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Traveling salesman problem in the function of freight transport optimization

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Abstract: The use of modern information technology means in solving the traveling salesman problem to optimize the routing of freight transportation in international traffic is motivated in this article. The process of solving the traveling salesman problem is automated by modern information technology means, in particular the Delphi Software and the function "Search Solution" in the Microsoft Office Excel table processor. The existing requirements and restrictions on the specificity and dimension of the problem are considered as well.

Keywords: Freight, logistics, information technology, traveling salesman problem, closed contour, optimization, route, checkpoint.

1. Introduction

Historical reference. In 1859, William Hamilton formulated a problem "Around the World Tour". The problem was focused on finding the shortest route, which would provide one-time visiting of each given settlement and returning to the starting point. The problem gave rise to a new direction in the theory of graphs, known as the search for Hamiltonian cycles in graphs. The Hamiltonian cycle of a graph with n vertices can be represented by the set of pairs of the graph adjacent vertices: $\{(i_1, i_2); (i_2, i_3); \ldots, (i_{n-1}, i_n); (i_{n-1}, i_1)\}$.

The problem of the Hamiltonian cycles in the graph theory gained different generalizations (Kozachenko, Vernygora, & Malashkin, 2015)]. One of these generalizations is the traveling salesman problem, which often occurs in various modifications in transport logistics when planning transportation. The traveling salesman problem is a modified problem of en-route to the destination point; however, in this case, the connection between the points should form a closed cycle.

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The traveling salesman (came from French, *commis voyageur*) leaves the first city, visits only once each of *n* cities and returns to the first city. The distances between cities are known. The challenge is to find a route to cities, which ensures the shortest closed cycle of salesman's travel.

2. Literature review

There are several distinct cases of general problem statement, in particular the geometric traveling salesman problem (so-called planar or Euclidean, when the distance matrix reflects the distance between points on a plane), the triangular traveling salesman problem (the triangle inequality occurs on the matrix of values), and the symmetric and asymmetric problems of a traveling salesman. There is also a generalization of the problem, the so-called generalized traveling salesman problem (Kunda, 2008).

Statement of the traveling salesman problem. There are n cities. A matrix of distances $C = \left|C_{ij}\right|$ between them is specified. In the general case, $C_{ij} \neq C_{ji}$. A traveling salesman leaves the first city A_0, and then visits the other cities one at a time and returns to the city A_0. Therefore, the route of a traveling salesman is a closed cycle without loops. It is necessary to define the order, in which the city can be driven around to minimize the total traveled distance.

Mathematical model of the problem. Let's introduce the variables: $x_{ij} = 1$, if a salesman moves from the city A_i to the city A_j; $x_{ij} = 0$ - vise versa

where $i, j = 1,2, \ldots, n; i \neq j$. It is necessary to find

$$\min \sum_{i=0}^{n} \sum_{j=0}^{n} c_{ij} \cdot x_{ij} , \tag{1}$$

under conditions

$$\sum_{j=0}^{n} x_{ij} = 1 \quad i = 1,2, \ldots, n, \tag{2}$$

$$\sum_{i=0}^{n} x_{ij} = 1 \quad j = 1,2, \ldots, n, \tag{3}$$

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

where u_i, u_j – arbitrary integral nonnegative numbers.

Condition (2) means that a salesman enters each city only once, except for the first one. Condition (3) means that carrier leaves each city only once as well. Condition (4) ensures the closure of the route containing *n* points, and the absence of loops (Lashenyh, & Kuzkin, 2006).

Society informatization is a global social process characterized by the fact that the dominant activity in the social production sphere is the collection, accumulation, production, processing, storage, transfer and use of information based on modern microprocessor and computer technology, and various means of information exchange (Prokudin, Danchuk, Tsukanov, & Tsymbal, 2013).

The importance of information technology application in the transport sector is indisputable. Optimization of freight delivery schemes is very important in the transport industry and logistics (Prokudin, 2006). In most segments of the market, the delivery of goods adds to its value an amount equivalent to the cost of the product itself. In addition, it should be noted that the use of modern information technology for optimization of such delivery leads to minimization of costs, often at least from 5 to 20% of the product total cost.

