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OPTIMIZATION OF DISTRIBUTION ROUTES BY WAY OF THE MULTILEVEL APPROACH TO THE TRAVELING SALESMAN PROBLEM

The article „Optimization of Distribution Routes by way of the Multilevel Approach to the Traveling Salesman Problem“ is concerned with the optimization of the distribution routes. The goal is to use the obtained data to try to optimize and propose alternatives of the circular routes for the company Vltavotynské lahůdky. For implementing this task, the principle of the module for solving the transport-related tasks was used. This module was developed by the Department of the Operational and System Analysis of the Czech University of Life Sciences in Prague.

Keywords: Optimization, transport, logistics, traveling salesman problem, nearest neighbor method, Hungarian method.

1. Introduction

The Vltavotynské lahůdky company operates a total of seven lines, with one driver and one vehicle allocated to each of them. For the company's needs, two lines on which the number of kilometres needs to be minimized were selected. The first chosen line is the line No. 2 (Tyn - Trebon - Nove Hradky - Tyn). The second line is line No. 5 which is in Table 2. (Tyn - Trhove Sviny - Tyn) [1 - 6].

Table 1 describes the current route of line No. 2 which contains the loading point (Tyn nad Vltavou) and other seven unloading points which the driver has to serve. After the last stop the driver returns back to the initial point (Tyn nad Vltavou) [7 - 9]. The route is indicated in Fig. 1.

Current line No. 2

Table 1

| Stop location | Order | Distance from the previous stop (km) | Cumulated distance (km) |
|---------------------|-------|--------------------------------------|-------------------------|
| Tyn nad Vltavou | 1 | 0 | 0 |
| Lisov 456 | 2 | 43.5 | 43.5 |
| Trebon 992 | 3 | 12.6 | 56.1 |
| Suchdol nad Luznici | 4 | 19.3 | 75.4 |
| Ceske Velenice | 5 | 17.5 | 92.9 |
| Nove Hradky 336 | 6 | 15.3 | 108.2 |
| Horni Stropnice 47 | 7 | 7.5 | 115.7 |
| Borovany 476 | 8 | 22.2 | 137.9 |
| Tyn nad Vltavou | 9 | 49.9 | 187.8 |

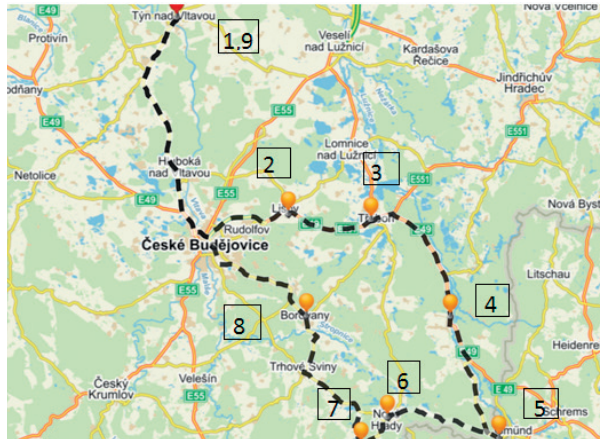
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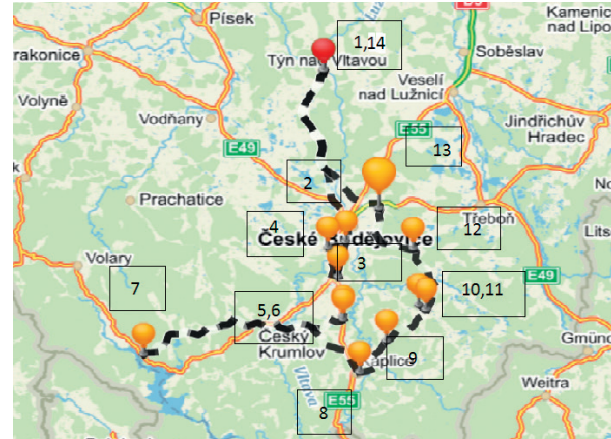


Source: Author
Fig. 1 Line No. 2

The entire route is 187.8 km long. The distribution is carried out every Wednesday using the lorry Iveco Turbo Daily 35C15. The car departs at 4:45 a.m. and finishes at about 9:15 a.m.

Table 2 describes the current distribution situation on line No. 5. Line No. 5 starts at Tyn nad Vltavou where the driver loads the required amount of products and then he drives to the consequent places listed in the table. After serving all the required places the vehicle returns back to the initial position [10]. The route is indicated in Fig. 2.

The total length of line No. 5 amounts to 251.4 km. The driver departs at 4:45 a.m. and finishes at 9:15 a.m.



