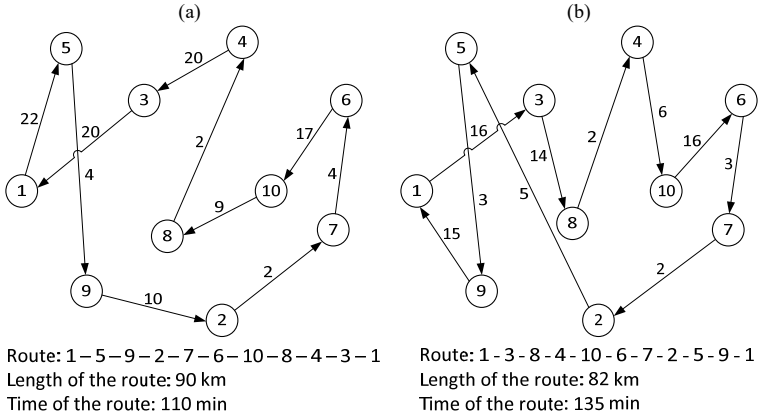


Figure 2. Optimal delivery route for 10 points: (a) by delivery time; (b) the length of the route

As can be seen from Figure 2, various optimal routes are obtained depending on the optimization parameter. In case of optimization of the route according to the time of delivery of goods (Fig. 2a) the length of the found route is 90 km. Time of the route is 110 minutes. In case of route optimization along the route length (Fig. 2b), its total length is 82 km, which is less than the previous by 8 km. The time of delivery of the cargo is 135 minutes, which is more than in the previous case by 25 minutes.

From the obtained results it can be seen that, depending on what is the optimization parameter, for the same initial data, in general, we get different delivery routes with different characteristics.

Consequently, the calculations show that there is a need for a correct choice of the optimization parameter, depending on the objective of goods delivery (minimum time or minimum delivery route).In addition, modeling simulations of the processes of building the optimal route and the results indicate the prospect of using ACO for solving routing problems.

In order to verify the correctness of the application of the modified ACO to solve the problems of finding the optimal route, given in this paper, the test of optimization of the route for the same network with 10 nodes (Table 1) was performed with the help of the exhaustive search method, as well as the method of branches and boundaries presented by Danchuk *et al.* (2017). The obtained results of research fully coincide with those obtained with the help of the corresponding ant algorithm.

Conducted test experiments using of a modified ACO for solving the problem of finding the optimal route for the delivery of goods, the initial data of which are shown in Table 1. Relatively good optimization results have been obtained, which indicate the promising application of the proposed modification of the algorithm. Here, test experiments were conducted on a computer with the following technical parameters: a 2.3 GHz Intel Core i5 processor with 8 GB RAM and a processor frequency of 2 MHz.

The results of the experiments are presented in the Table 2. Here t is the time of finding the optimal solution; N is the number of optimization cycles at a specific iteration; Topt is the time of the optimal route. Analysis of the results shows that with a sufficiently small number of cycles (up to 5000) and the time of their execution (up to 6.00 s), the proposed ACO modification gives the optimal solution. A further increase in the number of cycles to 50000 shows that the optimal value found does not change. In this connection, it can be argued that the result obtained is optimal.

Table 2. The results of the test experiments

1 iteration		2 iteration		3 iteration		4 iteration		5 iteration		6 iteration		7-9 iteration	
N, cycle	**Topt, min**	**N, cycle**	**Topt, min**	**N, cycle**	**Topt, min**	**N, cycle**	**Topt, min**	**N, cycle**	**Topt, min**	**N, cycle**	**Topt, min**	**N, cycle**	**Topt, min**
208	120	209	128	1	176	2	142	133	131	12	131	113	138
1245	114	227	127	3	120	157	140	1089	129	616	128	132	133
1736	112	505	122	2216	117	164	124	2217	124	3815	127	1340	130
4311	110	815	112	-	-	2480	121	4965	123	4540	126	1961	129
50000	110	50000	112	50000	117	50000	121	50000	123	50000	126	50000	129
t, s	5.17	-	0.98	-	2.66	-	2.98	-	5.96	-	5.45	-	2.35

4.2. Building of the optimal route for the delivery of cargo on the URN of Kyiv, taking into account the real dynamics of traffic flows. Results and discussion

In this section, the results of simulation modeling on optimization of the route of cargo delivery in conditions close to the real dynamics of transport flows on the URN of Kyiv are represented.