This study is mainly focused on the use of modern information technology means in solving the salesman problem to optimize the routing of freight transportation in international traffic. The most important factors that need to be considered in solving the task are:

– the distances between points of departure and destination, and customs posts;
– time of service at checkpoints (customs clearance);
– time of loading and unloading operations;
– average speed of the vehicle (V);
– time of rest under the European agreement regarding the work of vehicle crews, which perform international automobile transportation (UTRT).

Based on the real data on the locations of points of departure and destination, and checkpoints (CP) across the state border of Ukraine, the distances between them, and average speeds of vehicles, the necessary calculations were made.

3. Presentation of the main material

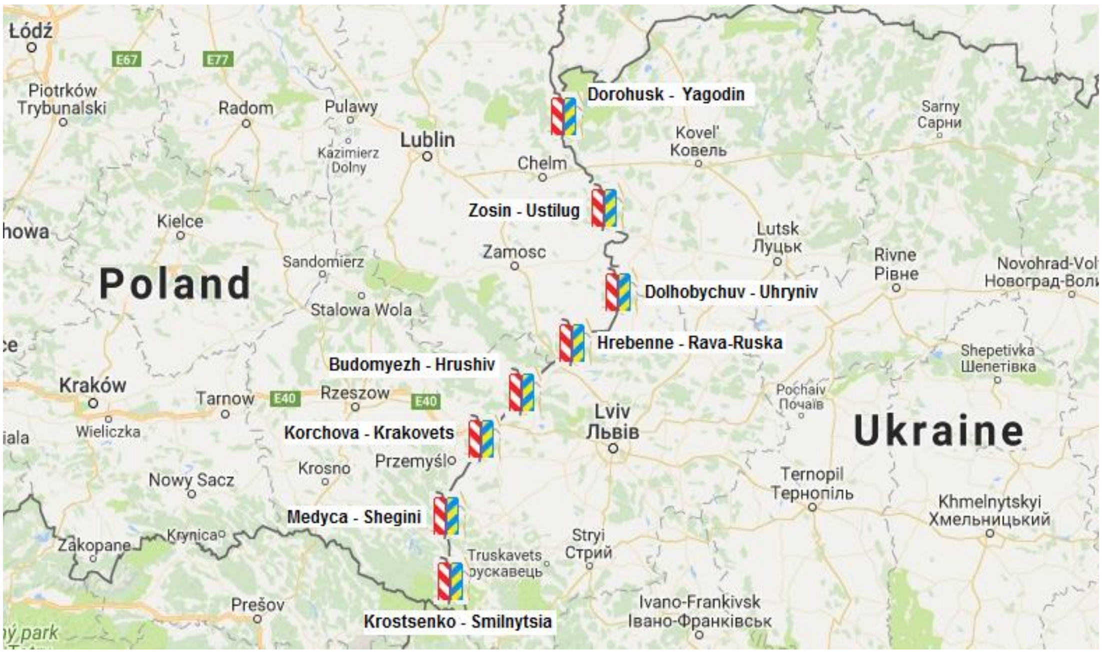
The research was conducted in Zhytomyr region. The wood and wood products make up 23% of the total exports of the region. Therefore, based on the data analysis of the State Statistics Service of Ukraine, laws and regulations, and the economic and social situation in our country, wooden pellets were selected as over-the-road freight. In Poland the vehicle will be loaded by wooden furniture.

In Zhytomyr region, 10 points of departure were selected: 1) Dubrivka; 2) Romaniv; 3) Liubar; 4) Malyn; 5) Ovruch; 6) Novograd-Volynsky; 7) Zhytomyr, 8) Korosten; 9) Berdychiv; 10) Radomyshl. These places are known to be the largest producers of wooden pellets in the region.

For further research, 2 automobile checkpoints were selected in Volyn region and 6 in Lviv region (Fig. 1). The determining factors for choosing a CP are the time for customs operations and the distance from the places of freight departure. The list of 8 checkpoints at the Ukrainian border is as follows:

1) Yagodyn; 2) Ustylug; 3) Ugryniv; 4) Rava-Ruska; 5) Grushiv; 6) Krakovets; 7) Shegini; 8) Smilnytsa.

