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Route optimization of Muafakat Johor bus service

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ABSTRACT

Muafakat Johor Bus Service is a service provided by the Johor State Government for free to all citizens. The aim of this service is to reduce the cost of living and also to facilitate and improve the quality of public transport services to citizens in the routes that have been identified. Therefore, any reduction in the operation cost of this bus service will be of help to the government. On the other hand, in order to improve the quality of public transport services, the bus is expected to arrive at the respective stops at the time specified by the schedule. It is seen that one way of achieving these goals is through the route design of the bus service. Thus, in this study, Vehicle Routing Problem with Time Window (VRPTW) is used to model the route of Muafakat Johor bus service under consideration. The model was solved by using LINGO which is an efficient software for solving optimization models. The optimal route is obtained with the optimal number of buses is two. By considering the time window constraint, the current practice of one bus covering all the stops is found to be infeasible.

Keywords: Bus Service; Vehicle Routing Problem with Time Window; Route Design.

1. INTRODUCTION

Vehicle Routing problem is an important research area which has been widely studied in Operations Research domain. An example of the problem is where the vehicle routing is needed to plan systematic schedule for a fleet of buses to pick up the passenger from one point to another and deliver them to a specific place based on the demand of the passenger. In Johor, free bus service is provided for all Malaysia citizens by the Johor state government and all of these buses are named as Muafakat Johor bus. The purpose of this service is to reduce the living cost of the citizen and improve the quality of public transport services based on the routes that have been identified.

The paper is organized as follows. In Section 2, we provide the literature review consist of basic definitions and some generalizations of the VRPTW. Section 3 briefly explains the application of the VRPTW to Muafakat Johor bus. The result and discussion are presented in Section 4. Lastly, in Section 5, concluding remarks are summarized.

2. LITERATURE REVIEW

Vehicle Routing Problem (VRP) is the early version of the problem, where the objective is to minimize the total cost of routes only [1]. Now, we consider the Vehicle Routing Problem with Time Windows (VRPTW), which is a generalization of the VRP where the service at any consumer starts within a certain time interval, called as time windows [2]. From [3], VPRTW is a service of customer in which involved pickup and deliver the passenger begin within the time window which can be defined as the earliest time and the latest time when the customer will be permitted to begin the service.

The VRPTW was obtained by extending the VRP with adding the time windows constraint which can be described as the problem of designing least cost routes from one depot to a set of geographically scattered points. The routes must be designed in such a way that each point is visited only once by exactly one vehicle within a given time interval, all routes start and end at the depot, and the total demands of all points on one particular route must not exceed the capacity of the vehicle [4]. The Vehicle Routing Problem with Time Windows (VRPTW) is an important problem occurring in many distribution systems.

The VRPTW can be defined as follows. Let $G = (V, C)$ be a connected digraph consisting of a set of $n+1$ nodes, each of which can be serviced only within a specified time interval or time window and a set A of arcs with non-negative weights representing travel distances with associated travel times. Let one of the nodes be designated as the depot. Each node i, except the depot, request a service of size q_k [5]. A vehicle is permitted to arrive before the opening of the time window, and wait at no cost until service becomes possible, but it is not permitted to arrive after the latest time windows [6].

In most of the surveyed papers, the objective is to find the minimum number of tours, K^*, for a set of identical vehicles such that each node is reached within its time window and the accumulated service up to any node does not exceed a positive number Q(vehicle capacity). A secondary objective is often either to minimize the total distance travelled or the duration of the routes. All problem parameters, such as customer demands and time windows, are assumed to be known with certainty. Moreover, each customer must be served by exactly one vehicle, thus prohibiting split service and multiple visits. The tours correspond to feasible routes starting and ending at the depot [4].

