Journal of KONBiN 2019
Volume 49, Issue 4
DOI 10.2478/jok-2019-0079

Jerzy MAŁACHOWSKI[1], Józef ŻUREK[2], Jarosław ZIÓŁKOWSKI[1], Aleksandra LĘGAS[1]
[1] *Military University of Technology (Wojskowa Akademia Techniczna)*
[2] *Air Force Institute of Technology (Instytut Techniczny Wojsk Lotniczych)*

APPLICATION OF THE TRANSPORT PROBLEM FROM THE CRITERION OF TIME TO OPTIMIZE SUPPLY NETWORK WITH PRODUCTS „FAST-RUNNING"

Zastosowanie zagadnienia transportowego z kryterium czasu do optymalizacji zaopatrzenia sieci sklepów z produktami szybko psującymi się

Abstract: *The article presents the application in practice of a transport problem with the criterion of time to optimize the supply of store chains. When transporting perishable goods (e.g. dairy products, fruits, vegetables) the most important goal is to minimize delivery time. Shortening the delivery time gives the opportunity to meet the expectations of potential customers, as well as to maintain the functional properties of transported goods.*
Keywords: transport, optimization, time

Streszczenie: *W artykule przedstawiono zastosowanie w praktyce zagadnienia transportowego z kryterium czasu do optymalizacji zaopatrzenia sieci sklepów. Podczas transportu towarów szybko psujących się (np. produkty mleczarskie, owoce, warzywa) najważniejszym celem staje się minimalizacja czasu realizacji dostawy. Skrócenie czasu dostaw daje możliwość zaspokojenia oczekiwań potencjalnych klientów, a także utrzymania właściwości użytkowych przewożonych towarów.*
Słowa kluczowe: transport, optymalizacja, czas

1. Introduction

The transport task is defined as the issue of integer programming. It is assumed that transport problems account for about 80% of logistic activities carried out in the company, at the same time being the essence of the efficiency of the logistics system [5].

Generally, the optimization goals are either minimization of distances or minimization of transport costs. However, given the diverse conditions in practice, there is often a need to take into account verification of assumptions regarding the selection of a delivery schedule. This is the case, for example, for the transport of products:

- perishable (for example meat, dairy products, fruits, vegetables);
- served on the basis of the Just In Time method (due to significant customer storage costs, limited storage capacities as well as delays in the delivery of the initial links in the supply chain).

For the above-mentioned product groups, the most important goal may be to minimize the delivery time. The reduction of delivery time makes it possible to maintain the usable properties of transported products as well as to meet the requirements of recipients expecting so-called intervention deliveries. Therefore, it is possible to reduce the costs arising during transport work through more efficient use of means of transport.

Bearing in mind the above, it may be more important to minimize the longest transport time in a given delivery system (through optimization) than to minimize the total amount of tonne hours.

The above assumptions apply to both commercial and service enterprises, in the collection of which there are: fire brigade, ambulance or companies dealing in the organization of all kinds of public events [10] for which the time criterion is important or even paramount.

2. Assumptions and methodology

The general form of the model showing the closed transport task, taking into account the time criterion [10]:

$$\max_{x_{ij}>0}\{t_{ij}\} \to min \tag{1}$$

$$\sum_{j=1}^{n} x_{ij} = a_i \ \ (i = 1, \dots, m) \tag{2}$$

$$\sum_{i=1}^{m} x_{ij} = b_j \ \ (j = 1, \dots, n) \tag{3}$$

$$x_{ij} \geq 0 \tag{4}$$

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j \tag{5}$$

where:
x_{ij} – the size of the product delivered from the supplier to the recipient,
t_{ij} – time of product transport on the route from the supplier to the recipient's destination,
n – the number of recipients,
m – the number of suppliers,
a_i – the supplier's supply,
b_j – the demand of the recipient.

In the case where the total supply is not equal to demand, the dependence (5) becomes out of date, and the supply (2) or demand (3) limitations take the form of inequality. Model (1) ÷ (5) was discussed inter alia in the works [1, 2, 3, 6, 9, 12, 13]. It refers to a situation where the decision-maker does not assume a single assumption related to, among others:

- limited size of vehicles transporting the product,
- the required minimum use of supply,
- the required minimum degree of meeting demand, as well
- different character of transport and unloading times.

