VEHICLE ROUTING PLANNING IN KOPOS KOLÍN COMPANY

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Abstract

Route planning currently deals with an increase in demands that must be satisfied swiftly and at the lowest possible costs. This is also the case with KOPOS Kolín Company, which is one of the largest manufacturers of electrical installation materials. This company uses its own trucks to transport goods to various locations. Before the planning phase, it is necessary to take into account the available transport capacities and the wide portfolio of products offered, with different ranges of dimensions, shapes and weights. In general, transport tasks require a lot of processing time as well as the resources needed for calculation. Overall, this means that each plan is specific and must have a unique approach based on the requirements. Due to the computational complexity of vehicle routing problems, heuristic algorithms are necessary to be used to obtain a suitable solution to the problem. The aim of this paper is to use a heuristic algorithm based on the insertion method, and to develop an application in VBA for MS Excel which KOPOS company can use for daily route planning. The advantage of the application is the saving of company's financial resources without the additional cost of special optimization software.

Keywords: Vehicle routing problem, heuristics algorithms, VBA for MS Excel, API key

1. INTRODUCTION

Planning is undoubtedly one of the greatest challenges facing humanity today. It is not an individual problem, but a problem for society. Planning is the daily business in which we live, but it is also linked to transport between the places where activities take place. The importance of planning is not only for a short period of time, but it has been essential since the time of the first routes in ancient Rome, the easiest connection between major places, ports and cities, including overcoming obstacles by bridges, viaducts etc. The creation of road networks had the main role in providing the necessities for development, expansion, trade and military bases including fast movement between them, but minimizing the costs and time on the other side [1]. The development of the road network was supported continuously. The first use of optimization was by Leonhard Euler in 1736, who was given the task of finding a closed path across seven bridges in the city of Königsberg, crossing each of them exactly once [2]. Over the last few decades, route planning has become a standard part of the everyday business. There are many reasons for its use, especially in production or logistics, with an impact on increasing profitability in the form of additional sales or savings.

From a logistical point of view, the distribution sector can be divided into two main streams: firstly, coordinated transport for several companies, where vehicles are hired for a specific service. The other is the opposite, where companies use their own vehicles to transport goods to their customers. Both ways have many advantages, disadvantages and problems, but at least one is common - cost efficiency. The solution to this problem is simple: increase capacity utilization and minimize route distance, which could lead to a reduction in the number of routes needed to fulfil customer orders. The potential of the availability of software to apply methods to find an optimal solution for given tasks has been expanded in recent years. It offers a wider range of applications and the opportunity to save costs and time.

The aim of the article is to describe the application of the method of route planning within a VBA for MS Excel on the basis of data provided by the KOPOS Kolín company. The data were previously used for transport to customers, which gives an opportunity to compare real and software routes.

2. METHODOLOGY

There are many ways to plan routes, such as the famous Travelling Salesman Problem. A well-known problem that focuses on finding the shortest route for a business traveller who starts his route from a starting point and has to visit n only once and then return. It is one of the most widely studied optimization problems in operations research and forms the backbone of the transport, logistics and planning industries [3-5]. In the case where the customers want an order to be delivered from the distribution center or for more complex tasks, it is advisable to use the Vehicle Routing Problem (VRP).

VRP is one of the most important applications in logistics management. The first distribution task was introduced in 1959 [6], where the authors' goal was to increase the reaction time of logistics movements [7]. The distribution problem is concerned with determining the optimal set of routes that a company should take with a given fleet of vehicles to serve the desired customers. It is one of the most important and studied optimization problems [8]. In the General Vehicle Routing Problem, a set of customer requests is considered as locations to be served by the same vehicle in a particular order [9]. Various modifications of VRP have occurred with the growth and development of logistics and based on the area where this method is used in, e.g. Vehicle Routing Problem with Time Windows [10], Electric Vehicle Routing Problem [11] or Heterogeneous Vehicle Routing Problem (HVRP) [12]. The last one is crucial for this article.