Figure 1: Automobile checkpoints at the Ukrainian-Polish border



The selected checkpoints in Poland are characterized by the same features as the checkpoints in Ukraine (see Fig. 1), namely:

1) Dorogusk; 2) Zosin; 3) Dolgobychuv; 4) Grebenne; 5) Budomyezh; 6) Korchova; 7) Medyca; 8) Krostsenko.

In Poland, the wooden pellets meet a ready market, and the furniture factories import their finished products to Ukraine. That is why, the selected destination points are as follows: 1) Slupsk; 2) Verushuv; 3) Ratsibuzh; 4) Elblong; 5) Morong; 6) Brodnytsia; 7) Warsaw; 8) Keltse; 9) Ostrovets-

Sventokshyskyi; 10) Vengruv. In the Microsoft Access database environment, a database was created with appropriate distances between checkpoints, points of departure and destination (Fig. 2).

Figure 2: Database of distances between CPs, points of departure and destination

Number	Point of departure	Destination	L
1	Dubrivka	Romaniv	55
2	Dubrivka	Lyubar	81
3	Dubrivka	Malin	187
4	Dubrivka	Ovruch	161
5	Dubrivka	Novograd-Volynsky	39
6	Dubrivka	Zhytomyr	97
7	Dubrivka	Korosten	130
8	Dubrivka	Berdychiv	127
9	Dubrivka	Radomyshl	200
10	Dubrivka	Yagodin	338
11	Dubrivka	Ustylug	314
12	Dubrivka	Ushryniv	337
13	Dubrivka	Rava-Ruska	389

For the convenience of further calculations, data on these distances are automatically re-formatted into a Microsoft Excel table processor file, as shown in Fig. 3. The software for solving the traveling salesman problem was designed using the Delphi programming algorithmic language (Johnson, 1990).

Figure 3: Distances between CPs, points of departure and destination in Microsoft Excel file format