As noted in Section 3, the main macroscopic parameters that describe the dynamics of a traffic flow according to Lobanov *et al.* (1970) are the intensity of traffic, the density and average speed of the vehicles forming the flow. For qualitative expressions of the dynamics of the traffic flow, the relative indicators that correspond to these parameters are considered, namely, the load factor *Z*, the density factor ρ, and the coefficient of velocity *C* of the traffic flow. Then, depending on certain boundary values of these indicators, all possible states of the transport flow are divided according to Kerner (2004); Lobanov *et al.* (1970) into certain phases or modes of traffic, which are given in Table 3.

The classification of the modes of traffic, given in Lobanov *et al.* (1970), is not unique Kerner (2004), but for qualitative interpretation of the results of simulation in this paper, it can be considered as quite acceptable.

Table 3. The classification of modes of traffic flow according to the levels of comfort in accordance with Kerner (2004); Lobanov *et al.* (1970)

Z	***C***	**ρ**	**According to Kerner (2004), the transport flow phases**	**Mode of traffic flow according to Lobanov *et al.* (1970)**
< 0.2	> 0.9	< 0.1	free flow	Free movement of cars with max speed
0.20–0.45	0.70–0.90	0.10–0.30	synchronized flow	Partially connected, cars are moving in small groups
0.45–0.70	0.55–0.70	0.30–0.70		Coupled movement, cars are moving in large groups
0.7–1.0	0.40–0.55	0.70–1.00	wide moving jam	Dense movement, cars move in a column at low speed, there are traffic jams
> 1.0	< 0.4	–		Full stop of traffic, traffic jams

Using the data on the actual values of the velocity of the transport flow and the velocity of the traffic flow with free motion in certain areas of the URN of Kyiv (Routing service Google map and Video surveillance resource for road network in Kiev), the rate of passage of the *ij*-th edge of the graph C_{ij} can be determined by formula (4).

For simulation studies, as the initial route, the optimal route obtained during the time optimization procedure for the unchanged initial velocities on the edges taken from Routing service Google map and Resolution of the Cabinet of Ministers of Ukraine, for the graph with 10 nodes was selected (Fig. 2a).In addition, for the sake of unambiguity, it was considered that the actual speed of traffic flows due to changes in traffic conditions can be simultaneously varied in three sections of the optimal route 2-7, 10-8 and 4-3 (Fig. 3a, red lines).In the initial optimal route, the average speeds and time of traffic flow in these areas of the URN were 53 km/h and 2 min, 49 km/h and 9 min, 49 km/h and 20 min respectively. For qualitative interpretation of the optimization results, the values of the speed coefficients for these areas, calculated by the formula (4), were used. At the same time, the value of free traffic flow rates in the section of 2-7, 10-8 and 4-3 URN of Kyiv was respectively 60 km / h, 50 km / h and 50 km / h, limited to the corresponding traffic signs and Resolution of the Cabinet of Ministers of Ukraine.

Using the data given in Table 3, for the specified areas of the URN, the traffic flow coefficient C_{ij}, the load factor Z_{ij} and the loading capacity of the URN μ_{ij} according to (4) and (2), respectively, were found. Further, based on the data obtained, the probabilities of transition of ant agents between the corresponding nodes of the graph were determined.

The results of the simulation studies are shown in Table 4. Here $\upsilon_{2\text{-}7}$,$\upsilon_{10\text{-}8}$, $\upsilon_{4\text{-}3}$; $t_{2\text{-}7}$, $t_{10\text{-}8}$, $t_{4\text{-}3}$; $C_{2\text{-}7}$, $C_{10\text{-}8}$, $C_{3\text{-}4;}$ and $Z_{2-7}, Z_{10-8}, Z_{4-3}$ – values of velocities, driving times, velocity coefficients and values of the coefficients of occupancy of sites 2-7, 10-8, 4-3, respectively; *T* is the time of travel on the optimized route, *L* is the length of the route optimized. In the course of studies, the reduction of the corresponding actual velocities in sections 2-7, 10-8 and 4-3 URN of Kyiv was carried out after the second iteration with a discreteness of 5 km / h (see Table 4). Figure 3 shows the stages of the route-optimized time formation after each iteration which is associated with an increase in the load in the specified areas of the URN.

