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Received: 2018-06-25 ; Accepted: 2018-11-05

OPTIMIZATION OF TRANSPORT PROCESSES USING THE EVOLUTIONARY SOLVER

Summary

The algorithm for calculating the shortest route for three vehicles with the limitation of their capacity and number of places per one vehicle using Microsoft Office Excel with the addition of OpenSolver 2.9.0 is presented. The algorithm was designed mainly for small transport companies whose number is several dozen times bigger than large companies. The evolutionary method was used, which belongs to the group of exact methods that guarantee calculation of the shortest possible route. Improving the work organization of transport means that can be achieved by using the presented computerized transport management system will result in reduction of carbon dioxide emissions and measurable savings as a result of reducing the distances necessary to overcome. Presented algorithm provides a step-by-step procedure with snapshots for improved performance. Visualization of the route allows for transparent display of the data developed.
Key words*: transport, optimization, operational research, OpenSolver, shortest route*

OPTYMALIZACJA PROCESÓW TRANSPORTOWYCH METODAMI EWOLUCYJNYMI

Streszczenie

Przedstawiono algorytm obliczania najkrótszej trasy przejazdu dla trzech pojazdów z ograniczeniem ich pojemności i liczby miejscowości przypadającej na jeden pojazd z wykorzystaniem programu Microsoft Office Excel z dodatkiem OpenSolver 2.9.0. Algorytm został przeznaczony głównie dla małych firm transportowych, których jest kilkadziesiąt razy więcej niż firm dużych. Zastosowano metodę ewolucyjną, która należy do grupy metod dokładnych gwarantujących obliczenie najkrótszej z możliwych tras. Poprawa organizacji pracy środków transportu, którą można osiągnąć przez zastosowanie przedstawionego komputerowego systemu zarządzania transportem, spowoduje ograniczenie emisji dwutlenku węgla oraz wymierne oszczędności na skutek zmniejszenia odległości koniecznych do pokonania. Wizualizacja przebiegu trasy umożliwia przejrzyste zobrazowanie opracowanych danych.
Słowa kluczowe*: transport, optymalizacja, badania operacyjne, OpenSolver, najkrótsza trasa*

1. Introduction

The transport services sector, closely related to logistics and forwarding, is considered to be a barometer of the economy, as the demand for transport services is decreasing as demand for products or services decreases. It is believed that the transport industry has about 10% share in the European Union GDP, and the activities of the entire TFL sector (transport, forwarding and logistics) in addition to industry, construction, trade and non-market services is a very important element creating gross value added [15]. However, external costs should also be taken into account, i.e. the negative effects of the TFL sector, manifested by environmental pollution and the increase in the greenhouse effect due to the emission of carbon dioxide. That is why the concept of sustainable transport taking into account ecological and economic stability in the long term has emerged in recent years.

Transport (road, air and sea) is thought to have the most damaging effects on the environment and health of all sectors of the economy and according to Barbu and Fernandez [4] this sector was responsible for generating 19% of carbon dioxide in 2005 in the European Union. Data on carbon dioxide emissions are quite different, but this is due to the method of calculations, because sometimes carbon dioxide emissions are taken into consideration when creating road infrastructure and its refurbishment, production of transport means, etc.

Significant benefits at relatively low expenditure may, however, bring improvement in the organization of work of transport means. It can be achieved through the use of computer transport management systems, whose task is to optimize transports carried out in the enterprise [7].

In the last period of time, many authors deal with the optimization of transport in maritime shipping, mainly in liner shipping, which is characterized by regular transport of cargo according to the timetables and dates of flights given above and the possibility of using services for all interested parties. One of the reasons for such interest is significant emission of carbon dioxide by liner shipping, which Notteboom [10] pointed out, stating that it is about 2.7% of the total emission in the world. Reinhardt et al. [13] used optimization methods in one of the shipping companies focusing on the implementation of container transport orders, while in the course of implementation of the issue they used Microsoft Office Excel with the addition of Opensolver 2.1. Brouer et al. [5] dealt with the problem of transporting empty containers, informing about the need to use a Solver in such issues. The Solver addition was also used during the optimization of container reloading used in liner shipping [3]. Attempts were also made to optimize intermodal transport for container transport, both by sea and by road [9, 14].

