Проаналізовано стан автомобільних вантажних перевезень в Україні та країнах-членах Європейського союзу. Досліджено процес транспортування вантажів у мережевому представленні з метою удосконалення схем їх доставки. Запропоновано використання сучасних засобів інформаційних технологій для розв'язання задачі комівояжера комбінаторним способом і транспортної задачі у вигляді дорожньо-транспортної мережі симплексним методом. Розглянуто як збалансовані, так і незбалансовані за обсягами перевезень вантажу транспортні задачі, враховано обмеження на пропускні здатності транспортних комунікацій. Використання удосконалених методів оптимізації міжнародних транспортних перевезень з залученням розроблених комп'ютерних програм дозволить автоматизувати процеси розрахунку і підвищить економічну ефективність перевезень

Ключові слова: дорожньо-транспортна мережа, задача комівояжера, транспортна задача, симплексний метод, оптимізація міжнародних транспортних перевезень

Проанализировано состояние автомобильных грузовых перевозок в Украине и странах-членах Европейского Союза. Исследован процесс транспортировки грузов в сетевом представлении с целью усовершенствования схем их доставки. Предложено использование современных средств информационных технологий для решения задачи коммивояжера комбинаторным способом и транспортной задачи в виде дорожно-транспортной сети симплексным методом. Рассмотрены как сбалансированные, так и несбалансированные по объемам перевозок груза транспортные задачи, учтены ограничения на пропускные способности транспортных коммуникаций. Использование усовершенствованных методов оптимизации международных транспортных перевозок с привлечением разработанных компьютерных программ позволит автоматизировать процессы расчета и повысить экономическую эффективность перевозок

Ключевые слова: дорожно-транспортная сеть, задача коммивояжера, транспортная задача, симплексный метод, оптимизация международных транспортных перевозок

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APPLICATION OF INFORMATION TECHNOLOGIES FOR THE OPTIMIZATION OF ITINERARY WHEN DELIVERING CARGO BY AUTOMOBILE TRANSPORT

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1. Introduction

Current market conditions make the Ukrainian transport sector that provides services not only to domestic enterprises but also to international transportation, very important. According to data from the State Statistics Committee, automobile enterprises of Ukraine delivered 175.6 million tons of freights during 2017, which is 4.7 % larger than in the previous year. The number of enterprises engaged in freight transportation has also increased. There were 2.3 thousand such enterprises in Ukraine at the beginning of 2018, including 2.2 thousand automobile transportation companies [1].

An analysis of statistical data shows positive trends of growth, observed in the automobile transportation industry of Ukraine [2, 3], with, consequently, a further increase in volumes, structure, and geography of transportation of various freights. Ukraine is a transit country for many directions of international freight traffic; the country hosts important international transport corridors.

The volumes of transported freight in the EU countries [4] also tend to grow and made up 1,921,434.5 million tkm in 2017, which is 3.99 % larger than in the previous year.

Development of optimal routes for delivery of goods in international traffic has a goal to increase the efficiency of international transportation. Delivery routes are constantly changing for various reasons, the main of which is the failure to match the volumes of supply against demand. Methods of calculation used in at present do not meet modern requirements of efficiency and require significant time for the relevant estimations. The application of improved methods will make it possible to bring down the cost of transportation of freight by automobile vehicles and improve the competitiveness of domestic carriers.

Given this, one of the urgent tasks of transportation industry at present is the task on optimization of schemes of freight delivery, especially under conditions when the volume of supply does not correspond to demand. Cargo transportation in most cases in practice are represented in the form of a transport problem (TP), which is a particular case of the general problem on linear programming (GPLP). To solve such problems, it is possible to apply the most known method for solving GPLP – simplex method, by first reducing the transport problem to the form of a problem on linear programming and by accounting for the specificity [5].

When managing cargo transportation, especially delivered by automobile vehicles, very often used in practice are the delivery and combined schemes of freight delivery whose optimization may employ the well-known traveling salesman problems.

Thus, the optimization of schemes of freight delivery by international traffic, applying modern information technologies, will make it possible to improve the efficiency of transportation and enhance the competitiveness of transport enterprises of Ukraine.

2. Literature review and problem statement

The application of information technologies in the field of transportation is gaining importance under modern conditions. Optimization of freight delivery schemes is one of the key tasks in the sector of transportation and logistical operations. In most market segments, delivery of goods adds the amount to its cost that is equivalent to the value of the goods. Along with this, it is worth noting that the use of modern information technologies for the optimization of such deliveries often helps save not less than 5–20 % of the total cost [6].

The issue of development of methods for the optimization of transportation is treated very seriously [7]. Organization of cargo transportation, especially delivered by automobile transport, is associated with the use of multi-drop and multi-pick routes for freight delivery. Multi-pick (collected) routes are a kind of circular routes that imply gradual unloading (loading) of cargo in each subsequent route point and returning to the original point of the route. They in essence represent different kinds of the well-known traveling salesman problem. The specified problem gave rise to the development of a separate direction in graph theory, which is known as the search for Hamilton cycles in graphs [8]. A Hamiltonian cycles problem in graph theory has received different generalization. One of these generalizations is the task of a salesman that in different modifications often occurs in transport logistics when planning transportations. The task of a salesman is a modified problem on assignment, however, in this case, the binding between the points should form a closed loop. There is also a generalization of the problem, the so-called generalized travelling salesman problem [9]. But the use of this method to optimize international transport could not be implemented because it does not take into consideration the factors that are associated with the organization of customs control at the borders and the modes of operation of the drivers in accordance with the European agreement concerning the work of crews of vehicles engaged in international road transport (AETR) [3].

Cargo transportation in most cases in practice are represented in the form of TP, which is a special case of GPLP, it is also possible to tackle it by applying the most known method for solving GPLP – simplex method [10]. However, the simplex method cannot be used to calculate the networks of international transport in the case when cargo transportation is not balanced for volumes [11]. To solve a given problem, one must reduce the specified transport problem to a tabular form.