Table 4. Results of construction of the route optimal for 10 knots while simultaneously changing the average velocity in the URN sections 2-7, 10-8 and 4-3

Iteration	$\upsilon_{2\text{-}7}$, km/h	$t_{2\text{-}7}$, min	$C_{2\text{-}7}$	Z_{2-7}	$\upsilon_{10\text{-}8}$, km/h	$t_{10\text{-}8}$, min	$C_{10\text{-}8}$	Z_{10-8}	$\upsilon_{4\text{-}3}$, km/h	$t_{4\text{-}3}$, min	$C_{4\text{-}3}$	Z_{4-3}	Route	T_{opt}, min	L, km
1	53	2	0.90	0.2	49	9	0.98	0.04	49	20	0.98	0.04	1-5-9-2-7-6-10-8-4-3-1	110	90
2	45	3	0.76	0.39	45	9	0.90	0.2	45	21	0.90	0.2	1-5-9-2-7-6-10-8-4-3-1	112	90
													1-2-5-9-7-6-10-8-4-3-1	112	95
3	40	3	0.68	0.505	40	11	0.80	0.325	40	24	0.80	0.325	1-2-5-9-7-6-10-8-4-3-1	117	95
4	35	3	0.59	0.645	35	12	0.70	0.45	35	27	0.70	0.45	1-2-5-9-7-6-10-8-4-3-1	121	95
													1-3-5-9-2-7-6-10-8-4-1	121	87
5	30	4	0.51	0.765	30	14	0.60	0.615	30	32	0.60	0.615	1-3-5-9-7-6-10-8-4-2-1	123	104
6	25	5	0.42	0.88	25	17	0.50	0.765	25	38	0.50	0.765	1-3-5-9-7-6-10-8-4-2-1	126	104
7	20	6	0.34	0.925	20	21	0.40	0.9	20	48	0.40	0.9	1-3-8-4-7-6-10-2-9-5-1	129	112
8	15	8	0.25	0.96	15	28	0.30	0.94	15	64	0.30	0.94	1-3-8-4-7-6-10-2-9-5-1	129	112
9	10	12	0.17	0.99	10	42	0.20	0.98	10	96	0.20	0.98	1-3-8-4-7-6-10-2-9-5-1	129	112
10	5	24	0.08	1	5	84	0.10	1	5	192	0.10	1	1-3-8-4-7-6-10-2-9-5-1	129	112

As can be seen from Table 4 (the corresponding values of the coefficients of velocities $C_{2-7} = 0.9, C_{10-8} = 0.98, C_{4-3} = 0.98$ and coefficients of load $Z_{2-7} = 0.22, Z_{10-8} = 0.04, Z_{4-3} = 0.04$ for model sections) the initial optimal time route (Fig. 3a) is realized when the free movement of cars is carried out in all three URN sections in accordance with Kerner (2004), which is given in Table 3. After the second iteration of optimization in time, when in the section 2-7 synchronized motion already takes place in accordance with Kerner (2004), and on the other two there is free movement of cars, an increase in the load in the corresponding sections leads to the emergence of two alternative optimal routes (T = 112 min), the first of which corresponds to the initial one, and the second one is transformed so that it removes the section of URN 2-7, which changed the mode of movement of cars (Tables 4, 3; Fig. 3b, 3c). In this case, the length of the route for the last route is greater than for the initial (95 km and 90 km respectively). Obviously, when the time of passing the routes is the same, and the length of the route is different, more suitable route can be considered, the length of which is less. A similar situation with two alternative routes is observed during the fourth iteration (with the same travel time at the optimized route T = 121 min, but different lengths L 95km and 87km respectively), when in all three sections 2-7, 10-8, 4-3 there is the same nature of the traffic flow associated with the synchronized movement of cars (see Table 4, Table 3, Fig. 3c, 3d). At the same time, from each of these routes, one ,but different, section is excluded, in which within the framework of the presented model, there is a decrease in the average speed as a result of an increase in load (for one - a section of 2-7, for another - a section 10-8).