HVRP, where an unlimited fleet with equal or different truck capacities is used. This problem determines the fleet composition and routes based on the fixed costs of each vehicle [13]. Heterogeneous fleets are mostly used by logistics companies due to their flexibility based on demand and available capacities, which leads to minimization of operating costs [14]. Mathematical model of HVRP with K types of vehicles with capacities V_k $(k = 1,2, \dots, K)$ [15]:

Minimize:

$$z = \sum_{k=1}^{K} \sum_{i=1}^{n} \sum_{j=1}^{n} d_k c_{ij} x_{ij}^k , \tag{1}$$

subject to:

$$\sum_{k=1}^{K} \sum_{j=1}^{n} x_{ij}^k = 1, \qquad i = 2,3, \dots, n, \tag{2}$$

$$\sum_{i=1}^{n} x_{ij}^k = \sum_{i=1}^{n} x_{ji}^k , \qquad j = 1,2, \dots, n, \qquad k = 1,2, \dots, K, \tag{3}$$

$$\sum_{j=2}^{n} x_{1j}^k \leq p_k \qquad k = 1,2, \dots, K, \tag{4}$$

$$u_i + q_j - \bar{V}\left(1 - x_{ij}^k\right) \leq u_j, \qquad i = 1,2, \dots, n, \quad j = 2,3, \dots, n, \quad k = 1,2, \dots, K, \tag{5}$$

$$u_i \leq \sum_{j=1}^{n}\sum_{k=1}^{K} x_{ij}^k V_k \qquad i = 1,2,\dots,n, \tag{6}$$

$$u_1 = 0, \tag{7}$$

$$x_{ij}^k \in \{0,1\}, \qquad i,j = 1,2,\dots,n, \qquad k = 1,2,\dots,K, \tag{8}$$

$$u_i \in R_+, \qquad i = 2,3,\dots,n. \tag{9}$$

In the model, d_k is a cost coefficient determined on the basis of vehicle consumption. The value $\bar{V}$ [m³] is equal to the maximum capacity of all vehicles. The value p_k represents the number of available vehicles of the k-th type. The coefficient c_{ij} [km] corresponds to the distance between locations i and j. The total demand ofthe j-th customer is denoted by q_j [m³]. In the model, the binary variables are x_{ij}^k, where k defines the vehicle type index. The value 1 represents the direct route between nodes i and j, otherwise the value is 0, which defines that there is no route between two locations. The objective function (1) represents the total travelling cost [CZK] for all the vehicles that are used. Constraint (2) prevents all locations from being visited more than once, except for the starting point, to which the vehicles must return. The system of equations (3) is included in the model to avoid situations where a different vehicle leaves a node than enters it. The maximum number of vehicles of a given capacity [m³] that can be assigned to each route is given by condition (4). Inequalities (5) prevent the creation of partial cycles and define the load balance. To satisfy condition (6), the capacity [m³] of all vehicles must be respected. Constraint (7) defines a zero load [m³] at the starting point for all routes.

Due to the computational complexity of VRP [16], heuristic methods are used for route planning. In this article, the insertion heuristic is used due to the need to satisfy several specific requirements that must be included in the algorithm. The insertion heuristic is simple and has many variants. The basic one starts with a tour of a subset of all nodes, then the rest is inserted by some other heuristics [17].

In the heuristic algorithm, the following notation is used. U_k^* is the sequence of locations generated for the route of the k-th vehicle, u_i^k is the i-th element of the sequence U_k^*, U_k is the set of previously unassigned locations that can be inserted into the route of the k-th vehicle. Furthermore, V_k is the capacity [m³] of the k-th vehicle, and G_k [m³] is its load value, which consists of the requirements [m³] of each location g_h $(h = 2,3,\dots,n)$. The algorithm consists of the following steps [15]:

Step 1: For $k = 1,2,\dots,K$ set $U_k = \{2,3,\dots,n\}$ a $G_k = 0$.

Find $(c_{1s} + c_{s1}) = \max\limits_{\substack{v \in U_1 \\ G_k + q_v \leq V_k}} (c_{1v} + c_{v1})$;

Set $U_1^* = \{1, s, 1\}$; $G_k = G_k + q_s$; $z_1 = (c_{1s} + c_{s1})$; $U_1 = U_1 - \{s\}$.

For $k = 2,3,\dots,K$ set:

$U_k = U_k - \{s\}$.

Step 2: For $k = 2,3,\dots,K$ repeat:

find $\sum_{p \leq k-1}(c_{i_2^p s} + c_{s i_2^p}) = \max\limits_{\substack{v \in U_k \\ G_k + q_v \leq V_k}} \sum_{p \leq k-1}(c_{i_2^p v} + c_{v i_2^p})$;

set $U_k^* = \{1, s, 1\}$; $G_k = G_k + q_s$; $z_k = (c_{1s} + c_{s1})$; $U_k = U_k - \{s\}$;

for $i = 1,2,\dots,K, i \neq k$ set:

$U_i = U_i - \{s\}$.

