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Effective Solutions to the Transport Distribution of Material by the Mayer Method

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ABSTRACT
This paper deals with streamlining the collection (pick-up) and distribution (delivery) activities within the technology of wood industry. Through the optimization process implemented using the issue of the distribution task of linear programming, specifically the Mayer method, the particular solution in order to minimize the total costs in practice of utilized distribution routes is proposed. The first part of the paper presents the characteristics of the vehicle routing problem and describes methods of solving this issue. Subsequently, the main part of the paper outlines a particular case study in the context of the Mayer method application within the field of transport-technology solution of the material distribution.

Keywords: transport, operational research, linear programming, vehicle routing problem, Mayer method

INTRODUCTION

Vehicle routing problem or traveling salesman problem (TSP) deals with the issue of several places (stations) operation, the route begins from one starting point, and after accomplishing the individual places operation, vehicle returns to the starting point. Each station can be operated only once, the order of stations is not determined, but the objective is to find the shortest possible route. Vehicle routing problem deals with the most economical distribution of products from suppliers to customers in order to meet their requirements (delivery date, etc.) [3,17,29].

METHODS OF SOLVING THE VEHICLE ROUTING PROBLEM

Most of these methods are based on mathematical calculations and algorithms. To solve the vehicle routing problem, several methods can be applied, particularly exact and heuristic methods. Exact methods include the method of linear integer programming, brute force method of examining every possible permutation, branch-and-bound methods, gradual improvement algorithms analogous to techniques of linear programming. The group of heuristic methods includes, for example, greedy algorithm or nearest neighbor method. Heuristic methods, in comparison with exact methods, are much less demanding in terms of calculations and only propose a good solution, but not optimal. In other sources, it is indicated that the resulting solutions have a deviation from the optimal solution of only 2–3% [1,2,4,11–16,23–27,31].

It can be declared that vehicle routing problem is a classic traffic problem on the general transport network S = (V, H), where V denotes the set of nodes on the transport network, and H denotes the set edges connecting individual nodes H on the transport network.

It should also be noted that the node indicated as V_0 expresses the center of the network. It can also be named as a central point or distribution point from which material is distributed to individual delivery points. These points (places requiring an operation) are indicated as nodes, V_i, …, V_n, where n denotes a number of nodes [15,20,22].

Sample of the transport network with nodes and edges is illustrated in following figure (Fig. 1).

There is a requirement for certain amount of transported goods in nodes. Goods are transported by vehicles while their capacity is limited from above and vehicle's route starts and ends at the same center V_0.

The task is to compile certain number of circular routes in order to always meet requirements of each delivery (customer) point, ensure only one operation for each place, achieve the smallest possible transport costs [6,18,22,30].

APPLICATION OF THE MAYER METHOD ON THE PARTICULAR CASE STUDY

Method of compiling the circular routes by selecting the minimum elements, i.e. Mayer method, is appropriate for multiple circuit (multiple vehicle path) tasks with a complete network of routes and limited capacity [25]. This is an approximate method which is suitable for compiling collection (pick-up) or distribution (delivery) vehicle plans. The process of solution is based on a symmetric distance matrix indicated in kilometers among points that are included within the solution. When solving this issue using Mayer method, thus, a symmetric distance matrix must be created [10,21,28].

In the matrix, individual places are compiled in succession by the distance from a central point (e.g., warehouse, distrubution center, etc.). The furthermost place is indicated as first, i.e. in the first row and the first column, a central point is indicated as last.

In a first step, the selection of places for each vehicle circular route is performed. Subsequently, in a second step, the solution within the circular routes for each vehicle separately is carried out. In regard to the first step, when choosing the place for individual circular routes, the furthermost place is a starting point – it is indicated as first in the matrix. This place is added into the first circular route. Next the place is then added to already selected place by the method that a place with the smallest distance to the first added place is found in the relevant column. After adding this place, it is necessary to make sum of requirements of selected places and compare them with the vehicle capacity.

If the capacity is not filled, the process continues with finding another place with the minimum distance to the two places which were already added. The same procedure continues until filling the vehicle capacity. Place selection for next circular route begins again by the furthermost place from the central point which have not been added to the previous circuit (circular route). In the second step of the Mayer method, after separation of all places into distribution groups, aligning (adding) within each route places takes place. Places selected into individual circular routes are ordered by a minimum length of individual connections and routes in total. Routes can be modified based on intuitive decision-making and knowledge [1,2,6,18,19,25].