During the next, the fifth iteration of time optimization, a situation arises which corresponds to the state of the URN, where in section 2-7 there is a movement of cars in the form of wide-moving clusters (wide moving jam) at low speed and with a high probability of occurrence of a congestion and in the other two - the synchronized movement of cars (Tables 3, 4). Here, the time optimal route is reconstructed in such a way that only one of three sections remains in it (section 10-8 - Table 4, Fig. 3e).

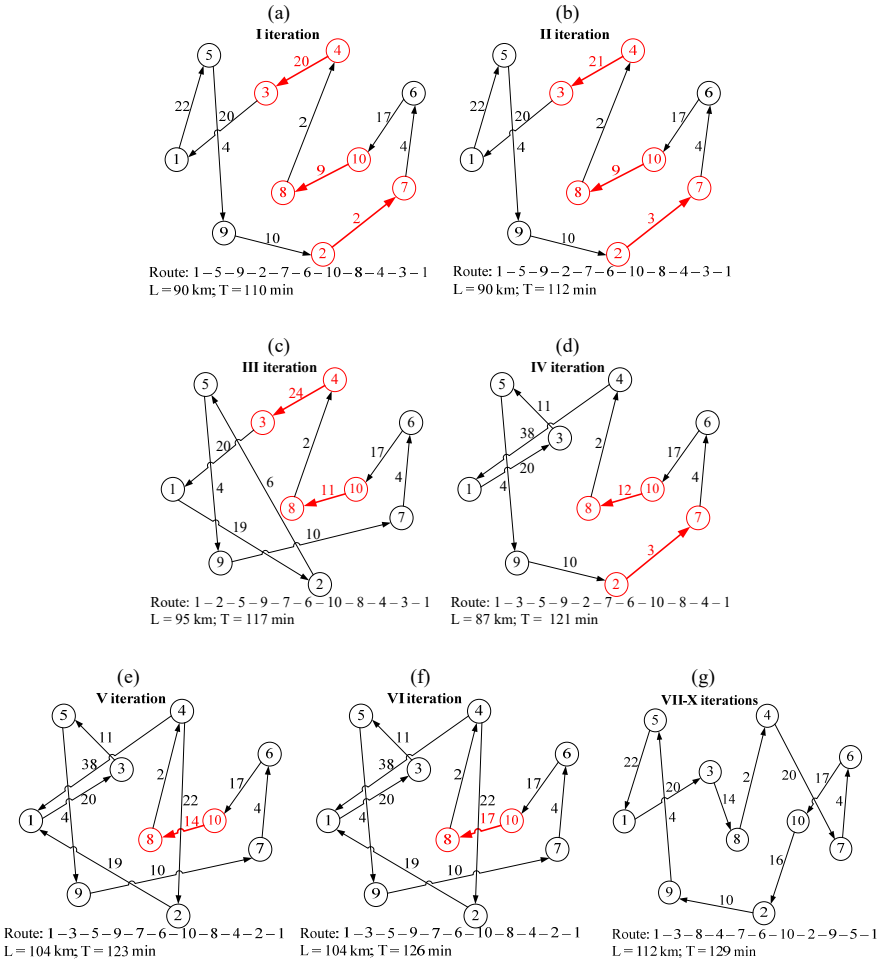


Figure 3. Construction of the optimal route with a gradual change in the speed of traffic at areas 2-7, 10-8 and 4-3 URN for 10 nodes. *The red shows the areas of URN, which are changing the average speed of the traffic flow*

Accordingly, starting with the seventh optimization iteration, where the increase of load of traffic flows in model areas of the URN reaches values corresponding to the values of load factors 0,925 and 0,9, that is, the mode of occurrence of traffic congestion in them (Tables 3, 4), the formed optimal route does not anymore contain these areas of URN (Table 4, Fig. 3g). And, it goes without saying that the further increase in the density of load in them no longer leads to the restructuring of the optimal route (Table 4, Fig. 3g).