The procedure to solve the model described by the dependencies (1) ÷ (5) is as follows: [10]:

1. Determining a possible basic solution using the minimal matrix element (MEM) method based on an array with times.
2. Determining the maximum delivery time (T^k) according to the formula (6):

$$T^k = \max_{x_{ij}>0}\{t_{ij}\} \tag{6}$$

where:
T^k – the maximum delivery time in the k-th iteration.

3. Presenting the cost table (c_{ij}) for the k-th solution using dependencies (7):

$$c_{ij}^k = \begin{cases} 0 & \\ 1 & if \\ 10 & \end{cases} \quad \begin{Bmatrix} t_{ij} < T^k \\ t_{ij} = T^k \\ t_{ij} > T^k \end{Bmatrix} \tag{7}$$

4. Verifying that the solution is optimal based on the cost table. When optimality assumptions (Δij) are non-negative for all base routes – STOP. Otherwise, proceed to step 5.

$$\Delta_{ij}^k = c_{ij}^k - \alpha_i^k - \beta_j^k \tag{8}$$

where:
α_i^k, β_j^k – dual variables (so-called potentials) in the k-th iteration.

5. Defining new acceptable base solutions, suggesting the most negative optimization criterion and joining step 2.

The method described above is based on the so-called potential method, the essence of which was presented in studies [4, 8, 11]. This means that when certain assumptions related to limited tonnage of vehicles are key in a specific decision problem, the presented algorithm must also refer to the principles adopted in the methodology developed for the transport problem with limited route capacity [7]. The procedure can be used as a manual method when you are dealing with small sized networks (for example, 3x4). In the case of particularly complicated problems, it is recommended to use the proper program created for the algorithm in the indicated programming language.

Another option for the presented methodology can be a ready-made optimization research tool in the form of Solver in an MS Excel spreadsheet. However, it should be noted that the type of tasks that can be solved depends on the version of the add-on. The new one has much greater possibilities as to the scope of the task size (number of conditions and variables), the type of functions used, as well as the time needed to solve the problem [10].

3. Numerical example

The network of "perishable" food stores has five wholesalers: V, W, X, Y, Z and a network consisting of 100 stores located geographically in 10 regions (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10). Each warehouse in accordance with the received goods is able to complete 20 sets. The regions are different, and their demand for sets is defined:

$$P_1 = 8, P_2 = 5, P_3 = 6, P_4 = 4, P_5 = 7, P_6 = 6, P_7 = 5, P_8 = 8, P_9 = 7, P_{10} = 4,$$
$$wherein\ \sum_{j=1}^{10} P_j = 60.$$

The time of service of separate regions by lorries consists of travel time (tab. 1) from the warehouse to the given region, however, it is independent of the number of stores in the region, as well as from the time of unloading, which is affected by the number of stores serviced (tab. 2) [4].

Table 1

Time of travel (t_{ij}^{p}) – in hours

Regions / Wholesalers	1	2	3	4	5	6	7	8	9	10
V	6	4	8	10	3	12	7	9	9	4
W	11	7	3	4	5	3	4	6	2	6
X	6	7	9	9	7	6	6	3	5	2
Y	8	5	2	3	4	5	4	6	3	6
Z	3	10	4	7	8	6	2	6	2	5

Table 2

Unit unloading time (t_i^r) – in hours

Regions	1	2	3	4	5	6	7	8	9	10
t_i^r	1/2	1/2	2/5	1/4	2/5	1/4	1/2	1/4	2/5	1/2

The presented numerical example is more complicated than the basic transport problem with the time criterion. For this reason, the record of the optimization task only partially resembles the mathematical model [4]. The purpose function in this case assumes the following form:

$$\begin{aligned}
&\max\{\left(6\cdot\min\{x_{11},1\}+\tfrac{1}{2}x_{11}\right),\left(4\cdot\min\{x_{12},1\}+\tfrac{1}{2}x_{12}\right),\left(8\cdot\min\{x_{13},1\}+\tfrac{2}{5}x_{13}\right),\\
&\left(10\cdot\min\{x_{14},1\}+\tfrac{1}{4}x_{14}\right),\left(3\cdot\min\{x_{15},1\}+\tfrac{2}{5}x_{15}\right),\left(12\cdot\min\{x_{16},1\}+\tfrac{1}{4}x_{16}\right),\\
&\left(7\cdot\min\{x_{17},1\}+\tfrac{1}{2}x_{17}\right),\left(9\cdot\min\{x_{18},1\}+\tfrac{1}{4}x_{18}\right),\left(9\cdot\min\{x_{19},1\}+\tfrac{2}{5}x_{19}\right),\\
&\left(4\cdot\min\{x_{20},1\}+\tfrac{1}{2}x_{20}\right),\left(11\cdot\min\{x_{21},1\}+\tfrac{1}{2}x_{21}\right),\left(7\cdot\min\{x_{22},1\}+\tfrac{1}{2}x_{22}\right),\\
&\left(3\cdot\min\{x_{23},1\}+\tfrac{2}{5}x_{23}\right),\left(4\cdot\min\{x_{24},1\}+\tfrac{1}{4}x_{24}\right),\left(5\cdot\min\{x_{25},1\}+\tfrac{2}{5}x_{25}\right),\\
&\left(3\cdot\min\{x_{26},1\}+\tfrac{1}{4}x_{26}\right),\left(4\cdot\min\{x_{27},1\}+\tfrac{1}{2}x_{27}\right),\left(6\cdot\min\{x_{28},1\}+\tfrac{1}{4}x_{28}\right),\\
&\left(2\cdot\min\{x_{29},1\}+\tfrac{2}{5}x_{29}\right),\left(6\cdot\min\{x_{30},1\}+\tfrac{1}{2}x_{30}\right),\left(6\cdot\min\{x_{31},1\}+\tfrac{1}{2}x_{31}\right),\\
&\left(7\cdot\min\{x_{32},1\}+\tfrac{1}{2}x_{32}\right),\left(9\cdot\min\{x_{33},1\}+\tfrac{2}{5}x_{33}\right),\left(9\cdot\min\{x_{34},1\}+\tfrac{1}{4}x_{34}\right),\\
&\left(7\cdot\min\{x_{35},1\}+\tfrac{2}{5}x_{35}\right),\left(6\cdot\min\{x_{36},1\}+\tfrac{1}{4}x_{36}\right),\left(6\cdot\min\{x_{37},1\}+\tfrac{1}{2}x_{37}\right),\\
&\left(3\cdot\min\{x_{38},1\}+\tfrac{1}{4}x_{38}\right),\left(5\cdot\min\{x_{39},1\}+\tfrac{2}{5}x_{39}\right),\left(2\cdot\min\{x_{40},1\}+\tfrac{1}{2}x_{40}\right),\\
&\left(8\cdot\min\{x_{41},1\}+\tfrac{1}{2}x_{41}\right),\left(5\cdot\min\{x_{42},1\}+\tfrac{1}{2}x_{42}\right),\left(2\cdot\min\{x_{43},1\}+\tfrac{2}{5}x_{43}\right),\\
&\left(3\cdot\min\{x_{44},1\}+\tfrac{1}{4}x_{44}\right),\left(4\cdot\min\{x_{45},1\}+\tfrac{2}{5}x_{45}\right),\left(5\cdot\min\{x_{46},1\}+\tfrac{1}{4}x_{46}\right),\\
&\left(4\cdot\min\{x_{47},1\}+\tfrac{1}{2}x_{47}\right),\left(6\cdot\min\{x_{48},1\}+\tfrac{1}{4}x_{48}\right),\left(3\cdot\min\{x_{49},1\}+\tfrac{2}{5}x_{49}\right),\\
&\left(6\cdot\min\{x_{50},1\}+\tfrac{1}{2}x_{50}\right),\left(3\cdot\min\{x_{51},1\}+\tfrac{1}{2}x_{51}\right),\left(10\cdot\min\{x_{52},1\}+\tfrac{1}{2}x_{52}\right),\\
&\left(4\cdot\min\{x_{53},1\}+\tfrac{2}{5}x_{53}\right),\left(7\cdot\min\{x_{54},1\}+\tfrac{1}{4}x_{54}\right),\left(8\cdot\min\{x_{55},1\}+\tfrac{2}{5}x_{55}\right),\\
&\left(6\cdot\min\{x_{56},1\}+\tfrac{1}{4}x_{56}\right),\left(2\cdot\min\{x_{57},1\}+\tfrac{1}{2}x_{57}\right),\left(6\cdot\min\{x_{58},1\}+\tfrac{1}{4}x_{58}\right),\\
&\left(2\cdot\min\{x_{59},1\}+\tfrac{2}{5}x_{59}\right),\left(5\cdot\min\{x_{60},1\}+\tfrac{1}{2}x_{60}\right)\}\to min
\end{aligned}\tag{9}$$