Pollaris [11] dealt with operational research in connection with the optimization of loading of cars carrying loads placed on pallets. Due to the progressing globalization, many authors take up the subject of supply chains. For example, Mula [8] presents mathematical models used by various authors in solving problems related to the supply chain. Afshar and Haghani [1], in turn, developed a mathematical model that solves the problem related to the flow of goods from the manufacturer, through all intermediaries, to the final recipient.

The aim of this work was to provide step by step the shortest route for three vehicles using Microsoft Office Excel with OpenSolver add-in intended for small enterprises.

2. Algorithms for determining the shortest route

The problem of determining the optimal route of vehicles has been dealt with for many years. One of the oldest issues is the traveling salesman problem (TSP), whose solution consists in determining the shortest route between towns that you can visit only once and you should return to the town from which you started. The development of this problem is the problem of determining many routes (vehicle routing problems - VRP), also called the problem of many traveling salesmen or the problem of routing. In this case, we additionally take into account the maximum capacity of individual means of transport. An example of the solution of the one traveling salesman problem with the use of the Solver was given by Baj-Rogowska [2], and with the use of OpenSolver - Węgrzyn [16]. The problem of many traveling salesmen has been discussed by some authors [1, 6, 12], but only theoretically. There are no examples in the literature of solutions to the problem of many traveling salesmen (VRP). In planning studies of this type of route, you can only find assumptions that should be met during calculations. The results calculated by commercial programs and the operation of these programs are also given. It should be noted that there are many small enterprises in the world that use transport, which cannot afford to purchase professional software, service and update it.

The presented work focuses only on the case of many traveling salesmen with limited capacity and limitation of the number of places visited, with the solution, step by step, given for example for three salesmen using the OpenSolver add-on. Since the solution of the problem is to be applied in practice, the theoretical part which can be found in many publications in this field is abandoned.

The presented algorithms may be used in any transport activity, but they will be most useful in the transport of food products, where transport time plays a big role, such as milk or strawberries for example. The program is relatively easily modifiable in a relatively short period of time, which is important when transporting milk, because there are often changes in the number of suppliers or changes in the cow's density in individual farms, which determines the amount of milk that must be transported by tankers. It should also be taken into account that milk can be collected from each farmer into a separate chamber or can be in one chamber from several farmers. It should also be noted that milk tankers can have a capacity of 3,000 to 30,000 liters with any number of chambers.

3. Route planning for many vehicles - Vehicle Routing Problem

The algorithm for determining the shortest route for many vehicles (in the presented case for three vehicles) differs from the previous one in that the carrying capacity of each vehicle used cannot be exceeded and, alternatively, the number of places per one vehicle is limited. An additional restriction has been introduced for the situation when milk is collected from the supplier in separate chambers. In the case at hand, the amount of milk is 20 746 liters and is transported from 16 farms. This problem was solved with the help of the free OpenSolver 2.9.0. add-in due to the large number of variables that exceeds the calculation capabilities of Solver.

The distances between the villages c_{ij} c_{ij} were arranged in the form of a matrix in the cells D3:T19 of the sheet shown in Fig. 1. On the main diagonal, large values have been introduced =999 for distances c_{ii}, which make it impossible to enter into the model non-existent arcs located on the main diagonal. The amount of milk to be picked up from each town has been entered into the cells B3:B19. An additional restriction has also been introduced - Subtreat Elimination Cadd-onstraints (SEC's). In the presented problem, there are two types of decision variables: binary x_{ij} and integer u_i. The decision variables x_{ij} were placed in the cells range D23:T39 (Fig. 2), and the variables u_i - in the cells range B23:B39.

The objective function was entered into cell B42 (Fig. 2). LHS SEC's were placed in the cells range D44:T60 (Fig. 3) with the exception of the main diagonal, where zero was entered. Cells range D44:T44 is not taken into account for calculations.