Some of the most useful applications of the VRPTW include bank deliveries, postal deliveries, industrial refuse collection, national franchise restaurant services, school bus routing, security patrol services, and just in time manufacturing [7]. Motivated by these works, this study focuses on modelling Muafakat Johor bus service as Vehicle Routing Problem with Time Window (VRPTW) to seek the optimal route in improving the bus service.

3. APPLICATION OF VRPTW

3.1 Problem Formulation

In Johor, free bus service is given to all Malaysia citizens for mobility to go to work or any place around Johor every day. The fee will be charged only for renewal of the Muafakat Johor bus card once per year. The fixed schedule of the buses is produced by Perbadanan Pengangkutan Awam Johor (PAJ). The operation and management of the bus service also handled by PAJ and supervised by Johor state government.

There are 30 buses provided for the trips all around Johor. But in this research, we just focus on Majlis Perbandaran Johor Bahru Tengah (MPJBT) region only. These services operate between 6.00 am and 10.00 pm for the convenience of the passengers. Muafakat Johor buses trips are divided into 15 different routes to cover the entire trips all around Johor. In this work, we consider to optimize one trip only. The nodes in our problem start from Terminal Bas Taman Universiti as the depot, followed by Fakulti Alam Bina UTM, Jalan Teratai, Jalan Pulai, AEON Taman Universiti, U-Mall and Pulai Perdana as the bus stops. There are two buses provided to rotate on this trip. Table 1 shows that the node that has been considered in this research.

Table 1 Nodes and bus stops

Node	Bus stop
1	Terminal Bas Taman Universiti
2	Fakulti Alam Bina UTM
3	Jalan Teratai
4	Jalan Pulai
5	Aeon Taman Universiti
6	U-Mall
7	Pulai Perdana

Figure 1 shows the map of Muafakat Johor bus route area presented using ARCGIS software. Using VRPTW we are trying to find the solution so that the route will be optimized with minimum cost and at the same time will deliver passengers within the time specified in the schedule.

Figure 1 Map of Muafakat Johor bus route area

3.2 Data

ARCGIS can be used to give us the distance. Thus, first we digitize the roads in Muafakat Johor bus route area in order to obtain the distance between each node. All the data for digitizing are obtained from Google Maps and transferred to ARCGIS. The result that we obtain is shown in Figure 2.

Figure 2 Map of digitized roads in Muafakat Johor bus route area

The data of the distance between each bus stop created using ARCGIS software is presented in Table 2. It can be seen that the data of the distance between nodes is actually a symmetric matrix. The unit of the distance is in kilometer. For $i=j$ we need to insert a large value so that it can be read in LINGO.

Table 2 Distance between node *i* to *j*

Node i/j	1	2	3	4	5	6	7
1	9999	3.5	5.1	4.4	1.2	2.2	5.4
2	3.5	9999	1.6	0.9	2.3	1.3	1.9
3	5.1	1.6	9999	0.7	3.9	2.9	0.3
4	4.4	0.9	0.7	9999	3.2	2.2	1
5	1.2	2.3	3.9	3.2	9999	1	4.2
6	2.2	1.3	2.9	2.2	1	9999	3.2
7	5.4	1.9	0.3	1	4.2	3.2	9999

In our case, we can see that the most important data that will help us to get the optimal route is distance, the quantity of demand and time window. Thus using ARCGIS help us to gain one of the crucial parts of this research. As for the demand and time interval from one node to another, the data is obtained using our real-life observation.

As for the capacity and speed of each buses, the data was obtained from the bus driver. Each of the bus can only accommodate up to 40 passengers and the maximum speed of the bus is 60 km/h. The travel time is used to set the time window. The data was collected by travelling from one node to another. The data of start and end time for the customer at node *i* and also the service time is presented in Table 3.