In addition, conditions (10) relating to the demand of regions should be specified:

$$x_{11}+x_{21}+x_{31}+x_{41}+x_{51}=8$$

$$x_{12}+x_{22}+x_{32}+x_{42}+x_{52}=5$$

$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} = 6$$

$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} = 4$$

$$x_{15} + x_{25} + x_{35} + x_{45} + x_{55} = 7$$

$$x_{16} + x_{26} + x_{36} + x_{46} + x_{56} = 6 \quad (10)$$

$$x_{17} + x_{27} + x_{37} + x_{47} + x_{57} = 5$$

$$x_{18} + x_{28} + x_{38} + x_{48} + x_{58} = 8$$

$$x_{19} + x_{29} + x_{39} + x_{49} + x_{59} = 7$$

$$x_{20} + x_{30} + x_{40} + x_{50} + x_{60} = 4$$

and conditions (11) relating to the supply of wholesalers:

$$x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} + x_{18} + x_{19} + x_{20} \le 20$$

$$x_{21} + x_{22} + x_{23} + x_{24} + x_{25} + x_{26} + x_{27} + x_{28} + x_{29} + x_{30} \le 20$$

$$x_{31} + x_{32} + x_{33} + x_{34} + x_{35} + x_{36} + x_{37} + x_{38} + x_{39} + x_{40} \le 20 \quad (11)$$

$$x_{41} + x_{42} + x_{43} + x_{44} + x_{45} + x_{46} + x_{47} + x_{48} + x_{49} + x_{50} \le 20$$

$$x_{51} + x_{52} + x_{53} + x_{54} + x_{55} + x_{56} + x_{57} + x_{58} + x_{59} + x_{60} \le 20$$

and the condition (12) referring to the integerity of the decision variables:

$$x_{11}, x_{12}, \dots, x_{60} \in N \quad (12)$$

where:
x_{11} – number of sets transported from warehouse V to region 1,
⋮x_{60} – number of sets transported from warehouse Z to region 10.

Figure 1 shows an example of a combination of basic data in an MS Excel spreadsheet. C4-L8 cells will be filled with optimal values of decision variables (x11, x12, ..., x60). The sums of fields in the separate columns of Table C4-L8, which are the conditions for the demand of the regions, are calculated in line 9. The reported demand is shown in line 10. In the M column, the sum of C4-L4, C5-L5, C6-L6, C7-L7 and C8-L8 fields was determined, defining the total number of sets transported from the V, W, X, Y and Z warehouses respectively. Supply values of each warehouse listed in column N.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
2														
3		HURTOWNIE/REJONY	1	2	3	4	5	6	7	8	9	10		PODAŻ
4		V											0	20
5		W											0	20
6		X											0	20
7		Y											0	20
8		Z											0	20
9			0	0	0	0	0	0	0	0	0	0		
10		POPYT	8	5	6	4	7	6	5	8	7	4		
11														
12		CZAS PRZEJAZDU DO REJONU	6	4	8	10	3	12	7	9	9	4		
13			11	7	3	4	5	3	4	6	2	6		
14			6	7	9	9	7	6	6	3	5	2		
15			8	5	2	3	4	5	4	6	3	6		
16			3	10	4	7	8	6	2	6	2	5		
17														
18		CZAS WYŁADUNKU	0,50	0,50	0,40	0,25	0,40	0,25	0,50	0,25	0,40	0,50		
19														
20		ŁĄCZNY CZAS WYŁADUNKU	0	0	0	0	0	0	0	0	0	0		
21			0	0	0	0	0	0	0	0	0	0		
22			0	0	0	0	0	0	0	0	0	0		
23			0	0	0	0	0	0	0	0	0	0		
24			0	0	0	0	0	0	0	0	0	0		
25														
26		ŁĄCZNY CZAS PRZEJAZDU (STAŁY) I WYŁADUNKU (ZMIENNY)	6	4	8	10	3	12	7	9	9	4		
27			11	7	3	4	5	3	4	6	2	6		
28			6	7	9	9	7	6	6	3	5	2		
29			8	5	2	3	4	5	4	6	3	6		
30			3	10	4	7	8	6	2	6	2	5		
31														
32		TRASY BAZOWE I NIEBAZOWE	0	0	0	0	0	0	0	0	0	0		
33			0	0	0	0	0	0	0	0	0	0		
34			0	0	0	0	0	0	0	0	0	0		
35			0	0	0	0	0	0	0	0	0	0		
36			0	0	0	0	0	0	0	0	0	0		
37														
38		ŁĄCZNY CZAS NA TRASACH BAZOWYCH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		FUNKCJA CELU
39			0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,0
40			0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		
41			0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		
42			0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		