Formulas that were used for calculations are presented in Table 1, and the OpenSolver dialog box for three vehicles is shown in Fig. 4.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1																				
2	**Town**	**Milk**	c_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
3	1	0	1	999	19,5	26,2	28,0	20,1	32,1	19,1	33,6	27,9	18,8	24,0	24,9	34,0	27,0	21,8	19,1	36,4
4	2	720	2	19,5	999	44,8	17,6	41,5	53,4	37,7	52,2	49,2	17,9	42,6	46,2	52,6	48,7	43,1	12,6	55,0
5	3	2267	3	26,2	44,8	999	45,4	33,7	46,0	14,3	18,6	41,4	29,0	19,4	38,8	7,8	41,3	35,7	35,5	12,2
6	4	2213	4	28,0	17,6	45,4	999	50,1	62,1	46,3	60,9	57,8	21,1	51,2	54,8	48,8	57,3	51,8	13,4	53,2
7	5	705	5	20,1	41,5	33,7	50,1	999	12,4	16,1	18,8	7,8	39,1	12,9	5,2	41,4	7,6	2,1	41,2	37,3
8	6	717	6	32,1	53,4	46,0	62,1	12,4	999	28,5	38,9	21,0	50,8	25,2	9,1	53,8	5,3	10,3	52,9	49,7
9	7	526	7	19,1	37,7	14,3	46,3	16,1	28,5	999	16,8	23,8	29,1	5,1	21,3	22,1	23,7	18,2	35,3	26,5
10	8	1344	8	33,6	52,2	18,6	60,9	18,8	38,9	16,8	999	26,5	41,1	21,8	24,0	26,4	26,4	20,9	47,2	22,3
11	9	887	9	27,9	49,2	41,4	57,8	7,8	21,0	23,8	26,5	999	46,8	20,6	8,6	49,2	12,9	9,8	49,0	45,0
12	10	1427	10	18,8	17,9	29,0	21,1	39,1	50,8	29,1	41,1	46,8	999	34,1	43,7	32,4	46,1	40,6	11,8	36,8
13	11	2212	11	24,0	42,6	19,4	51,2	12,9	25,2	5,1	21,8	20,6	34,1	999	18,0	27,2	20,5	14,9	40,2	31,1
14	12	923	12	24,9	46,2	38,8	54,8	5,2	9,1	21,3	24,0	8,6	43,7	18,0	999	46,6	4,3	3,1	45,7	42,4
15	13	1903	13	34,0	52,6	7,8	48,8	41,4	53,8	22,1	26,4	49,2	32,4	27,2	46,6	999	49,1	43,5	44,0	6,9
16	14	924	14	27,0	48,7	41,3	57,3	7,6	5,3	23,7	26,4	12,9	46,1	20,5	4,3	49,1	999	5,6	48,2	44,9
17	15	1873	15	21,8	43,1	35,7	51,8	2,1	10,3	18,2	20,9	9,8	40,6	14,9	3,1	43,5	5,6	999	46,6	39,4
18	16	364	16	19,1	12,6	35,5	13,4	41,2	52,9	35,3	47,2	49,0	11,8	40,2	45,7	44,0	48,2	46,6	999	48,4
19	17	1741	17	36,4	55,0	12,2	53,2	37,3	49,7	26,5	22,3	45,0	36,8	31,1	42,4	6,9	44,9	39,4	48,4	999
20	∑	20746																		

Source: own work / Źródło: opracowanie własne

Fig. 1. Distances between towns and the amount of milk to receive
Rys. 1. Odległości między miejscowościami i ilość mleka do odbioru

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
21																					
22	Town	u_i	x_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
23	1	17	1	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	3
24	2	16	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
25	3	1	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
26	4	15	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
27	5	1	5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
28	6	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
29	7	16	7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
30	8	15	8	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
31	9	2	9	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
32	10	2	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
33	11	1	11	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
34	12	3	12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
35	13	2	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
36	14	4	14	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
37	15	6	15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
38	16	3	16	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
39	17	3	17	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
40				3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
41	Objective function																				
42		297,7	f(xij)→min																		