Source: Author
Fig. 2 Line No. 5

2. Optimization of Distribution Routes by way of the Multilevel Approach to the Traveling Salesman Problem

In this type of problems, there is a single supplier (consumer) who distributes (loads) the goods to the places of consumption. After visiting the last place the means of transport returns back to the initial point. Every place is visited only once. The goal of the solution is to set the order of the visited places so that the total number of kilometers or the total costs (CZK) of transportation were minimum. The Hungarian method was applied to solve the traveling salesman problem. The source and target objects are identical here

Current line No. 5

Table 2

| Stop location | Order | Distance from the previous stop (km) | Cumulated distance (km) |
|----------------------|-------|--------------------------------------|-------------------------|
| Tyn nad Vltavou | 1 | 0 | 0 |
| Roznov 207 | 2 | 35.9 | 35.9 |
| Kamenny Ujezd 497 | 3 | 8.7 | 44.6 |
| Homole u C. B. | 4 | 8.2 | 52.8 |
| Třeba Veselín | 5 | 15 | 67.8 |
| Veselín 1 | 6 | 0.1 | 67.9 |
| Horní Plana | 7 | 41.9 | 109.8 |
| Kaplice | 8 | 47.5 | 157.3 |
| Výrobní Besednice | 9 | 8.4 | 165.7 |
| Zaruba- Trhove Sviny | 10 | 10.9 | 176.6 |
| Trhove Sviny 185 | 11 | 0.9 | 177.5 |
| Ledenice 469 | 12 | 15 | 192.5 |
| Adamov 166 | 13 | 20.1 | 212.6 |
| Tyn nad Vltavou | 14 | 38.8 | 251.4 |

Source: Author

and represent the source and target points. The connection between the identical points is unacceptable; hence, there are prohibitive rates on the main diagonal of the matrix [10 - 14].

2.1. Optimization of distribution routes - line No. 5

First step: Identification of distances

The matrix of distances (Table 3) contains the current distances between the distribution points with a prohibitive rate on the main diagonal.

Second step: Line reduction

After finding the lowest value on each line, we will deduct this value from each value on the given line. The goal of the reduction is to obtain as many zeros (0) as possible in the matrix of rates. This step is solved in Table 4.

Third step: Column reduction

After finding the lowest value in each column, we will again deduct this value from each value in the given column. The values of the third step are contained in Table 5.

Matrix of distances of the line No. 2

Table 3

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|------|------|------|------|------|------|------|------|
| 1 | x | 43.5 | 44.4 | 62 | 79 | 68 | 68 | 49.9 |
| 2 | 43.5 | x | 12.6 | 30.4 | 47.5 | 39.9 | 38.8 | 15.4 |
| 3 | 44.4 | 12.6 | x | 19.3 | 36.4 | 28.5 | 34.1 | 17.6 |
| 4 | 62 | 30.4 | 19.3 | x | 17.5 | 16.3 | 21.9 | 19.2 |
| 5 | 79 | 47.5 | 36.4 | 17.5 | x | 15.3 | 22.2 | 33.9 |
| 6 | 68 | 39.9 | 28.5 | 16.3 | 15.3 | x | 7.5 | 23.1 |
| 7 | 68 | 38.8 | 34.1 | 21.9 | 22.2 | 7.5 | x | 22.2 |
| 8 | 49.9 | 15.4 | 17.6 | 19.2 | 33.9 | 23.1 | 22.2 | x |

Source: Author

Line reduction

Table 4

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|------|------|------|------|------|------|------|------|
| 1 | x | 0 | 0.9 | 18.5 | 35.5 | 24.5 | 24.5 | 6.4 |
| 2 | 30.9 | x | 0 | 17.8 | 34.9 | 27.3 | 26.2 | 2.8 |
| 3 | 31.8 | 0 | x | 6.7 | 23.8 | 15.9 | 21.5 | 5 |
| 4 | 45.7 | 14.1 | 3 | x | 1.2 | 0 | 5.6 | 2.9 |
| 5 | 63.7 | 32.2 | 21.1 | 2.2 | x | 0 | 6.9 | 18.6 |
| 6 | 60.5 | 32.4 | 21 | 8.8 | 7.8 | x | 0 | 15.6 |
| 7 | 60.5 | 31.3 | 26.6 | 14.4 | 14.7 | 0 | x | 14.7 |
| 8 | 34.5 | 0 | 2.2 | 3.8 | 18.5 | 7.7 | 6.8 | x |