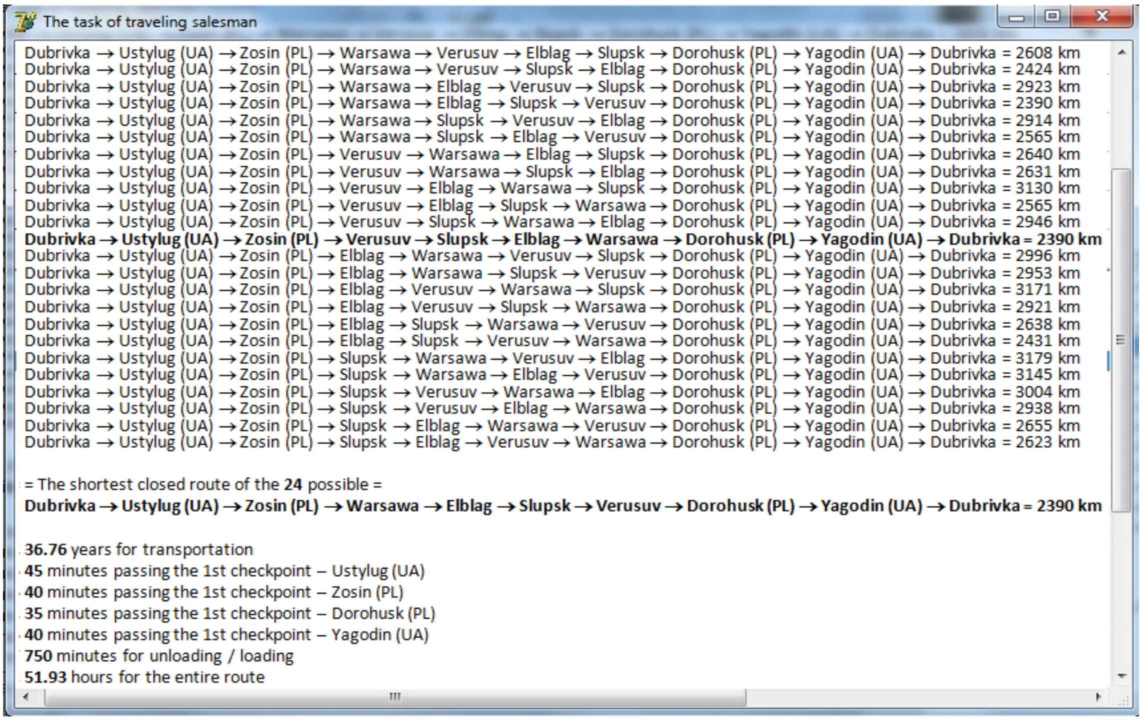
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1		**Town**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
2	**1**	Dubrivka	0	55	81	187	161	39	97	130	127	200	338	314	337	389	432	417	426	455
3	**2**	Romaniv	55	0	50	152	182	73	64	136	63	137	381	357	368	443	445	460	457	486
4	**3**	Lyubar	81	50	0	174	219	112	84	173	69	157	395	343	329	378	407	393	413	447
5	**4**	Malin	187	152	174	0	94	146	88	58	128	36	404	405	442	508	537	532	557	591
6	**5**	Ovruch	161	182	219	94	0	139	133	48	173	127	384	385	422	488	521	505	530	564
7	**6**	Novograd-Volynsky	39	73	112	146	139	0	84	108	125	157	316	292	307	367	406	395	420	454
8	**7**	Zhytomyr	97	64	84	88	133	84	0	87	41	74	392	368	403	454	483	471	496	530
9	**8**	Korosten	130	136	173	58	48	108	87	0	127	90	357	357	394	460	489	474	499	533
10	**9**	Berdychiv	127	63	69	128	173	125	41	127	0	115	433	409	395	431	473	459	484	513
11	**10**	Radomyshl	200	137	157	36	127	157	74	90	115	0	437	437	474	531	559	544	566	600
12	**11**	Yagodin (PP)	338	381	395	404	384	316	392	357	433	437	0	83	120	212	239	256	283	325
13	**12**	Ustylug (PP)	314	357	343	405	385	292	368	357	409	437	83	0	60	148	179	196	218	265
14	**13**	Ushryniv (PP)	337	368	329	442	422	307	403	394	395	474	120	60	0	103	134	150	173	220
15	**14**	Rava-Ruska (PP)	389	443	378	508	488	367	454	460	431	531	212	148	103	0	32	55	93	162
16	**15**	Hrushiv (PP)	432	445	407	537	521	406	483	489	473	559	239	179	134	32	0	26	82	151
17	**16**	Krakovets (PP)	417	460	393	532	505	395	471	474	459	544	256	196	150	55	26	0	33	89
18	**17**	Shegini (PP)	426	457	413	557	530	420	496	499	484	566	283	218	173	93	82	33	0	57
19	**18**	Smilnytsia (PP)	455	486	447	591	564	454	530	533	513	600	325	265	220	162	151	89	57	0

To begin with, a page to entry the input data for further calculations is developed, namely the time characteristics of loading and unloading operations in this route. The process of loading and unloading pallets and furniture is mechanized. The time of service in the CP and the average technical speed of the vehicle are set (V_t = 65 km/h).

Let's consider an example of the traveling salesman problem with 1 point of departure in Ukraine, 4 CPs (two in Ukraine and two in Poland), 4 destination points in Poland. That is, in one of the cities of Zhytomyr region, 20 tons of wooden pellets are loaded. The process of loading is mechanized. In each 4 cities of Poland, 5 tons of freight are unloaded (20 tons in total); and in the last city, 20 cubic meters of furniture are loaded (also approximately 20 tons). Both wooden pellets and furniture belong to the 1st class of goods, that is, the coefficient of static use of the vehicle carrying capacity is equal to ($\gamma_{cm} = 1$). It should be noted that the program works in two modes, manual and automatic. That is, CPs can be selected independently, or the program does it automatically, selecting the closest ones to the point of departure.

The program generates a table, which clearly shows the distances between the specified cities and the CPs. It allows finding possible closed routes and choosing the shortest of all variants (Fig. 4).