Source: own work / Źródło: opracowanie własne

Fig. 2. Decision variables x_{ij} and objective function

Rys. 2. Zmienne decyzyjne x_{ij} x_{ij} *i funkcja celu*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
42																				
43			SEC's	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
44	ui-uj+(n-1)xij<=n-2		1																	
45			2	15	0	15	1	15	11	0	1	14	14	15	13	14	12	10	13	13
46			3	-16	-15	0	-14	0	-4	-15	-14	-1	-1	0	-2	15	-3	-5	-2	-2
47			4	-2	15	14	0	14	10	-1	0	13	13	14	12	13	11	9	12	12
48			5	-16	-15	0	-14	0	-4	-15	-14	15	-1	0	-2	-1	-3	-5	-2	-2
49			6	-12	-11	4	-10	4	0	-11	-10	3	3	4	2	3	1	15	2	2
50			7	15	0	15	1	15	11	0	1	14	14	15	13	14	12	10	13	13
51			8	-2	-1	14	0	14	10	15	0	13	13	14	12	13	11	9	12	12
52			9	-15	-14	1	-13	1	-3	-14	-13	0	0	1	15	0	-2	-4	-1	-1
53			10	-15	-14	1	-13	1	-3	-14	-13	0	0	1	-1	0	-2	-4	15	-1
54			11	-16	-15	0	-14	0	-4	-15	-14	-1	15	0	-2	-1	-3	-5	-2	-2
55			12	-14	-13	2	-12	2	-2	-13	-12	1	1	2	0	1	15	-3	0	0
56			13	-15	-14	1	-13	1	-3	-14	-13	0	0	1	-1	0	-2	-4	-1	15
57			14	-13	-12	3	-11	3	15	-12	-11	2	2	3	1	2	0	-2	1	1
58			15	5	-10	5	-9	5	1	-10	-9	4	4	5	3	4	2	0	3	3
59			16	-14	-13	2	4	2	-2	-13	-12	1	1	2	0	1	-1	-3	0	0
60			17	-14	-13	2	-12	2	-2	-13	4	1	1	2	0	1	-1	-3	0	0