Source: Author

Column reduction

Table 5

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|------|------|------|------|------|------|------|------|
| 1 | x | 0 | 0.9 | 16.3 | 34.3 | 24.5 | 24.5 | 3.6 |
| 2 | 0 | x | 0 | 15.6 | 33.7 | 27.3 | 26.2 | 0 |
| 3 | 0.9 | 0 | x | 4.5 | 22.6 | 15.9 | 21.5 | 2.2 |
| 4 | 14.8 | 14.1 | 3 | x | 0 | 0 | 5.6 | 0.1 |
| 5 | 32.8 | 32.2 | 21.1 | 0 | x | 0 | 6.9 | 15.8 |
| 6 | 29.6 | 32.4 | 21 | 6.6 | 6.6 | x | 0 | 12.8 |
| 7 | 29.6 | 31.3 | 26.6 | 12.2 | 13.5 | 0 | x | 11.9 |
| 8 | 3.6 | 0 | 2.2 | 1.6 | 17.3 | 7.7 | 6.8 | x |

Source: Author

Fourth step: Selection of independent zeros and routing of the covering lines

In this step we will choose the „independent“ zeros, i.e. those zeros which are stand-alone on the line or in the column. We will draw a line horizontally and vertically to cover all zeros while drawing the minimum number of lines.

Fifth step: Selection of minimum and modification of the matrix

We will choose the lowest value from the remaining uncovered values. The not covered elements will be reduced by the „a“ elements. The elements which are covered will not change. The elements which are covered twice will increase by the „a“ value.

Sixth step: Final solution

If we do not find the optimum solution, we will repeat the line coverage process until we find the optimum solution. With respect to the relative labor intensity of the manual procedure, the Dumkosa module for solving the transport problem, developed by the Department of the Operational and System Analysis of the Czech University of Life Sciences in Prague, was used [12 - 14].

Solution using the Dumkosa macro in Excel

Identification of the final route is illustrated in Table 6.

After loading the Dumkosa macro, all distances were transformed into the MS Excel environment. As the program cannot work with the value „x“ it was replaced with the prohibitive rates, specifically 1000 to prevent the program from selecting this value. The final first solution according to the above Table 6 was not optimal as the cycle was closed prematurely (marked in yellow in the Table). Then the final data were modified – the prohibitive rates were allocated to prevent the allocation of the original rates. The whole procedure was repeated a few times until the optimum variant was achieved. A total of 4 iterations (marked in color) were carried out.

The individual steps of the route optimization gave rise, with respect to the minimization of the number of the traveled kilometres, to the combination of individual partial solutions. The following options of the circular routes were suggested based on the four iterations in the makro Dumkosa.

Table 7 contains 6 options of the route; the first route corresponds to the current model of distribution. From the other five selected options, only variant No. 6 is appropriate

Matrix of solution

Table 6

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|------|------|------|------|------|------|------|------|
| 1 | x | 43.5 | 44.4 | 62 | 79 | 68 | 68 | 49.9 |
| 2 | 43.5 | x | 12.6 | 30.4 | 47.5 | 39.9 | 38.8 | 15.4 |
| 3 | 44.4 | 12.6 | x | 19.3 | 36.4 | 28.5 | 34.1 | 17.6 |
| 4 | 62 | 30.4 | 19.3 | x | 17.5 | 16.3 | 21.9 | 19.2 |
| 5 | 79 | 47.5 | 36.4 | 17.5 | x | 15.3 | 22.2 | 33.9 |
| 6 | 68 | 39.9 | 28.5 | 16.3 | 15.3 | x | 7.5 | 23.1 |
| 7 | 68 | 38.8 | 34.1 | 21.9 | 22.2 | 7.5 | x | 22.2 |
| 8 | 49.9 | 15.4 | 17.6 | 19.2 | 33.9 | 23.1 | 22.2 | x |

Source: Author

Legend:

| | |
|--------|-----------------------------------|
| Yellow | 1 st optimization step |
| Green | 2 nd optimization step |
| Blue | 3 rd optimization step |
| Red | 4 th optimization step |

Options of the route

Table 7

| 1 | 1-2-3-4-5-6-7-8-1 | 43.5+12.6+19.3+17.5+15.3+7.5+22.2+49.9= | 187.8 km |
|---|-------------------|--|----------|
| 2 | 1-2-8-6-5-7-3-4-1 | 43.5+15.4+23.1+15.3+22.2+34.1+19.3+62= | 234.9 km |
| 3 | 1-3-5-7-6-8-2-4-1 | 44.4+36.4+22.2+7.5+23.1+15.4+30.4+62= | 241.4 km |
| 4 | 1-6-4-2-5-7-8-3-1 | 68+16.3+30.4+47.5+22.2+22.2+17.6+44.4= | 268.6 km |
| 5 | 1-8-6-3-5-7-4-2-1 | 49.9+23.1+28.5+36.4+22.2+21.9+30.4+43.5= | 255.9 km |
| 6 | 1-2-8-7-6-5-4-3-1 | 43.5+15.4+22.2+7.5+15.3+17.5+19.3+44.4= | 185.1 km |