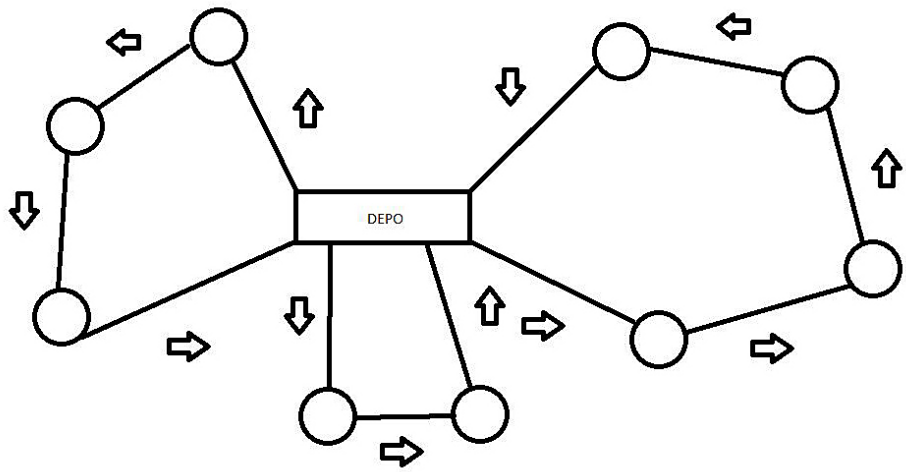

Fig. 1. Sample of the transport network with nodes and edges [authors]

In practice, optimization of consignments distribution was realized for these transport points (customers):

- Central point Šlapanice – starting point,
- Shopping center Bystřice nad Pernštejnem
- Shopping center České Budějovice,
- Shopping center Humpolec,
- Shopping center Jindřichův Hradec,
- Shopping center Pilsen,
- Shopping center Prostějov,
- Prostějov – Sale of joinery timber and construction timber,
- Shopping center Strakonice,
- Shopping center Tábor,
- Shopping center Třebíč – Stařeč,
- Shopping center Zlín.

Following figure (Fig. 2) shows the specific delivery points on a map of the Czech Republic.

Objective of the solved problem

The task of the given problem is especially to optimize:

- Number of vehicles,
- Distances of individual routes.

Everything must be done so that the sum of the lengths of routes for all vehicles is minimal and meets all specified requirements. In order to make a calculation, it is necessary to know the following parameters [8,14,18,19]:

- Average vehicle speed on the network [c = 65 (km/h)],
- Time period required for cargo unloading [t = 0.5 h],
- Time period of stay outside the starting point V_0 [T = 16 h],
- Vehicle capacity [C_V = 24 tons],
- Amount of goods transported from place V_0 to V_i.

Data about the amount of transported goods from the starting point to individual centers are summarized in other steps of calculations, specifically in subchapter with the title "Compilation of the initial solution" (see Tab. 2).

Compilation of the distance matrix D

In regard to this method, elements are ordered so that the furthermost nodes from the starting node are in the first place, i.e. Pilsen, which is the furthermost place from the starting node Šlapanice, is placed first in the table.

The distance matrix D is compiled in the following Table 1.

Compilation of the initial solution

In the next step of the solved method, it is necessary to compile a table of initial solutions which include the total number of routes. This table also contains the value of q_i which is goods quantity unit required at a particular place.

Furthermore, the route distance, both in one direction as well as the route distance which is equal to the sum of a distance of routes from a starting point to the place of shopping center and back indicated in total kilometers, are summarized in the table.

On the basis of the average speed, the following values are also specified [1,7,18,25]:

- Time t_i from the starting point to individual operation places and back,

Fig. 2. Map of the specific delivery points [authors]

Table 1. Distance matrix D [authors]

km (i/j)	PL	ST	CB	TA	JH	HU	ZL	TR	BY	PR	PR-R
Šlapanice	317	239	197	174	145	118	94	80	65	58	58
Pilsen (PL)	0	97	149	127	170	180	405	233	270	370	370
Strakonice (ST)		0	60	68	113	126	330	180	207	297	297
Č. Budějovice (CB)			0	60	52	109	287	117	174	247	247
Tábor (TA)				0	48	60	260	118	143	223	223
J. Hradec (JH)					0	56	235	68	122	195	195
Humpolec (HU)						0	207	60	70	167	167
Zlín (ZL)							0	170	150	66	66
Třebíč (TR)								0	56	137	137
Bystřice n. P. (BY)									0	80	80
Prostějov (PR)										0	0
Prostějov – R (PR-R)											0

Table 2. Overview of initial solution with the required data values [authors]

Route	q_i (pcs)	Route distance from V_0 to V_n	Route distance from V_0 to V_n and back	Time t from V_0 to V_n (h)	Time t_{ij} (h)	Time t_m (h)	Time T (h)
V_0-BY-V_0	6,400	65	130	1	2	0,5	2.5
V_0-CB-V_0	4,500	197	394	3.03	6.06	0.5	6.56
V_0-HU-V_0	7,400	118	236	1.82	3.63	0.5	4.13
V_0-JH-V_0	2,000	145	290	2.2	4.46	0.5	4.96
V_0-PL-V_0	2,300	317	634	4.88	9.75	0.5	10.25
V_0-PR-V_0	6,200	58	116	0.89	1.78	0.5	2.28
V_0-PR-R-V_0	2,000	58	116	0.89	1.78	0.5	2.28
V_0-ST-V_0	3,500	239	478	3.68	7.35	0.5	7.85
V_0-TA-V_0	1,100	174	348	2.68	5.35	0.5	5.85
V_0-TR-V_0	2,500	80	160	2.23	2.46	0.5	2.96
V_0-ZL-V_0	7,100	94	188	1.45	2.89	0.5	3.39

- Time t_m which is the time required for unloading,
- Total time T (sum of driving time and time of cargo unloading).