Step 3: Set $\Delta z = \infty$.

For $k = 1,2, \dots, K$ repeat:

for all $r \in U_k$ repeat:

find $\Delta z_{rj} = \min\limits_{\substack{i=1,2,\dots,|U_k^*|-1 \\ G_k+q_r \le V_k}} \left(c_{u_i^k,r} + c_{r,u_{i+1}^k} - c_{u_i^k,u_{i+1}^k} \right)$.

If $\Delta z_{rj} < \Delta z$ then

set $\Delta z = \Delta z_{rj}; v = r; w = j; m = k$.

To sequence U_m^*, add node v behind element u_w^m.

Set $U_m = U_m - \{v\}; G_m = G_m + q_v; z_m = z_m + \Delta z; z = z + \Delta z$.

For $k = 1,2, \dots, K, k \neq m$ set:

$U_k = U_k - \{v\}$.

Step 4: If $U_k = \emptyset$ for $\forall\, k = 1,2, \dots, K$ then follow step 5,

otherwise, if $\Delta z = \infty$ then set $K = K + 1$ and follow step 1, otherwise, follow step 3.

Step 5: End.

The algorithm is demonstrated in the following graphical solution, which contains a green starting point 1 and six blue nodes 2, 3, …. 7 to be served by three vehicles. In the first step, the location furthest from the depot whose demand does not exceed the capacity [m^3] of the k-th vehicle is found and marked as the first route, for which a sequence $U_1^* = \{1, 5, 1\}$ is created. In the second step of the algorithm, the initialization of the routes for the remaining vehicles begins by including in their routes the locations furthest from the nodes that are already involved in the previous routes (**Figure 1**). This creates the routes U_k^* from the starting point for all three vehicles.

In a third step, additional locations are progressively added based on minimizing the extension of existing routes. Within each route k, the node r that would be inserted after the location u_j^k on that route is determined. The one with the minimum extension [km] is then selected from all the routes. The selected node is denoted by the index v, and the index u_w^m denotes the node after which it is inserted. The given route is denoted by the index m. The location v is then excluded from all sets U_k. In the fourth step, it is checked whether all the locations are included in the routes. If they are, the algorithm terminates. Otherwise, it continues with step 3. **Figure 2** shows the result of the routes plan.

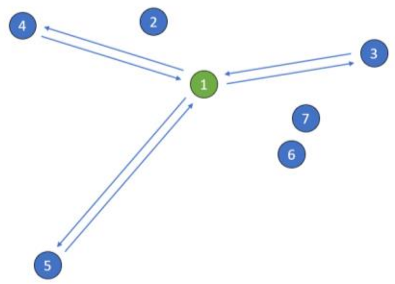

Figure 1 Initialization of the routes of all vehicles

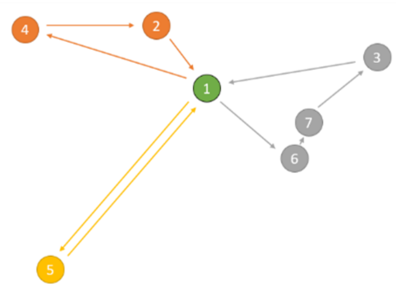

Figure 2 Complete routes

3. APPLICATION OF ALGORITHM

The algorithm is prepared for specific requirements and created at the request of the KOPOS Kolín Company for its best application. This company is a producer of electrical installation materials that are mostly made of plastic. The available fleet consists of 10 vehicles that can be used for transport. The following conditions must be met in the algorithm:

- Their products, e.g. wiring tubes or boxes, usually have free space in between the packaging. They are also lightweight. Within the algorithm, it is more important to use the volume index [m^3] rather than the weight [kg] as vehicles are usually not fully loaded based on the weight factor. The volume index is multiplied by a coefficient 1.25, which ensures that the vehicle's capacity [m^3] isn't exceeded.
- Each vehicle has a different capacity [m^3].
- The model must reflect an unloading time of 30 minutes per customer.
- Shift time of 9 hours per day, with the possibility of extending to 10 hours per day twice a week.
- The maximum number of customers served within a route is set at 5. In general, the further a vehicle is from the depot, the fewer customers it can serve.