Thus, the relevant problem is the need to improve existing methods for the optimization of transportation by applying modern means of information technology. That is necessary to improve the effectiveness of international freight transportation, taking into consideration the features of the organization of customs controls at the borders between states, as well as operational modes of crews of vehicles engaged in international road transport [12].

3. The aim and objectives of the study

The aim of present study is to improve the efficiency of cargo transportation along international routes by applying modern tools of information technology.

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

1. To improve a combinatorial method and develop software for solving a traveling salesman problem along a road transport network (RTN) taking into consideration the patterns in international automobile transportation and customs services and constraints for the throughput of transport infrastructure.

2. To apply the simplex method and develop software for solving a transport problem represented in a network form using the methods that imply reducing a transport problem, unbalanced in terms of transportation cargo volumes, to the transport problem of the balanced form, by introducing an additional fictitious transportation node, proportional and different, as well as by taking into consideration constraints for the throughput of routes along which freight is transported.

4. Impact of transport technologies on the efficiency of cargo transportation along international routes

4. 1. Representation of a salesman task in the road-transport network and approaches to solving it

Problem statement. There are *n* transport nodes in RTN. We assign a matrix of distances between them $L=\left|L_{i,j}\right|$. In a general case, $L_{i,j} \neq L_{j,i}$. Departing from the initial transport node A_0, a truck must deliver or collect freight to/from all or the rest of the RTN transport nodes, calling them once, and return to the initial transport node A_0. Therefore, the route of the truck is circular in its structure. It is required to determine the order to travel to the transport nodes of RTN so that the total distance travelled is minimal.

Mathematical model of the problem. We introduce Boolean variables: $z_{i,j}$=1 if a salesman moves from point A_i to point A_j; $z_{i,j}$=0 – otherwise. Where $i, j = 1,2,\ldots,n;\quad i \neq j.$ It is required to find

$$\min \sum_{i=1}^{n}\sum_{j=1}^{n} l_{i,j} \cdot z_{i,j}, \tag{1}$$

under conditions

$$\sum_{j=1}^{n} z_{i,j} = 1,\quad i = 1,2,\ldots,n \tag{2}$$

$$\sum_{i=1}^{n} z_{i,j} = 1,\quad j = 1,2,\ldots,n, \tag{3}$$

$$u_i - u_j + n \cdot z_{i,j} \leq n-1,\quad i,j = 1,2,\ldots,n;\quad i \neq j, \tag{4}$$

where u_i, u_j are the arbitrary positive integers.

Condition (2) defines that a salesman enters each point once, except for the starting point. Condition (3) defines that he leaves each point once. Condition (4) ensures the closeness of the itinerary, which contains n points, and the absence of loops [10]. Additionally, we shall introduce the following constraints:

$$d_{i,j} \geq x_{i,j} \geq 0, \tag{5}$$

where $d_{i,j}$ is the throughput of a route section of cargo transportation from A_i to A_j, and $x_{i,j}$ is the volume of cargo transported between them.

It should be noted that this constraint should be considered only in the case of significant volumes of cargo transportation along the specified route.

The task of a traveling salesman refers to NP-complete problems, that is, in which at even at a relatively small number of places he visits (66 and more), it cannot be solved by a simple brute force method for all variants (combinatorial technique) by any theoretically possible computers in time less than several billion years. However, based on the practice of freight transportation, the number of transport nodes in multi-drop (combined) transportation routes is significantly less than the above value (20 and less). In addition, combinations of transport nodes, generated and entered into databases in advance, which make up the routes for transportation networks of the specified above dimensionality, represent the Hamiltonian cycles, thereby significantly reducing computational time.

When solving the task of a traveling salesman in real transportation networks, which lack transport links between each transportation node and all the rest, the number of combinations of transportation nodes is significantly reduced, which also has a positive effect on their solving time.

4. 2. Representation of the transport problem in a tabular form and approaches to solving it

We shall represent the process of cargo transportation in a tabular form, that is, in the form of a transport table (TT) (Table 1), where:

A_i – points of cargo delivery (*DP*), each of which accumulates, respectively, a_i of its volume ($i = \overline{1,m}$);

B_j – points of cargo utilization (*UP*), which placed orders for this cargo, respectively, of volume b_j ($j = \overline{1,n}$);

$c_{i,j}$ – the unit cost of transporting a cargo from A_i to B_j, and $x_{i,j}$ is the volume of cargo transported between them.

The result of solving TP is the minimizing of the objective function C, which is the total cost of cargo transportation, that is,

$$C = c_{1,1} \cdot x_{1,1} + c_{1,2} \cdot x_{1,2} + \ldots + c_{m,n} \cdot x_{m,n} => \min, \tag{6}$$

under condition of picking up the stocks of cargo from all its suppliers (a_i) and meeting all the orders (b_j) from all consumers, as well as fulfilling the following constraints (in contrast to constraints (5) with a different route):

$$d_{i,j} \geq x_{i,j} \geq 0, \tag{7}$$

where $d_{i,j}$ is the throughput of the route of transporting a cargo from A_i to B_j.