Figure 4: Result of the program work

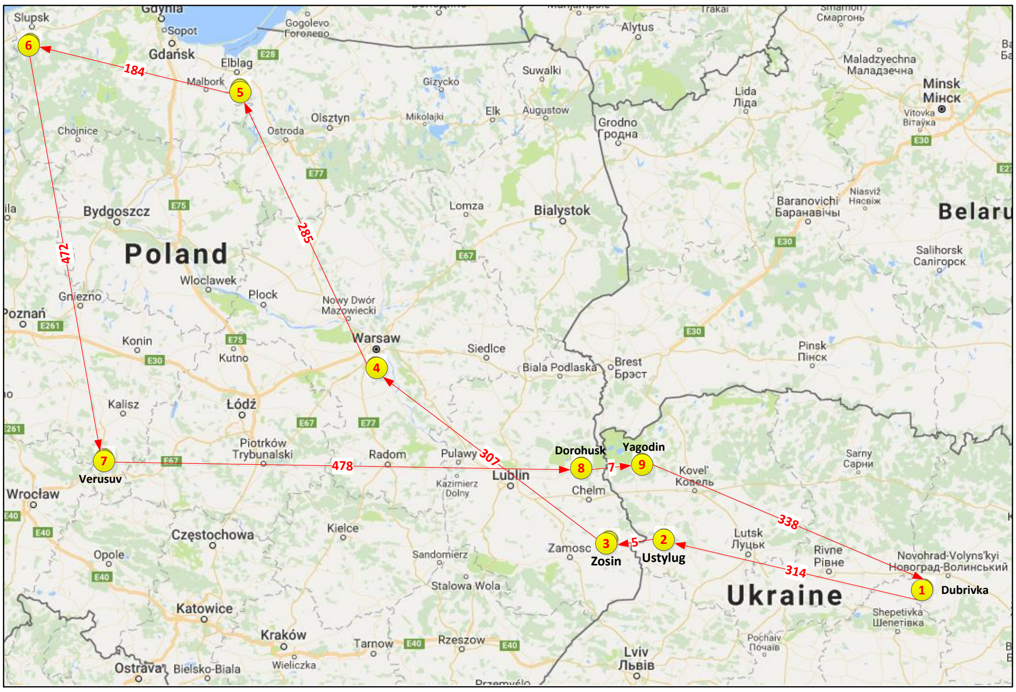

The task of traveling salesman
Dubrivka → Ustylug (UA) → Zosin (PL) → Warsawa → Verusuv → Elblag → Slupsk → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2608 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Warsawa → Verusuv → Slupsk → Elblag → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2424 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Warsawa → Elblag → Verusuv → Slupsk → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2923 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Warsawa → Elblag → Slupsk → Verusuv → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2390 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Warsawa → Slupsk → Verusuv → Elblag → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2914 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Warsawa → Slupsk → Elblag → Verusuv → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2565 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Verusuv → Warsawa → Elblag → Slupsk → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2640 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Verusuv → Warsawa → Slupsk → Elblag → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2631 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Verusuv → Elblag → Warsawa → Slupsk → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 3130 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Verusuv → Elblag → Slupsk → Warsawa → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2565 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Verusuv → Slupsk → Warsawa → Elblag → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2946 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Verusuv → Slupsk → Elblag → Warsawa → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2390 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Elblag → Warsawa → Verusuv → Slupsk → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2996 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Elblag → Warsawa → Slupsk → Verusuv → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2953 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Elblag → Verusuv → Warsawa → Slupsk → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 3171 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Elblag → Verusuv → Slupsk → Warsawa → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2921 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Elblag → Slupsk → Warsawa → Verusuv → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2638 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Elblag → Slupsk → Verusuv → Warsawa → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2431 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Slupsk → Warsawa → Verusuv → Elblag → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 3179 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Slupsk → Warsawa → Elblag → Verusuv → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 3145 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Slupsk → Verusuv → Warsawa → Elblag → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 3004 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Slupsk → Verusuv → Elblag → Warsawa → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2938 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Slupsk → Elblag → Warsawa → Verusuv → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2655 km
Dubrivka → Ustylug (UA) → Zosin (PL) → Slupsk → Elblag → Verusuv → Warsawa → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2623 km

= The shortest closed route of the **24** possible =
Dubrivka → Ustylug (UA) → Zosin (PL) → Warsawa → Elblag → Slupsk → Verusuv → Dorohusk (PL) → Yagodin (UA) → Dubrivka = 2390 km

36.76 years for transportation
45 minutes passing the 1st checkpoint – Ustylug (UA)
40 minutes passing the 1st checkpoint – Zosin (PL)
35 minutes passing the 1st checkpoint – Dorohusk (PL)
40 minutes passing the 1st checkpoint – Yagodin (UA)
750 minutes for unloading / loading
51.93 hours for the entire route

Based on the combinatorial method (Prokudin, 2014), the program automatically calculates the total distance of the route and selects the one where the distance between the cities is the shortest. Map of the specified route is presented in Fig. 5.