Fig. 1. Basic data

Lines 12÷42 contain the necessary formulas and parameters necessary to determine the purpose function. The total unloading time was calculated by multiplying the unit unloading times (row 18) by the number of transported sets (rows 4 ÷ 8) – fig. 2.

19												
20		ŁĄCZNY CZAS WYŁADUNKU	0	0	0	0	0	0	0	0	0	0
21			0	0	0	0	0	0	0	0	0	0
22			0	0	0	0	0	0	0	0	0	0
23			0	0	0	0	0	0	0	0	0	0
24			0	0	0	0	0	0	0	0	0	=L$18*L8

Fig. 2. Determining the total landing time

The method of determining the total travel time and total unloading time (rows 26÷30) is depicted in fig. 3.

26	ŁĄCZNY CZAS PRZEJAZDU (STAŁY) I WYŁADUNKU (ZMIENNY)	6	4	8	10	3	12	7	9	9	4
27		11	7	3	4	5	3	4	6	2	6
28		6	7	9	9	7	6	6	3	5	2
29		8	5	2	3	4	5	4	6	3	6
30		3	10	4	7	8	6	2	6	2	=L16+L24

Fig. 3. Determining the total travel and unloading time

In the case when the quotient (13) is equal to 1, the analyzed route is basic. However, the zero value of the quotient indicates a route on which carriage will not occur – fig. 4.

$$\frac{x_{ij}}{x_{ij}+0{,}00001} \tag{13}$$

32	TRASY BAZOWE I NIEBAZOWE	0	0	0	0	0	0	0	0	0	0
33		0	0	0	0	0	0	0	0	0	0
34		0	0	0	0	0	0	0	0	0	0
35		0	0	0	0	0	0	0	0	0	0
36		0	0	0	0	0	0	0	0		=L8/(L8+0,00001)

Fig. 4. Determination of base and non-base routes

Using the presented method, only the times associated with the base routes can be taken into account at the final stage. The calculation of total time on base routes is shown in fig. 5.

38	ŁĄCZNY CZAS NA TRASACH BAZOWYCH	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
39		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
40		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
41		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
42		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	=L30*L36

Fig. 5. Determining the total time on the base routes

Single cells (fig. 5) in lines 38 ÷ 42 generate the next arguments of the function {max} specified in the formula (9). The objective function is shown in cell N39 (fig. 1).

In order to obtain the optimal solution, the Solver dialog should be filled in by selecting the setting of non-negative values for variables, and finally the "Solve" command (fig. 6).