Table 1

Initial transportation table

Points		Utilization: B_1	B_2	...	B_n	Stock
Delivery	A_1	$c_{1,1}$ $x_{1,1}$+	$c_{1,2}$ $x_{1,2}$+	...	$c_{1,n}$ +$x_{1,n}$	=a_1
	A_2	+$c_{2,1}$ $x_{2,1}$+	+$c_{2,2}$ $x_{2,2}$+	...	+$c_{2,n}$ +$x_{2,n}$	=a_2
	...	...	...	...	...	...
	A_m	+$c_{m,1}$ $x_{m,1}$+	+$c_{m,2}$ $x_{m,2}$+	...	+$c_{m,n}$ +$x_{m,n}$	=a_m
Orders		‖ b_1	‖ b_2	...	‖ b_n	

Before filling the simplex table (ST) (Table 2) with values for the parameters from the original TT, we shall perform two preliminary steps, namely:

– replace variables $x_{1,1}$ with x_1, $x_{1,2}$ with x_2, $x_{1,3}$ with x_3, etc., $x_{m,n}$ with x_{mn}, that is, we convert two indexes at variable x into one index by multiplying them (for instance, $x_{3,5}$ by x_{15});

– add, as required by the simplex method, to all the equations additional variables x_{mn+1}, x_{mn+2} and so on to $x_{mn+m+n-1}$, which will make up the initial basis solution to TP, by artificially assigning to their coefficients in the objective function C the values that are deliberately larger than all existing coefficients.

Each (m+n–1) ST line corresponds to one of the linear equations that represent either m equations m of TT lines (for example: $x_{1,1}$+$x_{1,2}$+...+$x_{1,n}$=a_1) or (n–1) equations of TT columns (for example: $x_{1,1}$+$x_{1,2}$+...+$x_{1,n}$=a_1). These equations are highlighted in Table 1 with a background color ($x_{1,1}$). Moreover, a value of 1 appears in the ST line in the case when the equation in TT has the corresponding variable x_i.

The last ST line contains calculated values of the objective function C and indexes Δ_i, which are the indicators of the end of the optimization process (a condition for the completion of optimization process is non-negative value).

The above non-classic transformation of the transport problem, assigned in the form of a transportation table, into a simplex table, is the basis for its subsequent computer calculation.

Table 2

Initial simplex table

CT			x_1	x_2	...	$x_{m{\cdot}n}$	$x_{m{\cdot}n+1}$	...	$x_{m{\cdot}n+m+n-1}$
C_{bi}	X_{bi}	AB_{bi}	$c_{1,1}$	$c_{1,2}$	...	$c_{m,n}$	B	...	B
B	$x_{m{\cdot}n+1}$	a_1	1	1	...	0	1	...	0
B	$x_{m{\cdot}n+2}$	a_2	0	0	...	0	0	...	0
...	...	...	...	...	...	...	...	...	...
B	$x_{m{\cdot}n+m+n-1}$	b_{n-1}	0	0	...	0	0	...	1
C			Δ_1	Δ_2	...	$\Delta_{m{\cdot}n}$	$\Delta_{m{\cdot}n+1}$	...	$\Delta_{m{\cdot}n+m+n-1}$

An additional feature of the problem statement is its subsequent solving both for the transportation problems, non-balanced in terms of cargo volumes, and for the transportation networks with a large quantity of not only transportation nodes for delivery and utilization of goods but intermediate transport nodes as well.

We developed and compiled the database of infrastructure of Ukraine's transport system, which includes 300 major transportation nodes across the motor roads of international and European importance. The software for the optimization of international freight transportation in the transport system of Ukraine takes into consideration the throughputs of transport infrastructure, as well as capable of solving transport problems under condition of disbalanced volumes of cargo transportation.

5. Application of modern information technology tools for the optimization of cargo delivery schemes along international routes

5. 1. Software-based improvement of the process of international cargo transportation in order to solve a traveling salesman problem

We shall use an example of TP in the form of a solution to the problem on transporting a cargo from the Zhytomyr oblast to Poland. The cargo is wooden pellets, since wood and products made from it account for 23 % of the total export of Zhytomyr oblast. The cargo to be picked up in Poland is wooden furniture. The goods to be delivered were selected based on data from the State Statistics Service of Ukraine [1], laws and regulations, as well as the economic and social situation in this country. We chose 10 pick-up points in Zhytomyr Oblast with the largest volumes in the production of wood pellets, specifically: Dubrivka, Romaniv, Lubar, Malin, Ovruch, Novohrad-Volynskyi, Zhytomyr, Korosten, Berdichev, Radomyshl (Fig. 1).

The decisive factors when choosing the checkpoints (c/p) were the duration of customs operations, as well as the distance from the points of cargo dispatch. The following c/p are in the territory of Ukraine: Yagodin, Ustilug, Uhryniv, Rava-Ruska, Hrushiv, Krakovets, Shehyni, Smilnica.

The following c/p are in the territory of Poland: Dorohusk, Zosin, Dolgobičuv, Grebenne, Budomêž, Korczowa, Medyka, Kroscenko.

Destinations points in Poland were selected based on the fact that there are consumers for wood pellets, as well as furniture factories that export their finished products to Ukraine. Thus, the destinations are the following: Słupsk, Verušuv, Racibórz, Elblag, Morąg; Brodnica, Warsaw, Kielce, Ostrowiec Świętokrzyski, Vengruv.

Employing the database management system Microsoft Access, we built a database with appropriate distances between c/p, points of departure and destination points (Fig. 2).

For convenience, the data on these distances are automatically converted into a file of the spreadsheet processor Microsoft Excel (Fig. 3). The software to solve a traveling salesman problem was developed using the algorithmic programming language Delphi [13].

To begin, we enter temporal characteristics of cargo handling operations along a given route. Loading and unloading the pellets and furniture will be mechanized. We assign service time at each c/p and the mean technical speed of a vehicle (V_t=65 km/h).