Source: own work / Źródło: opracowanie własne

Fig. 3. SEC's variables

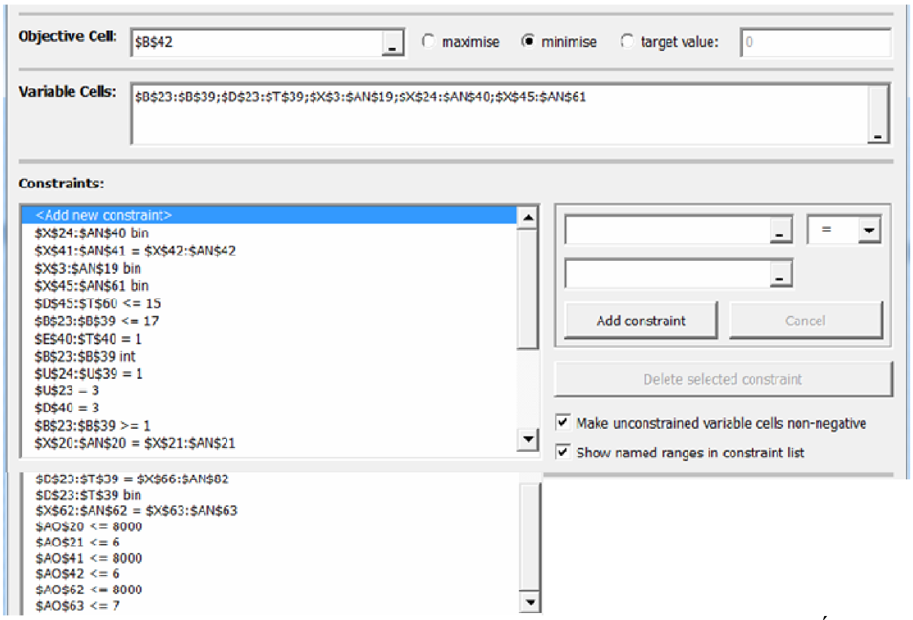
Rys. 3. Zmienne SEC's

Table 1. List of formulas used for calculations

Tab. 1. Wykaz formuł do wykresu

Cell	Formula	Copied to
D40	=SUM(D23:D39)	E40:T40
U23	=SUM(D23:T23)	U24;U39
D45	=VLOOKUP($C45;$A$23:$B$39;2)- VLOOKUP(D$43;$A$23:$B$39;2) +16*D24	Other cells D45:T60
B42	=SUMPRODUCT(D3:T19;D23:T39)	-
X20	=SUM(X3:X19)	Y20:AN20
AO3	=SUM(X3:AN3)	AO4:AO19
Y21	=SUM(OFFSET($X$3:$AN$3;X$2;0))	Z21:AN21
AO20	=SUMPRODUCT(AO3:AO19;B3:B19)	-
AO21	=SUM(AO3:AO19)	-
X21	=1	X42; X63
X41	=SUM(X24:X40)	Y41:AN41
AO24	=SUM(X24:AN24)	AO25:AO40
Y42	=SUM(OFFSET($X$24:$AN$24;X$23;0))	Z42:AN42
AO41	=SUMPRODUCT(AO24:AO40;B3:B19)	-
AO42	=SUM(AO24:AO40)	-
X62	=SUM(X45:X61)	Y62:AN62
AO45	=SUM(X45:AN45)	AO46:AO61
Y63	=SUM(OFFSET($X$45:$AN$45;X$44;0))	Z63:AN63
AO62	=SUMPRODUCT(AO45:AO61;B3:B19)	-
AO63	=SUM(AO45:AO61)	-
X66	=SUM(X3;X24;X45)	Tab. X66:AN82

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 4. OpenSolver dialog box
Rys. 4. Okno dialogowe parametrów dodatku OpenSolver

For the purpose of the task, another three matrices of binary variable x_{ij} x_{ij} were created, each assigned to one vehicle (Figs 5 and 6). The sum of these three matrices is included in the cells range of X66:AN82 and must be equal to the elements of the variable x_{ij} x_{ij}, which is in the cells range of D23:T39. The limit for D40 and U23 cells is number 3, because three vehicles leave the base town at the same time.

The sheets after solving are presented in Figs 5 and 6. From the values of elements of binary variables x_{ij} x_{ij} for each vehicle, we can read the order of the towns visited. There is 1 in cell AH3, which means that the vehicle will leave the base town to town 11, because the column AH is assigned to town 11, and row 3 to base town number 1. Then in the line assigned to town 11 we search for the value 1, which is in the column AG assigned to the town 10. This means that the next town that will be visited by vehicle number 1 will be 10. The order of the visited places was placed in BK3: BK7 cells (Fig. 7).

	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1																				
2		x^1_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
3		1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
4		2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
5		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6		4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8		6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9		7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10		8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11		9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12		10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
13		11	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
14		12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15		13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16		14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17		15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18		16	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19		17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20			1	1	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	6936
21			1	1	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	6
23		x^2_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
24		1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
25		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26		3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
27		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28		5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29		6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30		7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
31		8	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
32		9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33		10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34		11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35		12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36		13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
37		14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38		15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39		16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40		17	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
41			1	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	1	7781
42			1	0	1	0	0	0	1	1	0	0	0	0	1	0	0	0	1	6

Source: own work / Źródło: opracowanie własne

Fig. 5. Solution: elements x^1_{ji}, x^2_{ij}
Rys. 5. Rozwiązanie: elementy x^1ij, x^2ij

	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
43																				
44		x^3_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
45		1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
46		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
47		3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49		5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
50		6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
51		7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
52		8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
53		9	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
54		10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
55		11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
56		12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
57		13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58		14	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
59		15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
60		16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
61		17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62			1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	6029
63			1	0	0	0	1	1	0	0	1	0	0	1	0	1	1	0	0	7