5. Conclusions

The method of building the optimal route of delivery of small-lot cargoes in large cities in the conditions of real (non-stationary) dynamics of transport flows in the regions of URN, which is based on the use of the modified ACO, is developed. The main element of such a modification is the inclusion within the framework of the classical ACO when determining the probability of transition of an ant agent between any two nodes of the graph of the effect of the load function of the areas of the URN. The function of load areas determines the nature of the dynamics of traffic flows in these areas.

The approbation of the proposed method was carried out by the example of the city of Kyiv for 10 nods corresponding to the destination points of the cargo. In this paper, simulation modeling on optimization of the route in conditions close to the real dynamic state of transport flows on the URN was conducted. Within the framework of this model of the presentation of the network containing 10 delivery

points, the simultaneous changes in average speeds of traffic flows and, respectively, load in several (three) URN sections were taken into account.

The analysis of the simulation results gives grounds to consider that the proposed method makes it possible to adequately optimize the routes of cargo delivery in such conditions. In the future, it can be applicable to solving the problems of operational management of the transportation process, namely, the formation in the online mode of the optimal routes, taking into account the actual state of traffic on the URN.

Further research strategy should be aimed at improving this method which would allow us to take into account the influence of instantaneous values of the actual parameters of the dynamics of transport flows in the areas of URN, traffic light control, etc., in the processes of optimization.

The results obtained this way can be used to improve existing intelligent transport systems and technologies for traffic management on URN of megacities.

References

1. Ali, H., Haris, M., Hadi, F., Ahmadullah, Salman and Shah, Y (2016) Solving Traveling Salesman Problem through Optimization Techniques Using Genetic Algorithm and Ant Colony Optimization. *Journal of Applied Environmental and Biological Sciences,* 6(4S), 55-62.
2. Balasescu, S. and Balasescu, M. (2014) Optimization methods for supply chain activities. *Bulletin of the Transilvania University of Brasov Series V: Economic Sciences*, 7(56), 9-16.
3. Bullnheimer, B., Hartl, R. and Straub, Ch. (1997) A new rank based version of the Ant System. A computational study. *Adaptive Information Systems and Modelling in Economics and Management Science*, 1, 1-14.
4. Chandekar, N. and Jayachandran Pillai, M. (2017) A Comparative Study of GA and ACO for Solving Travelling Salesman Problem. *International Journal of Mechanical and Production Engineering,* 5(11), 34-37.
5. Danchuk, M.V. and Kravchuk, A.P. (2013) Features of Value-at-risk Methodology Application for Business Risks Estimation under Nonlinear Dynamics of Economic Development. *Actual Problems of Economic*, 148, 207-213.
6. Danchuk, V. and Svatko, V. (2012) Modified ant method of optimizing the route in the dynamic travelling salesman problem. *Visnik National Transport University*, 25, 378-382.
7. Danchuk, V., Bakulich, O. and Svatko, V. (2017) An Improvement in Ant Algorithm Method for Optimizing a Transport Route with Regard to Traffic Flow. *Procedia Engineering*, 187, 425-434.
8. Dorigo, M. and Gambardella, L. M. (1997) Ant Colony System: A Cooperative Learning Approach to the Traveling Salesman Problem. *IEEE Transactions on Evolutionary Computation*, 1, 53-66.
9. Dorigo, M. and Gambardella, L.M. (1997) Ant colonies for the traveling salesman problem. *BioSystems*, 43 (2), 73–81.
10. Dorigo, M., Maniezzo, V. and Colorni, A. (1996) The Ant System: Optimization by a colony of cooperating agents. *IEEE Transactions on Systems, Man, and Cybernetics-Part B*, 26(1), 29-41.
11. Gambardella, L.M. and Dorigo, M. (1995) Ant-Q: A Reinforcement Learning Approach to the Traveling Salesman Problem. In: *Proceedings of the Twelfth International Conference on Machine Learning*, Tahoe City, California, July 9–12, 1995, 252-260.
12. Glover, F., Kochenberger, G. (2003) *Handbook of Metaheuristics, Series: International Series in Operations Research & Management Science*, 57, 570 p.
13. Goldberg, A., Kaplan, H., and Werneck, R. (2005) Reach for A*: Efficient Point-to-Point Shortest Path Algorithms, *Technical Report MSR-TR-2005-132, Microsoft Research.*
14. Haken, H. (2004) *Synergetics. Introduction and Advanced Topics*. Berlin, Heidelberg: Springer, 758p.
15. Karmakar, R. (2016) Solving TSP Using Improved Elitist Ant System Based on Improved Pheromone Strategy and Dynamic Candidate List. *MAYFEB Journal of Computer Science*, 1, 8-15.
16. Kerner, B.S. (2004) *The Physics of Traffic*. Berlin, Heidelberg, New York: Springer, 683 p.
17. Knight, H. (2014) New algorithm can dramatically streamline solutions to the ‘max flow’ problem. *MIT News*, 2014, 21–26.
18. Lobanov, E., Silianov, V., Sitnikov, L. and Sapegin, L. (1970) *Throughput capacity of highways*. M.: Transport, 152.
19. Lukinskiy, V. and Dobromirov, V. (2016) Methods of evaluating transportation and logistics operations in supply chains. *Transport and Telecommunication,* 17, 55-59.