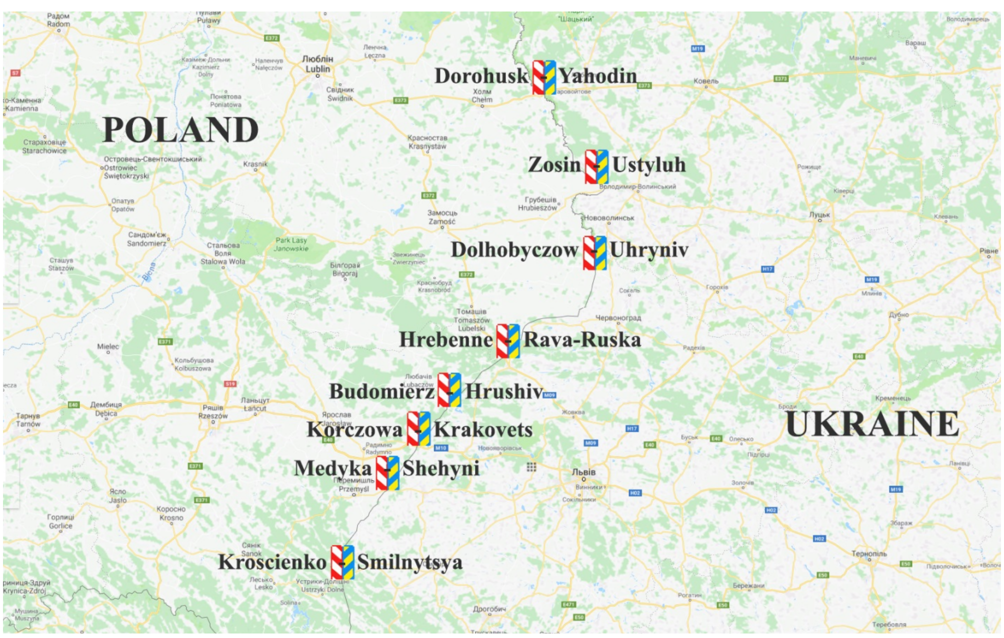


Fig. 1. Automobile check-points at the Ukrainian-Polish border

No.	Point of departure	Destination point	L
1	Dubrivka	Romaniv	55
2	Dubrivka	Lubar	81
3	Dubrivka	Malin	187
4	Dubrivka	Ovruch	161
5	Dubrivka	Novograd-Volynskiy	39
6	Dubrivka	Zhytomyr	97
7	Dubrivka	Korosten	130
8	Dubrivka	Berdichev	127
9	Dubrivka	Radomyshl	200
10	Dubrivka	Yahodin (CP)	338
11	Dubrivka	Ustyluh (CP)	314
12	Dubrivka	Uhryniv (CP)	337
13	Dubrivka	Rava-Ruska (CP)	389

Fig. 2. Database of distances between c/p, points of departure and destination points

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1		City	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	1	Dubrivka	0	55	81	187	161	39	97	130	127	200	338	314	337	389
3	2	Romaniv	55	0	50	152	182	73	64	136	63	137	381	357	368	443
4	3	Lubar	81	50	0	174	219	112	84	173	69	157	395	343	329	378
5	4	Malyn	187	152	174	0	94	146	88	58	128	36	404	405	442	508
6	5	Ovrutch	161	182	219	94	0	139	133	48	173	127	384	385	422	488
7	6	Novograd-Volynskiy	39	73	112	146	139	0	84	108	125	157	316	292	307	367
8	7	Zhytomyr	97	64	84	88	133	84	0	87	41	74	392	368	403	454
9	8	Korosten	130	136	173	58	48	108	87	0	127	90	357	357	394	460
10	9	Berdichev	127	63	69	128	173	125	41	127	0	115	433	409	395	431
11	10	Radomyshl	200	137	157	36	127	157	74	90	115	0	437	437	474	531
12	11	Yahodin (CP)	338	381	395	404	384	316	392	357	433	437	0	83	120	212
13	12	Ustiluh (CP)	314	357	343	405	385	292	368	357	409	437	83	0	60	148
14	13	Uhryniv (CP)	337	368	329	442	422	307	403	394	395	474	120	60	0	103
15	14	Rava-Ruska (CP)	389	443	378	508	488	367	454	460	431	531	212	148	103	0

Fig. 3. Distances between c/p, points of departure and destination points in the Microsoft Excel file format

Consider an example of the traveling salesman problem with one point of departure in Ukraine, four c/p (two in Ukraine and two in Poland), four destination points in Poland. That is, in one of the cities of Zhytomyr oblast we load 20 tons of wood pellets. Loading is mechanized. In 4 cities of Poland we unload 5 tons of cargo, and in the final point we load 20 m^3 of furniture (about 20 tons). Both wooden pellets and furniture belong to cargo of class 1, that is, the coefficient of static use of the carrying capacity of the vehicle is equal to unity ($\gamma_{st} = 1$).

It should be noted that when adding c/p to the route, the software operates in two modes: manual and automated. That is, c/p can be selected independently, or the software performs this automatically, by choosing the nearest one to the point of departure. The software generates a respective table, which clearly shows distances between the specified cities and c/p. We build possible closed routes and choose the shortest route among all options (Fig. 4).

By using a combinatorial technique, we build possible closed routes and choose the shortest route among all options (Fig. 4).

Next, based on the results of a combinatorial technique [14], the software generates the resulting shortest route consisting of sections that it includes (Fig. 5).

Thus, we determined that of all the software-identified 24 possible routes, the most efficient one would be:

Dubrivka→Ustiluh→Zosin→Warsaw→Elblong→
→Slupsk→Verushuv→Dorohusk→Yahodyn→Dubrivka.

The length of the route is 2,390 km. Total time of transportation is 36.76 hours, service time at the first c/p Ustiluh is 45 min, at the second (Zosin) – 40 min, at the third (Dorohusk) – 35 min, at the fourth (Yahodyn) – 40 min. Duration of loading and unloading operations is 750 min. Total time to perform the route is 51.93 hours.