Source: Author

Final route after applying the solution using the Hungarian method

Table 8

| Stop location | Order | Distance from the previous stop | Cumulated distance |
|---------------------|-------|---------------------------------|--------------------|
| Tyn nad Vltavou | 1 | 0 | 0 |
| Lisov 456 | 2 | 43.5 | 43.5 |
| Borovany 476 | 3 | 15.4 | 58.9 |
| Horni Stropnice 47 | 4 | 22.2 | 81.1 |
| Nove Hradky 336 | 5 | 7.5 | 88.6 |
| Ceske Velenice | 6 | 15.3 | 103.9 |
| Suchdol nad Luznici | 7 | 17.5 | 121.4 |
| Trebon 992 | 8 | 19.3 | 140.7 |
| Tyn nad Vltavou | 9 | 44.4 | 185.1 |

Source: Author

as it achieves shorter distances than the current route of the company. Final route after applying the solution using the Hungarian method is in Table 8 and Fig. 3 [12-14].



Source: Author

Fig. 3 Map of the optimized route of line No. 2

2.2. Optimization of distribution routes - line No. 5

The same procedure as for line No. 2 was also used for line No. 5. With respect to the similarity of the model, only the final solution is provided.

The first variant (Table 9) is the current route of distribution which the company follows. Except for variant 6, all variants represent the worse solution and they would

not be helpful in the route optimization. Route No. 6 is 244.8 kilometres long, which is optimal for making the modification of line No. 5 [12 - 14].

3. Conclusions

Despite finding the possibility of saving the number of kilometres using the above method, it can be concluded that the company uses the existing routes of lines No. 2 and 5 efficiently. The given solution is an alternative to other methods which deal with the similar problem. Although the final solution is not maximalist, it proves that the use of the alternative methods has its place in the current practice. For more information see Table 10.

The main purpose was to make the selected circular routes more effective in order to help to save the costs of transportation. To this end, the methods for optimization of the transport problems were used. The calculation of the traveling salesman problem was carried out in MS Excel using the Dumkosa module. The implementation of the problem has helped to find the more advantageous routes which, if introduced by the company, would help reduce the costs of the company. From the long-term perspective, they bring interesting savings [14].

Options of the route

Table 9

| | | | |
|---|---------------------------------|--|----------|
| 1 | 1-2-3-4-5-6-7-8-9-10-11-12-13-1 | 35.9+8.7+8.2+15+0.1+41.9+47.5+8.4+10.9+0.9+15+20.1+38.8= | 251.4 km |
| 2 | 1-12-9-11-10-8-5-6-7-4-3-13-2-1 | 45.3+24.7+10.2+0.9+19.2+12.2+0.1+41.9+48.2+8.2+21.7+12.2+35.9= | 280.7 km |
| 3 | 1-3-5-6-7-4-12-9-8-10-11-13-2-1 | 42.1+9.6+0.1+41.9+48.2+18.5+24.7+8.4+19.2+0.9+28.9+12.2+35.9= | 290.6 km |
| 4 | 1-4-5-3-2-12-9-7-6-8-10-11-13-1 | 37.7+15+9.6+8.7+15.2+24.7+50+41.9+12.1+19.2+0.9+28.9+38.8= | 302.7 km |
| 5 | 1-4-2-3-5-7-8-6-10-9-11-12-13-1 | 37.7+6.2+8.7+9.6+41.8+47.5+12.1+16.2+10.9+10.2+15+20.1+38.8= | 274.8 km |
| 6 | 1-13-2-3-7-5-6-8-9-11-10-12-4-1 | 38.8+12.2+8.7+42.9+41.8+0.1+12.1+8.4+10.2+0.9+12.5+18.5+37.7= | 244.8 km |

Source: Author

Comparison of annual costs

Table 10

| | | Line No. 2 | Line No. 5 |
|------------------|-------------------------------|------------|------------|
| Optimization | Distance (km) | 9.625 | 58.752 |
| | Costs (CZK) Internal rates | 32.640 | 149.817 |
| Original values | Distance (km) | 9.766 | 60.336 |
| | Costs (CZK) Internal rates | 33.120 | 153.857 |
| Total difference | Distance (km) | 141 | 1.584 |
| | Costs (CZK) | 480 | 4.040 |

Source: Author

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