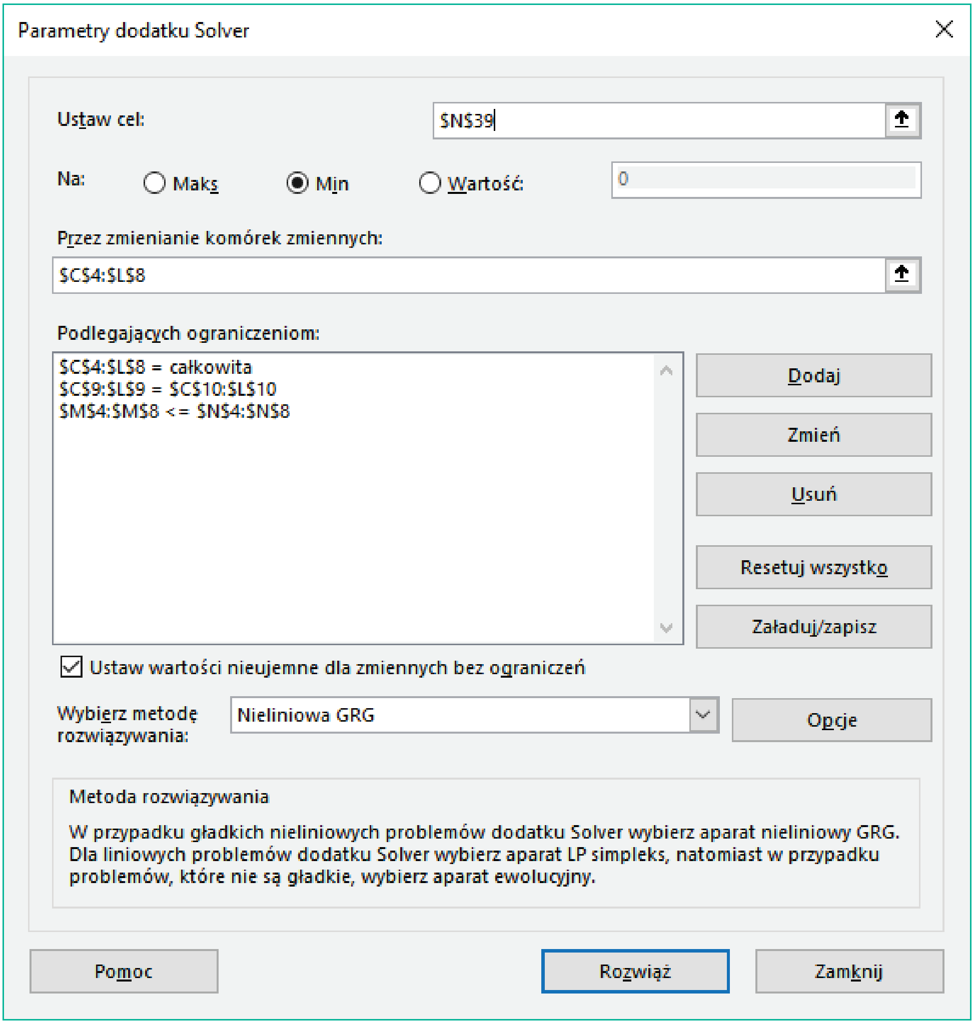

Fig. 6. Filling the Solver dialog

The solution obtained is shown in fig. 7.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2														
3		HURTOWNIE/REJONY	1	2	3	4	5	6	7	8	9	10		PODAŻ
4		V	1,0	3,0	0,0	0,0	4,0	0,0	0,0	0,0	0,0	0,0	8	20
5		W	0,0	0,0	2,0	3,0	1,0	4,0	1,0	0,0	0,0	0,0	11	20
6		X	0,0	0,0	0,0	0,0	0,0	0,0	0,0	7,0	2,0	4,0	13	20
7		Y	0,0	2,0	2,0	1,0	2,0	1,0	1,0	0,0	2,0	0,0	11	20
8		Z	7,0	0,0	2,0	0,0	0,0	1,0	3,0	1,0	3,0	0,0	17	20
9			8	5	6	4	7	6	5	8	7	4		
10		POPYT	8	5	6	4	7	6	5	8	7	4		
11														
12		CZAS PRZEJAZDU DO REJONU	6	4	8	10	3	12	7	9	9	4		
13			11	7	3	4	5	3	4	6	2	6		
14			6	7	9	9	7	6	6	3	5	2		
15			8	5	2	3	4	5	4	6	3	6		
16			3	10	4	7	8	6	2	6	2	5		
17														
18		CZAS WYŁADUNKU	0,50	0,50	0,40	0,25	0,40	0,25	0,50	0,25	0,40	0,50		
19														
20		ŁĄCZNY CZAS WYŁADUNKU	0,50	1,50	0,00	0,00	1,60	0,00	0,00	0,00	0,00	0,00		
21			0,00	0,00	0,80	0,75	0,40	1,00	0,50	0,00	0,00	0,00		
22			0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,75	0,80	2,00		
23			0,00	1,00	0,80	0,25	0,80	0,25	0,50	0,00	0,80	0,00		
24			3,50	0,00	0,80	0,00	0,00	0,25	1,50	0,25	1,20	0,00		
25														
26		ŁĄCZNY CZAS PRZEJAZDU (STAŁY) I WYŁADUNKU (ZMIENNY)	6,50	5,50	8,00	10,00	4,60	12,00	7,00	9,00	9,00	4,00		
27			11,00	7,00	3,80	4,75	5,40	4,00	4,50	6,00	2,00	6,00		
28			6,00	7,00	9,00	9,00	7,00	6,00	6,00	4,75	5,80	4,00		
29			8,00	6,00	2,80	3,25	4,80	5,25	4,50	6,00	3,80	6,00		
30			6,50	10,00	4,80	7,00	8,00	6,25	3,50	6,25	3,20	5,00		
31														
32		TRASY BAZOWE I NIEBAZOWE	1	1	0	0	1	0	0	0	0	0		
33			0	0	1	1	1	1	1	0	0	0		
34			0	0	0	0	0	0	0	1	1	1		
35			0	1	1	1	1	1	1	0	1	0		
36			1	0	1	0	0	1	1	1	1	0		
37														
38		ŁĄCZNY CZAS NA TRASACH BAZOWYCH	6,5	5,5	0,0	0,0	4,6	0,0	0,0	0,0	0,0	0,0		FUNKCJA CELU
39			0,0	0,0	3,8	4,7	5,4	4,0	4,5	0,0	0,0	0,0		6,5
40			0,0	0,0	0,0	0,0	0,0	0,0	0,0	4,7	5,8	4,0		
41			0,0	6,0	2,8	3,2	4,8	5,2	4,5	0,0	3,8	0,0		
42			6,5	0,0	4,8	0,0	0,0	6,2	3,5	6,2	3,2	0,0		