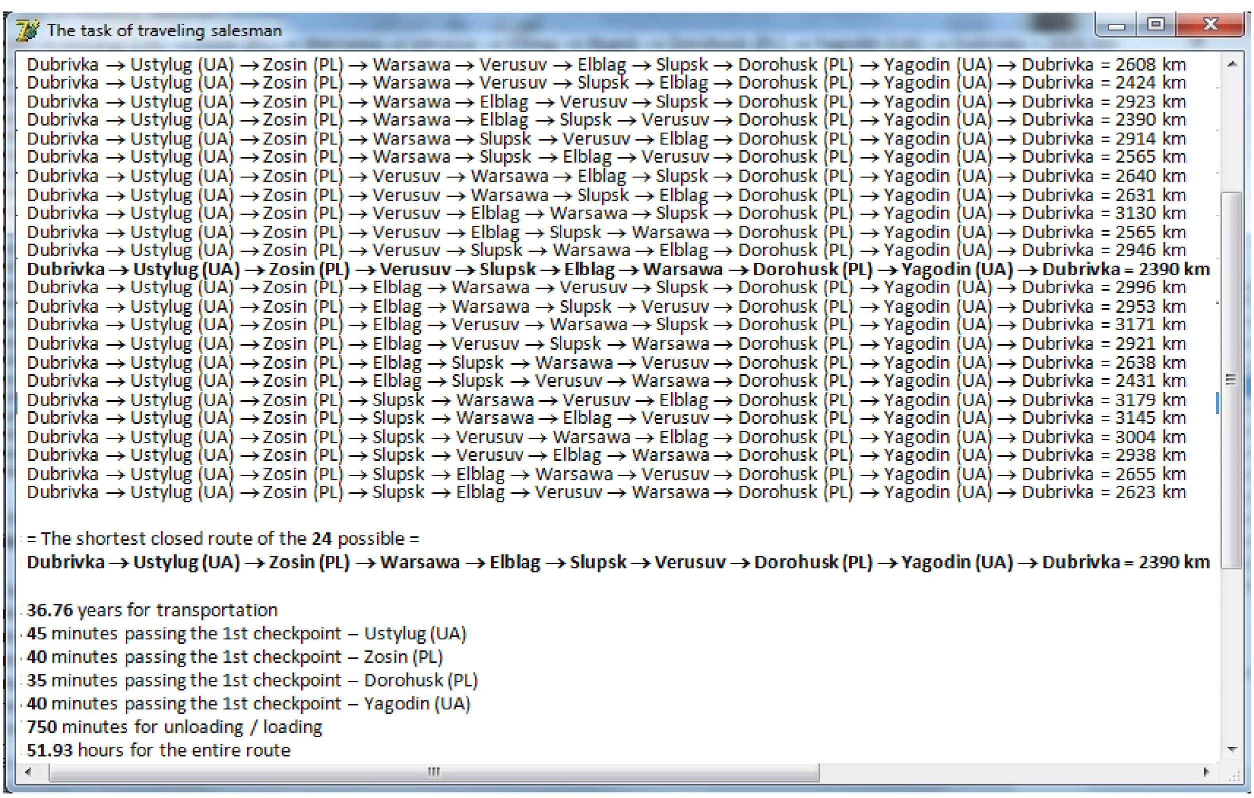


Fig. 4. Result of the software operation

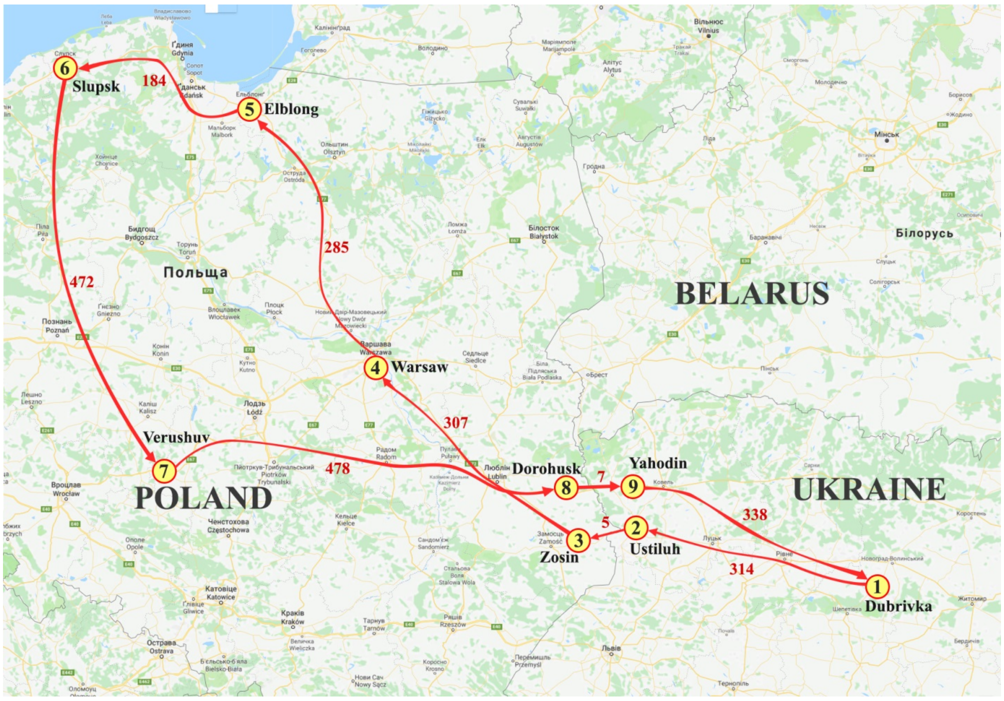


Fig. 5. Itinerary of the specified closed route

5. 2. Software-based improvement of the process of international freight transportation in order to solve a transport problem

We shall use as an example of TP two delivery points (*DP*) – A_1 (Dubrivka) and A_2 (Zhytomyr), four transit points – C_1 (Yahodyn), C_2 (Dorohusk), C_3 (Zosin), and C_4 (Ustyluh), and four utilization points (*UP*) – B_1 (Warsaw), B_2 (Elblag), B_3 (Slupsk), and B_4 (Verušuv) (refer to RTN in Fig. 6).