Figure 5: Map of a defined closed route



Thus, the program identified 24 possible routes; the route Dubrivka (Ukraine) → Ustylug (CP, Ukraine) → Zosin (CP, Poland) → Warsaw (Poland) → Elblong (Poland) → Slupsk (Poland) → Verushuv

(Poland) → Dorogusk (CP, Poland) → Yagodyn (CP, Ukraine) → Dubrivka (Ukraine) was considered the most effective one. The length of the route is 2390 km. The total time of transportation is 36.76 h, the time of service at the first CP (Ustylug) – 45 min, at the second CP (Zosin) – 40 min, in the third CP (Dorogusk) – 35 min, in the fourth CP (Yagodyn) – 40 min. The time expenditure for loading and unloading – 760 min. Based on the above timing data, the total time to complete the route with exception of time characteristics for the driver's sleep is 52.10 h (according to UTRT).

A detailed analysis of applying the model of the optimal purpose to solve the traveling salesman problem has shown that in this model, in addition to n! Hamiltonian (full) contours, there are also many incomplete (isolated) contours that cover only certain groups of cities. This fact greatly complicated the solving of the traveling salesman problem and made the researchers look for other more effective methods of its solution.

Further, an example of the traveling salesman problem solution for n = 9 (1 city-supplier in Ukraine, 2 CPs in Ukraine, 2 CPs in Poland, 4 city-consumers in Poland) in the Microsoft Office Excel spreadsheet using the Search Solution function is presented (Kuzmychov & Medvediev, 2005). We select the same CPs and cities, as in the previous example.

In Fig. 6, an Excel spreadsheet with source data (distances) between cities is shown. However, to solve the traveling salesman problem for any (and fully oriented) graphs, the absence of an arc between nodes in the transport correspondence matrix should be designated by the infinity $V_{ij} = \infty$. It means that the numbers of 2-3 orders of magnitude larger than the maximum distance should be entered in these cells, namely, in our case, the number is assumed to be equal to 99999.

Figure 6: Starting matrix of distances between cities

	A	B	C	D	E	F	G	H	I	J
1		Dubrivka	Yagodin	Ustylug	Dorohusk	Zosin	Warsawa	Verusuv	Elblag	Slupsk
2	Dubrivka	99999	338	314	99999	99999	99999	99999	99999	99999
3	Yagodin	338	99999	99999	7	99999	99999	99999	99999	99999
4	Ustylug	314	99999	99999	99999	5	99999	99999	99999	99999
5	Dorohusk	99999	7	99999	99999	99999	270	478	539	734
6	Zosin	99999	99999	5	99999	99999	307	515	583	786
7	Warsawa	99999	99999	99999	270	307	99999	313	285	471
8	Verusuv	99999	99999	99999	478	515	313	99999	461	472
9	Elblag	99999	99999	99999	539	583	285	461	99999	184
10	Slupsk	99999	99999	99999	734	786	471	472	184	99999