20. McCall, J. (2005) Genetic algorithms for modelling and optimization. *Journal of Computational and Applied Mathematics,* 184, 205-222.
21. Potvin, J.-Y. (1996) Genetic algorithms for the traveling salesman problem. *Annals of Operations Research*, 63, 339-370.
22. Prokudin, G., Chupaylenko, O., Dudnik, O., Dudnik, A., and Omarov, D. (2016) Improvement of the Methods for Determining Optimal Characteristics of Transportation Networks. *Eastern-European Journal of Enterprise Technologies*, 6/3(84), 54-61. - https://doi.org/10.15587/1729-4061.2016.85211
23. Puchkovska, G.O., Makarenko, S.P., Danchuk, V.D. and Kravchuk, A.P. (2005) Temperature Study of Resonance Intermolecular Interaction in Normal Long-Chain Carboxylic Acid Crystals Using IR Absorption Spectra. *Journal of Molecular Structure*, 744-747, 53-58.
24. Qingyou, Y. and Zhang, Q. (2015) The Optimization of Transportation Costs in Logistics Enterprises with Time-Window Constraints. *Discrete Dynamics in Nature and Society*, 2015, 10-15.
25. Rejer, I. and Lorenz, K. (2015) Classic genetic algorithm vs. genetic algorithm with aggressive mutation for feature selection for a brain-computer interface. *Przegląd Elektrotechniczny,* 91(2), 98-102.
26. Resolution of the Cabinet of Ministers of Ukraine from 10.11.2017 № 883 «On changes to the rules of the road». Available at: http://zakon3.rada.gov.ua/laws/show/883-2017-%D0%BF
27. Routing service Google map. Available at: https://www.google.com.ua/maps/
28. Statistics price of cargo in Ukraine. Available at*:* http://degruz.com/price_statistics
29. Stützle, T. and Hoos, H. (1997) MAX-MIN Ant System and local search for the traveling salesman problem. *IEEE International Conference on Evolutionary Computation*, 309-314.
30. Video surveillance resource for road network in Kiev. *Available at:* http://videoprobki.ua
31. Xiaojun, L., Zhonghua, N. and Xiaoli, Q. (2016) Application of Ant Colony Optimization Algorithm in Integrated Process Planning and Scheduling. *The International Journal of Advanced Manufacturing Technology*, 84 (1), 393–404.
32. Zhaoyuan, W., Huanlai, X. and Tianrui, L. (2016) A Modified Ant Colony Optimization Algorithm for Network Coding Resource Minimization. *IEEE Transactions on Evolutionary Computation*, 20 (3), 325-342.