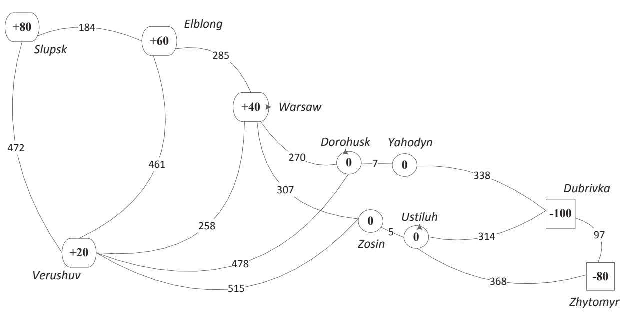


Fig. 6. Graphical representation of a road transport network

At the edges of a given RTN, we assigned distances between the corresponding points, in kilometers, and the volumes of cargo, in tons (indicated at the vertices of the graph), which need to be picked up at *DP* (indicated with sign –) and must be delivered to *UP* (indicated with sign +). It is required to minimize transportation costs under condition that there should be 20 tons of cargo more than currently is, specifically:

$$\sum_{i=1}^{2} a_i = 180 \neq \sum_{j=1}^{4} b_i = 200,$$

that is, we have a TP, unbalanced (open) in terms of cargo transportation volume.

First, we optimize the TP represented in a network form using the three methods to reduce a TP, unbalanced in terms of cargo transportation volume, to the balanced form, specifically: introduction of an additional fictitious transportation node, proportional and different.

Optimization of freight transportation in RTN will be conducted by using the computerized optimization system of cargo transportation in RTN (COSCT in RTN) [15]. The result of work of a computerized system whose methodological basis for optimization is the simplex method is shown in Fig. 7. Preliminarily, we reduce the proposed transport problem to a tabular form – transport table (TT) (Table 1).

In the case of reducing open TP to the balanced form by introducing an additional fictitious *DP* A_F, which in our case is the transit point C_1 (Yahodyn), this TT will contain the result of solving a given TP (Table 1), which is shown with bold numbers in it.

Solution is optimal
10 iterations executed

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1				615	900	1084	823	680	965	1149	888	277	562	746	485	270	555	739	478
2	1084	3	80	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
3	823	4	20	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
4	277	9	20	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
5	270	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
6	312	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	307	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	680	5	20	1	0	0	0	1	0	0	0	0	-1	-1	-1	0	-1	-1	-1
	900	2	0	1	1	0	0	0	0	-1	-1	0	0	-1	-1	0	0	-1	-1
	965	6	60	-1	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1

180220

Fig. 7. Results of COSCT operation in RTN, balanced by the introduction of an additional fictitious transportation node

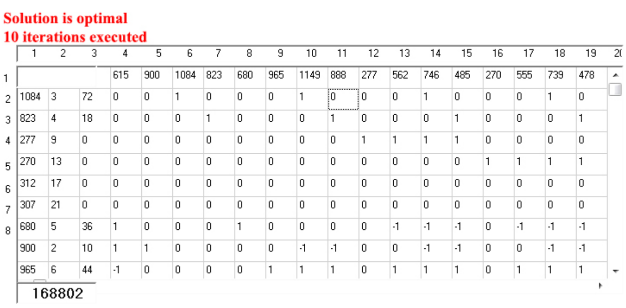
Table 3 gives optimal cargo transportation volumes, which are achieved along the most economically beneficial routes; the distances of freight delivery between the respective points are the numbers in the upper right corner of each table cell. These routes were obtained using the method of finding the shortest routes along a transportation network [16]; the actual volume of transportation work is 174,680 tkm. This is explained by the fact that cargo with a volume of 20 tons is not actually taken from fictitious point C_1 to UP B_1.

Table 3

Transport table, balanced by the introduction of an additional fictitious transportation node

RTN parameters				Utilization points			
				B_1	B_2	B_3	B_4
				Volume of orders (b_j)			
				40	60	80	20
Delivery points	A_1	Stock volume (a_i)	100	615	900	1084 **80**	823 **20**
	A_2		80	680 **20**	965 **60**	1149	888
	A_F (C_1)		20	277 **20**	562	746	485
	C_2		0	270	555	739	478
	C_3		0	312	597	781	520
	C_4		0	307	592	776	515
Transportation work volume (tkm)				180220 (174680)			

In Fig. 8 presented the results of the KSOVP on the balanced proportional method of RTN. The basis of this method lies is proportional to the volume of stocks (applications) reduction proposals (demand) cargoes of all without exception, PP or PS.


Solution is optimal
10 iterations executed

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1				615	900	1084	823	680	965	1149	888	277	562	746	485	270	555	739	478
2	1084	3	72	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
3	823	4	18	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
4	277	9	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
5	270	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
6	312	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	307	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	680	5	36	1	0	0	0	1	0	0	0	0	-1	-1	-1	0	-1	-1	-1
	900	2	10	1	1	0	0	0	0	-1	-1	0	0	-1	-1	0	0	-1	-1
	965	6	44	-1	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1

168802

Fig. 8. Results of COSCT operation in RTN, balanced using a proportional method

In the case when demand for a cargo exceeds its supply, we calculate respective coefficient k for a reduction in the volume of orders from all DP (j=1, n) according to formula:

$$k=\frac{\sum_{j=1}^{n} b_j-\sum_{i=1}^{m} a_i}{\sum_{j=1}^{n} b_j}. \tag{8}$$

Next, these volumes of orders are decreased to magnitudes $b_j^*=(1-k)*b_j$ and cargo transportations are balanced again with the same volumes of stocks a_i (i=1, m) and the same dimensionality. In our example, coefficient k==(200–180)/200=0.1, and, accordingly, b_1=36 t, b_2=54 t, b_3=72 t, b_4=18 t.