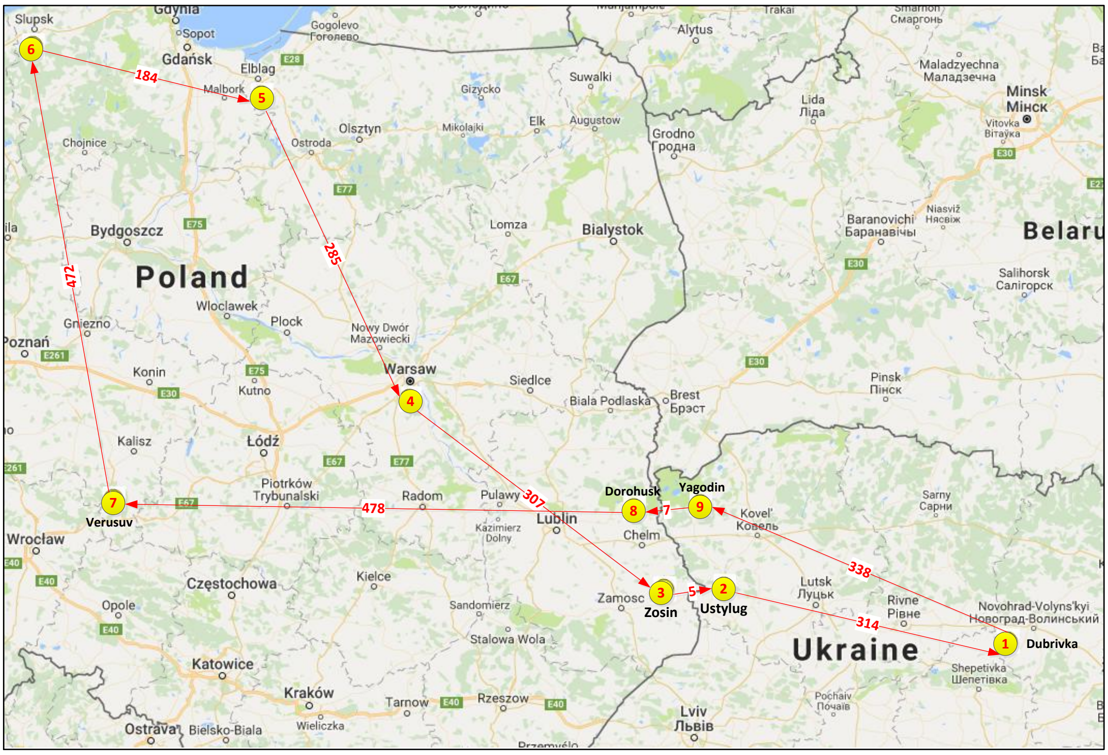
The process of calculating the traveling salesman problem in Excel includes the following steps: inputting the initial data (see Fig. 6); forming a matrix, where the sum of elements in rows and columns is calculated; forming a constraint matrix of consistency and a target function; forming a model of the optimization problem; obtaining the final result (Fig. 7).

Figure 7. Obtaining the final result

12		Dubrivka	Yagodin	Ustylug	Dorohusk	Zosin	Warsawa	Verusuv	Elblag	Slupsk	Out
13	Dubrivka	0	1	0	0	0	0	0	0	0	1
14	Yagodin	0	0	0	1	0	0	0	0	0	1
15	Ustylug	1	0	0	0	0	0	0	0	0	1
16	Dorohusk	0	0	0	0	0	0	1	0	0	1
17	Zosin	0	0	1	0	0	0	0	0	0	1
18	Warsawa	0	0	0	0	1	0	0	0	0	1
19	Verusuv	0	0	0	0	0	0	0	0	1	1
20	Elblag	0	0	0	0	0	1	0	0	0	1
21	Slupsk	0	0	0	0	0	0	0	1	0	1
22	In	1	1	1	1	1	1	1	1	1	
36	Target function		2390,0								

Consequently, based on the calculations in the Excel table processor, an optimal closed route of freight transportation is obtained (Fig. 8).

Figure 8: Presentation of the optimal transportation route on the map



The length of the calculated route (Dubrovka → Yagodyn → Dorogusk → Warsaw → Elblong → Slupsk → Verushuv → Zosin → Ustylug → Dubrovka) is 2390 km. It should be noted that in two variants of solving this task (using the Delphi software environment and the Excel spreadsheet), the same length of the route 2390 km is calculated, although the sequence of passing cities in both variants is different.

4. Conclusion

During this study, the use of the Delphi Software and the function "Search Solution" in the Microsoft Office Excel table processor in solving the traveling salesman problem to optimize the routing of freight transportation in international traffic is motivated in this article. The existing requirements and restrictions on the specificity and dimension of the problem are considered as well.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://jsdtl.sciview.net

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