65		x_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
66		1	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
67		2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68		3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
69		4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70		5	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
71		6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
72		7	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
73		8	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
74		9	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
75		10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
76		11	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
77		12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
78		13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
79		14	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
80		15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
81		16	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
82		17	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Source: own work / Źródło: opracowanie własne

Fig. 6. Solution: elements x^3_{ij}, x_{ij}
Rys. 6. Rozwiązanie: elementy x^3ij, xij

	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP
1																						Coordinates			
2	x^-_{ij}	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		Route		Town		Route	
3	1											11							11	1	1	17,83	50,20	17,83	50,2
4	2	1																	1	11	2	17,76	50,10	17,95	50,28
5	3																		0	10	3	18,13	50,21	17,97	50,09
6	4		2																2	16	4	17,85	49,99	17,87	50,06
7	5																		0	4	5	17,86	50,35	17,85	49,99
8	6																		0	2	6	17,74	50,39	17,76	50,1
9	7																		0	1	7	18,01	50,28	17,83	50,2
10	8																		0		8	18,08	50,36		
11	9																		0		9	17,91	50,41		
12	10																16		16		10	17,97	50,09		
13	11										10								10		11	17,95	50,28		
14	12																		0		12	17,84	50,38		
15	13																		0		13	18,22	50,20		
16	14																		0		14	17,79	50,38		
17	15																		0		15	17,84	50,36		
18	16				4														4		16	17,87	50,06		
19	17																		0		17	18,25	50,23		

Source: own work / Źródło: opracowanie własne

Fig. 7. Determination of the route for vehicle No. 1
Rys. 7. Wyznaczanie marszruty dla pojazdu nr 1

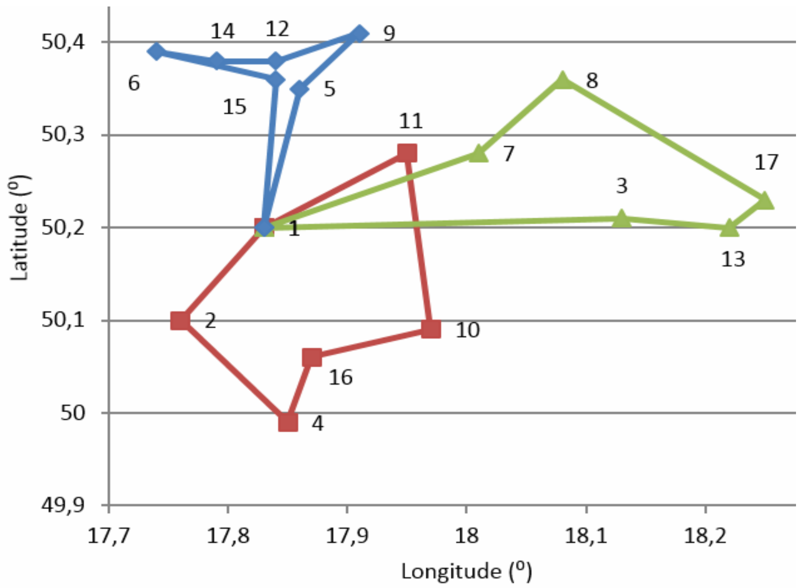
The coordinates of all cities are provided in BM3:BN19 cells. In cell BO3 there is the formula = INDEKS($BL$3:$BN$19;BK3;2), which is copied to cells BO4:BO9, while in cell BP3 - formula =INDEKS($BL$3:$BN$19;BK3;3), which we copy to cells BP3:BP9. In these cells there are placed the coordinates of the place in the order in which they are visited. Using these points, we create a line graph showing the distance traveled by the vehicle. We introduce data labels. For a clearer presentation of the calculations results we introduce in the labels instead of the points coordinates, place numbers, which we carry out by marking the "cell value" and entering their range BK3:BK9. The ability to change coordinates in labels for point values is only possible from the Microsoft Office Professional Plus 2013 version.

An additional algorithm was also proposed that enabled the creation of the final graph without the need to look for next places (Table 2). Its use causes that after pressing the button solve and waiting for several minutes a graph appears (Fig. 8), which presents the visualization of all three routes of vehicles.