The working system used is based on the usual routes that are most suitable, but the system takes a long time to pinpoint every detail because the logisticians have no algorithm to help them. What takes tens of minutes, a system can help even in tens of seconds. The algorithm uses VBA for MS Excel. First, the input data is transformed to a simple format, keeping only the necessary information (number, date, time, volume [m^3] and addresses of orders). In the next step, the locations are formed into distance [km] and time matrices [min], which are filled based on the algorithm of Chandoo [18], working in cooperation with the API keys of the Google Maps [19] and MS Excel. API keys allows communication between two applications. The third part continues with the filled matrices based on the explained algorithm. The heuristic algorithm is applied, and a feasible solution is found.

4. COMPARISON OF RESULTS

The real data is based on the routes performed in the Czech Republic during one day in 2022. A total of 19 customers were served on 6 routes using 5 trucks and 1 van. Their total loading capacity is 556 m^3, while the sum of all requirements gives a total load of 163.03 m^3. The time available for the transport is 600 minutes. For the purposes of comparison, it should also be noted that the distances and transport times obtained from Google Maps may differ from the actual GPS data. This can be caused by maintenance such as refuelling, operations and other activities that increase distance and travel time. These factors are not included in any of the maps as they are unpredictable and cannot be reliably planned for. To eliminate this difference, the same data from Google Maps is used to compare real data with the proposed system. **Table 1** gives a detailed summary of each of the routes with real data.

The proposal, **Table 2**, gives an overview of a schedule containing five routes after applying the algorithm. The number of nodes included is 19, which means that all customers have been served. The most important point is that the capacities of the vehicles and the maximum available time are not exceeded. As the plan consists of one route less, there is an opportunity to use the vehicles more efficiently. It takes about 2 minutes to find this feasible solution.

Table 3 shows the comparison of the real and proposed routes. The total distance needed to serve all nodes in the real situation was 2,601.58 kilometers and 2,693.28 minutes. The proposed solution needs additional 59.41 kilometers and 61.19 minutes to meet the same criteria. However, it is possible to serve all nodes with 5 vehicles.

Table 1 Overview of real routes

Route 1	Route 2	Route 3	Route 4	Route 5	Route 6
Number of locations (*incl. 2x starting point*)					
5	6	5	6	4	5
Capacity [m^3]					
18.88	102	102.06	102.06	115.61	115.61
Load [m^3]					
5.77	10.68	14.46	22.72	99.48	9.92
Total distance [km]					
538.82	483.87	275.83	219.04	581.12	502.89
Total time [min]					
534.74	489.18	293.70	327.09	576.97	471.60
Plan of the route					
1	1	1	1	1	1
13	20	11	9	10	8
18	5	12	3	17	6
4	7	19	14	1	2
1	15	1	16		1
	1		1		

Table 2 Overview of proposed routes

Route 1	Route 2	Route 3	Route 4	Route 5
Number of locations (*incl. 2x starting point*)				
7	6	5	6	5
Capacity [m^3]				
18.88	102	102.06	102.06	115.61
Load [m^3]				
13.13	10.68	14.25	25.13	99.83
Total distance [km]				
591.75	479.25	568.37	529.35	492.27
Total time [min]				
575.78	484.51	581.18	542.65	570.34
Plan of the route				
1	1	1	1	1
13	20	12	9	10
2	5	19	8	3
16	7	17	14	11
18	15	1	6	1
4	1		1	
1				

Table 3 Comparison

Comparison	Real data	Proposal
Number of routes	6	5
Number of customers	19	19
Total distance [km]	2,601.58	2,660.99
Total time [min]	2,693.28	2,754.47
Difference of proposal:		
Distance [km]	+59.41	
Time [min]	+61.19	

5. CONCLUSION

There is no doubt that transport planning is beneficial. There are approaches that can address this issue, or at least help to shape it. These include vehicle routing problems, which can be modified to find new environments in which they can be applied. For more complex tasks, the use of heuristic algorithms is appropriate. Without appropriate tools or systems, working with information and schedules is very complex and time-consuming, but this can be significantly reduced and improved. In this article, VBA for MS Excel is a crucial tool for the application of prepared and explained heuristic algorithm. An equally important element is the Google Maps API key. It allows to calculate distances between addresses, including travel times. Data from KOPOS Kolín Company are used to compare the real situation with the solution provided by the algorithm. The result is that in this case it is possible to reduce the number of routes by one. The system itself cannot calculate with possible events that may occur during a route, but people can predict them better. Therefore, the system has a great advantage in reducing the time needed to prepare a plan, but still requires human supervision.

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