Fig. 7. Optimal solution

4. Conclusions

The presented methodology allowed to optimize the supply of stores with "perishable" products, using a ready-made research tool in the form of Solver in MS Excel. According to the optimal transport plan, the longest delivery time is 6.5 hours. Compared to the initial base solution of 12 hours, it is 5.5 hours shorter, which means a reduction of nearly 46%. It will appear on two routes: V-1, as well as Z-1. Each area will get the required number of sets based on the reported demand. It is worth noting that the supply of none of the wholesalers has been fully utilized, and the network of stores with perishable food will be provided with 24 means of transport.

5. References

1. Anholcer M.: Algorithm for the Stochastic Generalized Transportation Problem. Operations Research and Decisions, 2012.
2. Buga J., Nykowski I.: Zagadnienia transportowe w programowaniu liniowym, PWN, Warszawa 1972.
3. Guzik B. (red.): Ekonometria i badania operacyjne: zagadnienia podstawowe. Materiały Dydaktyczne 115, Wydawnictwo Akademii Ekonomicznej, Poznań 2003.
4. Hein L.W.: The Quantitative Approach to Managerial Decisions, Prentice-Hall, New Jersey 1967.
5. Kauf S., Tłuczak A.: Optymalizacja decyzji logistycznych, Difin, Warszawa 2016.
6. Sikora W. (red.): Badania operacyjne. Polskie Wydawnictwo Ekonomiczne, Warszawa 2008.
7. Sikora W.: Modele i metody optymalizacji dóbr. Zeszyt Naukowy nr 127, Akademia Ekonomiczna w Poznaniu, Poznań 1993.
8. Szkutnik J., Ziółkowski J.: Optymalizacja kosztów transportu w sferze zaopatrzenia. Logistyka nr 4/2015.
9. Szkutnik-Rogoż J., Ziółkowski J.: Wyznaczanie kosztów transportu z wykorzystaniem Octave 3.4.3. Prace naukowe z. 111, Metody badania procesów logistycznych i systemów transportowych, Oficyna wydawnicza Politechniki Warszawskiej, Warszawa 2016.
10. Szymczak M. (red.): Decyzje logistyczne z Excelem. Difin, Warszawa 2011.
11. Trzaskalik T. (red.): Wprowadzenie do badań operacyjnych z komputerem, wydanie II zmienione. PWE, Warszawa 2008.
12. Ziółkowski J., Bonkowska K.: Zamknięte zadanie transportowe- przykład liczbowy, SLW nr 45, WAT, Warszawa 2016.
13. Ziółkowski J., Szkutnik-Rogoż J.: Zarządzanie transportem samochodowym z uwzględnieniem analizy kosztów, Studia Ekonomiczne. Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach, podseria Zarządzanie nr 337/2017.