Table 2. List of formulas for the chart
Tab. 2. Wykaz formuł do wykresu

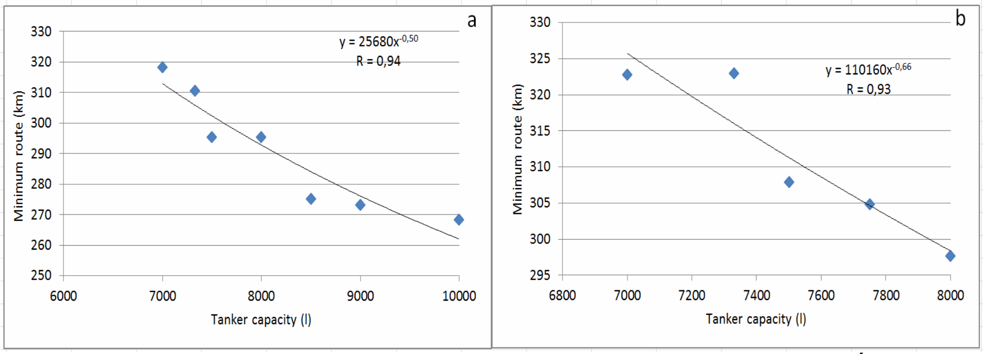
Cell	Formula	Copied to
AS3	=IF(X3=1;AS$2;"")	Tab. AS3:BI19
BJ3	=SUM(AS3:BI3)	BJ4:BJ19
BK3	=AR3	-
BK4	=IF(AR3>$AO$21;"";VLOOKUP(BK3;$AR$2:$BJ$19;19))	BK5:BK11

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 8. Visualization of the route
Rys. 8. Wizualizacja marszruty



Source: own work / Źródło: opracowanie własne

Fig. 9. The relationship between the capacity of the tanker and the minimum route
Rys. 9. Zależność pomiędzy pojemnością cysterny i minimalną odległością do przebycia

A simulation was also carried out to determine the effect of tanker capacity on the length of the road traveled through the tanker (Fig. 9). By assumption, the increase in their capacity should cause shortening of the road, but it turns out that this decrease is not linear, and that there are limit values below which the shortening of the road is no longer possible. In the case of tankers without a limitation of the number of chambers (Fig. 9a), this value is 10,000 liters, and with a limited number of chambers (Fig. 9b) - only 8,000 liters. It was also found that with a milk volume of 20,746 liters, the use of the capacity of all tankers (without separate chambers) equal to 21,000, almost the minimum possible, increases the distance traveled by 16% compared to 24,000 liters. When using chambers, this increase is only 8%, which is a bit of a surprise, because the introduction of two restrictions results in a smaller increase in the shortest route. For the same data, the route for one vehicle was also calculated, i.e. without the limitations of tank capacity and the number of chambers, which amounted to 221.2 km.

4. Conclusion

It is believed that transport, irrespective of the environment it covers, has the most harmful impact on the natural environment of all sectors of the economy and is responsible for generating around 20% of carbon dioxide in the countries of the European Union. Its limitation can be brought by the improvement of the organization of the work of transport means, which can be achieved by using computer-based transport management systems. Of course, improving the organization can also bring measurable savings due to the reduction of distances necessary to overcome. The presented algorithm, solved with the help of the free Microsoft Office Excel program with the addition of OpenSolver 2.9.0., possible to be mastered by every IT specialist, will enable practical application mainly in small companies dealing with transport, whose number is several dozen times bigger than large companies and which cannot afford professional software. Based on the conducted simulation, it was found that the increase in tanker capacity causes a power, not a linear, decrease in the length of the shortest route for three vehicles, regardless of whether the case is analyzed only with the limitation of capacity or additionally with the limitation of the number of places visited by each vehicle. The shortest route is in the case of route planning for one vehicle (without capacity limit) and is equal to 221.2 km. When using three vehicles, the shortest route is from 295.5 to 341.7 km depending on the tanker capacity and the optional use of individual milk chambers.

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