The following table (Table 2) of initial solution includes an overview with the specific required data.

As mentioned above, these parameters are required for calculation (1) of average vehicle speed on the network – c = 65 (km/h), (2) time period required for cargo unloading [t = 0.5 h], (3) time period of stay outside the starting point V_0 [T = 16 h], (4) vehicle capacity [C_V = 24 tons = 24000kg] and (5) amount of goods transported from place V_0 to V_i (see Table 2).

Obtained results

Precisely according to the steps of this method procedure, it is necessary to identify the route for each iteration (specifically for our case study, we have to perform 12 iterations). It is also important to determine the admissibility of these routes. Actually, by using individual iterations, we perform de facto the optimization calculation of the most favorable routes [9,19,25].

1. iteration:

- The furthermost place from the starting point Šlapanice = Pilsen,
- The closest place near Pilsen = Strakonice.

Thus, the resulting route for the first iteration is: Šlapanice – Pilsen – Strakonice – Šlapanice.

Driving time is calculated as follows (Equation 1 – values are obtained from Table 1):

$$317 + 97 + 239 = \frac{653}{65} = 10.05 \text{ (h)} \tag{1}$$

Time of cargo unloading (t) is calculated as follows (Equation 2):

$$t = 2 * 0.5 = 1 \text{ (h)} \tag{2}$$

Time period of stay outside the starting point V_0 [T] and the vehicle capacity [C_V] are calculated as follows (Equations 3 and 4):

$$T = 10.05 + 1 = 11.05 < 16\ (\text{h}) \tag{3}$$

$$C_v = 2300 + 3500 = 5800 < 24000\ (\text{kg}) \tag{4}$$

The route is admissible because it does not exceed limit values of T and C_v.

As mentioned above, using 2–12th iterations, optimization calculation of the most favorable routes is performed subsequently. The overall process of solving this issue applying the Mayer method provided two resulting routes which are optimal with respect to the calculation procedure [5].

The resulting routes:

- Route No. 1 is: Šlapanice – Pilsen – Strakonice – České Budějovice – Jindřichův Hradec – Humpolec – Třebíč – Šlapanice
- Route No. 2 is: Šlapanice – Tábor – Bystřice nad Pernštejnem – Prostějov – Prostějov – R. – Zlín – Šlapanice.

Evaluation of routes using the Mayer method in km:

Route No. 1 distance =
= 317 + 97 + 60 + 52 + 56 + 60 + 80 = 722

Route No. 2 distance =
= 174 + 143 + 80 + 0 + 66 + 94 = 557

Total distance = 722 + 557 = 1279 km

Given the fact that transport is provided exclusively by external carriers, a transport model suitable for own distribution (delivery) activities is proposed. In relation to the original transport model, where external carriers are used, a number of traveled kilometers during uncoordinated routes is 3090 km. Thus, in terms of operation, the proposed model is significantly cheaper compared to the model with external carriers.

As for the charge of CZK 44 per 1 traveled km, the price for the uncoordinated model is CZK 135960 per week, while costs for the model with two distribution routes are CZK 56276 (1279 * 44).

CONCLUSIONS

1. As above mentioned, for the current state of goods deliveries (uncoordinated model of the distribution system), distribution costs for using external carriers are at the value of CZK 135960 per week. If we take into consideration the proposal for regular distribution by internal transport, distribution costs will reduce at the value of CZK 56276 per week.
2. Thus, distribution costs would be reduced, however, considering the need to purchase special vehicles, it is necessary to calculate the procurement costs for their purchase yet. Due to the fact that regular delivery of goods to the shopping centers will be required, it would be advantageous to implement own internal transport. Regular deliveries of goods in particular wood company are expected because of the necessity to respond to customer requirements immediately and goods cannot be stored at individual centers for a long time.
3. Considering ten years of vehicles depreciation, even with the inclusion of buying two new vehicles, operation for the coordinated routes will be economically more advantageous. From a long-term point of view, operational costs for the coordinated routes, in comparison with external carriers, will be CZK 116426 per week and for external carriers CZK 135960.
4. Thus, internal transport would be about CZK 19534 per week cheaper. For the purpose of calculations, the purchase price of CZK 5000000 for a new articulated vehicle was taken into account.
5. It can be concluded that the use of optimization techniques and methods is not purely academic interest, however, their use is appropriate and reasonable even in practice.

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