Table 4 gives TT with the results of optimization.

Fig. 9 shows result of COSCT operation in RTN, balanced by a difference method. When using this method to reduce cargo transportations to the balanced form, difference module

$$\left|\sum_{i=1}^{m} a_i-\sum_{j=1}^{n} b_j\right| \text{ is deducted from } UP \text{ (at } \sum_{i=1}^{m} a_i<\sum_{j=1}^{n} b_j\text{)},$$

which has the highest value for demand. This method is not applicable in the case when the greatest demand value, which decreases, is less than the module of difference

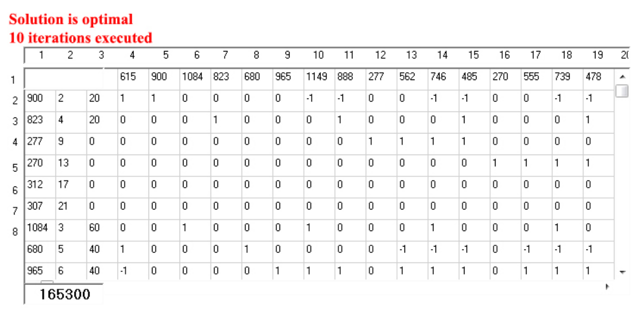
$$\left|\sum_{i=1}^{m} a_i-\sum_{j=1}^{n} b_j\right|.$$

In our case, this is B_3 and its new value is equal to B_3=80–20=60 tons.

Table 4

Transportation table, balanced using a proportional method

RTN parameters				Utilization points			
				B_1	B_2	B_3	B_4
				Volume of orders (b_j)			
				36	54	72	18
Delivery points	A_1	Stock volume (a_i)	100	615	900 **10**	1084 **72**	823 **18**
	A_2		80	680 **36**	965 **44**	1149	888
	C_1		20	277	562	746	485
	C_2		0	270	555	739	478
	C_3		0	312	597	781	520
	C_4		0	307	592	776	515
Transportation work volume (tkm)				168802			


Solution is optimal
10 iterations executed

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1				615	900	1084	823	680	965	1149	888	277	562	746	485	270	555	739	478
2	900	2	20	1	1	0	0	0	0	-1	-1	0	0	-1	-1	0	0	-1	-1
3	823	4	20	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
4	277	9	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
5	270	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
6	312	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	307	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1084	3	60	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
	680	5	40	1	0	0	0	1	0	0	0	0	-1	-1	-1	0	-1	-1	-1
	965	6	40	-1	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1

165300

Fig. 9. Results of COSCT operation in RTN, balanced using a difference method

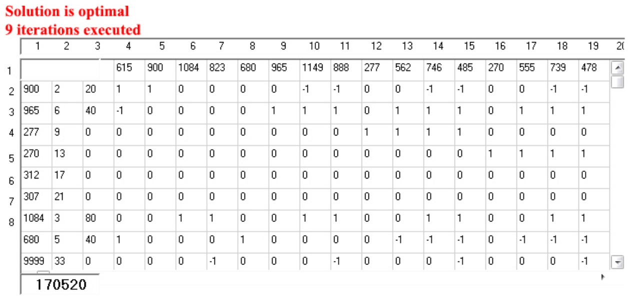
Table 5 gives TT with the results of optimization.

Table 5

Transportation table, balanced using a difference method

RTN parameters				Utilization points			
				B_1	B_2	B_3	B_4
				Volume of orders (b_j)			
				40	60	60	20
Delivery points	A_1	Stock volume (a_i)	100	615	900 **20**	1084 **60**	823 **20**
	A_2		80	680 **40**	965 **40**	1149	888
	C_1		20	277	562	746	485
	C_2		0	270	555	739	478
	C_3		0	312	597	781	520
	C_4		0	307	592	776	515
Transportation work volume (tkm)				165300			

We shall try to obtain an optimal plan of cargo transportation in the unbalanced RTN (result of the work of the computerized system is shown in Fig 10), by preliminarily reducing the proposed TP to a tabular form – TT (Table 4).


Solution is optimal
9 iterations executed

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1				615	900	1084	823	680	965	1149	888	277	562	746	485	270	555	739	478
2	900	2	20	1	1	0	0	0	0	-1	-1	0	0	-1	-1	0	0	-1	-1
3	965	6	40	-1	0	0	0	0	1	1	1	0	1	1	1	0	1	1	1
4	277	9	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
5	270	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
6	312	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	307	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1084	3	80	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
	680	5	40	1	0	0	0	1	0	0	0	0	-1	-1	-1	0	-1	-1	-1
	9999	33	0	0	0	0	-1	0	0	0	-1	0	0	0	-1	0	0	0	-1

170520

Fig. 10. Result of COSCT operation in the unbalanced RTN

The result of solving this TP (Table 6) is given by bold numbers.

Table 6

Unbalanced transportation table

<table>
<tr><td colspan="4" rowspan="4">RTN parameters</td><td colspan="4">Utilization points</td></tr>
<tr><td>B_1</td><td>B_2</td><td>B_3</td><td>B_4</td></tr>
<tr><td colspan="4">Volume of orders (b_j)</td></tr>
<tr><td>40</td><td>60</td><td>80</td><td>20</td></tr>
<tr><td rowspan="6">Delivery points</td><td>A_1</td><td rowspan="6">Stock volume (a_i)</td><td>100</td><td>615</td><td>900
20</td><td>1084
80</td><td>823</td></tr>
<tr><td>A_2</td><td>80</td><td>680
40</td><td>965
40</td><td>1149</td><td>888</td></tr>
<tr><td>C_1</td><td>20</td><td>277</td><td>562</td><td>746</td><td>485</td></tr>
<tr><td>C_2</td><td>0</td><td>270</td><td>555</td><td>739</td><td>478</td></tr>
<tr><td>C_3</td><td>0</td><td>312</td><td>597</td><td>781</td><td>520</td></tr>
<tr><td>C_4</td><td>0</td><td>307</td><td>592</td><td>776</td><td>515</td></tr>
<tr><td colspan="3">Transportation work volume (tkm)</td><td colspan="5">170520</td></tr>
</table>

Data from Tables 3–6 show the optimal plans to transport a cargo in the balanced and non-balanced RTN, obtained using the simplex method, do not converge.

In Fig. 11, the RTN dotted lines indicate the most economical (minimal) optimal plan of freight transportation (165,300 tkm), obtained using a difference method for reducing a TP, unbalanced in terms of cargo transportation, to the TP in the balanced form.

6. Discussion of results of the application of information technologies for the optimization of cargo delivery schemes along international routes

6. 1. Solving a traveling salesman problem using software

Our study addresses the use of modern information technologies in solving a salesman problem in order to optimize the process of compiling the itinerary for cargo transportation along international routes. The following factors were largely ignored when solving the set problem:

– distances between the points of departure, destination points, and customs posts;

– duration of service at checkpoints (customs clearance);

– duration of cargo handling operations;

– the mean speed of a vehicle;

– rest time in line with AETR.

In our calculations, we used real data about the location of points of departure, destination points, and CP at the State border of Ukraine, distance between them, as well as the mean speed.

We report a procedure for the automation of process aimed at solving a traveling salesman problem by a combinatorial method, which takes into consideration existing requirements and constraints for the specificity and dimensionality of the problem. For convenience, data on the distance between the points of transportation are automatically converted into a file of the spreadsheet processor Microsoft Excel. The software for solving a traveling salesman problem was developed using the algorithmic programming language Delphi.

It should be noted that when adding intermediate transportation points to the route, the software operates in two modes: manual and automated. That is, intermediate points can be selected independently, or the software performs this automatically, by choosing the nearest one to the point of departure.

In addition, combinations of transportation nodes, generated and entered into databases in advance, which make up the routes for transportation networks of any dimensionality, represent the Hamiltonian cycles, thereby significantly reducing computational time.

Based on the experience of cargo transportation, the number of transport nodes in multi-drop (combined) routes of cargo transportation does not exceed 20. That is why all variants of cargo transportation routes, generated and entered into databases in advance, in transportation networks with a dimensionality below the magnitude specified above (20), which represent the Hamiltonian cycles, significantly reduce computational time.

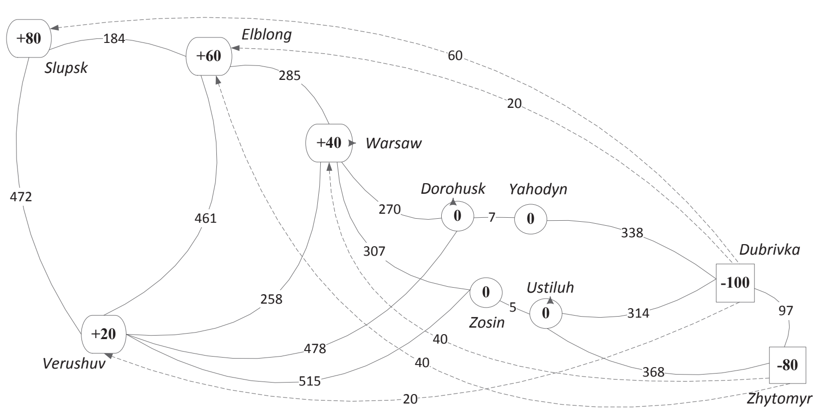


Fig. 11. Optimal itinerary of cargo transportation in RTN

The software generates a corresponding table, which clearly shows distances between the specified cities and intermediate points. This allows us to build possible closed routes and choose the shortest variant. By using a combinatorial method, the software calculates the total distance of the route and selects the one that is the shortest.

6. 2. Solving a transport problem using software

The proposed simplex method showed its effectiveness when solving both the balanced and non-balanced international cargo transportation.

By using the simplex method, we optimized the transport problem represented in a network form, by three methods for reducing a transport problem, unbalanced in terms of cargo transportation volumes, to the balanced form, specifically the introduction of an additional fictitious transportation node, proportional method, and a difference method.

Optimization of cargo transportation in RTN was carried out using a computerized optimization system of freight transport, by preliminarily reducing the proposed transport problem to the tabular form – a transportation table.

Underlying the method of computerized optimization system of freight transport in a road-transport network, balanced by a proportional method, is a decrease in proposal (demand), proportional to the volume of stocks (orders), for cargoes from all, without exception, delivery points (utilization). In the case demand for a cargo exceeds its proposal, we calculate a corresponding coefficient of reduction in the volume of orders from all checkpoints.

The application of a computerized optimization system of cargo transportation in a road transport network, supplemented by a decision support system, will make it possible practically always choose the most beneficial solutions among all the proposed.

7. Conclusions

1. The application of a combinatorial technique for solving a traveling salesman problem in a road transport network made it possible to take into consideration the existing requirements and constraints for the specificity and dimensionality of the problem, which allowed a reduction in the transportation costs, by 8 % on average, for delivering the goods to end users along international automobile routes.

2. The approach to employing the simplex method for solving a transport problem, represented in a network form, has proven its effectiveness when solving both balanced and non-balanced cargo transportation. The developed computer system implies a reduction, proportional to the volume of stock (orders), in the proposals (demand) for cargoes from all, without exception, supply points (utilization). That made to possible to reduce the volume of transportation operations, performed along international routes, by 6 % on average.

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