Table 3 Start, end and service time on each node

Node(i) / Time(min)	1	2	3	4	5	6	7
Start	0	38	27	32	8	13	20
End	2	40	29	34	10	15	22
Service	8	9	4	7	5	7	7

3.3 The Mathematical Model Of Muafakat Johor Bus Routing Problem

We want to construct a set of minimal cost routes, one for each vehicle, such that each customer is visited exactly once, where every route originates at vertex 1 and ends also at vertex 1, the time windows and the capacity constraints are observed. Thus, the objective function can be formulated as below

$$min \sum_{k=1}^{2} \sum_{i=1}^{7} \sum_{j=1}^{7} c_{ij} x_{ijk} \tag{1}$$

To make sure every passenger will be visited only once, the first constraint is

$$\sum_{k=1}^{2} \sum_{j=1}^{7} x_{ijk} = 1 \ \forall i \in C \tag{2}$$

Now we want to make sure that all buses can be loaded up not exceeding their capacity, the constraint as below

$$\sum_{i=1}^{7} d_i \sum_{j=1}^{7} x_{ijk} \leq q_k \ \forall k \in V \tag{3}$$

To ensure that each of the buses leaves the depot 1. Thus the fourth constraints are

$$\sum_{j=2}^{7} x_{1jk} = 1, \qquad \forall k \in V \tag{4}$$

After the bus arrived at the customer, the bus will leave again. Thus, we apply the constraints as below

$$\sum_{i=1}^{7} x_{ihk} - \sum_{j=1}^{7} x_{hjk} = 0, \qquad \forall h \in C, \forall k \in V \tag{5}$$

To make sure all of the buses need to arrive at depot 1, we apply the fifth constraint

$$\sum_{i=2}^{7} x_{i1,k} = 1, \qquad \forall k \in V \tag{6}$$

For the allocation of time windows, we apply the constraint below

$$t_{ik} + s_i x_{ijk} - M\left(1 - x_{ijk}\right) \leq t_{jk}, \forall i,j \in N, \forall k \in V \tag{7}$$

If the bus visits customer *i*, it must be in the time window

$$a_i \leq t_{ik} \leq b_i, \qquad \forall i \in N, \qquad \forall k \in V \tag{8}$$

For all the variable to be binary, we apply the last constraints

$$x_{ijk} \in \{0,1\}, \qquad \forall i,j \in N, \qquad \forall k \in V \tag{9}$$

4. RESULT AND DISCUSSION

After implementing the model into LINGO software, optimal solution was found. Given figure 3 are the results from LINGO.

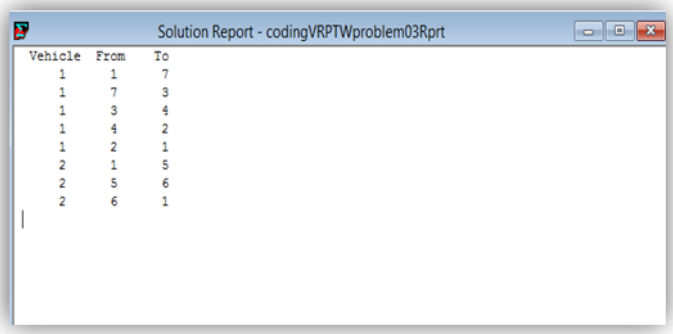

Figure 3 Result from LINGO software

The result obtained shows that the route for the first bus is 1 – 7 – 3 – 4 – 2–1 that is from Terminal Bas Taman Universiti (depot) to Pulai Perdana then Jalan Teratai then Jalan Pulai then Fakulti Alam Bina UTM and head back to the depot. While for the second bus, the route is 1 – 5 – 6 – 1 that is from Terminal Bas Taman Universiti followed by AEON Taman Universiti and U-Mall then head back to the depot.

By comparing with the previous total distance for two buses which is 29.2 km, the distance has decreases up to 14 km using this route. By this, we can conclude that the cost has been reduced using the given distance. Using this route the distance has been decreasing since the number of stops is reduced. In addition, if this route is implemented the bus manages to arrive at every stop within the allocated time interval. It will be total advantages to the passenger as they can spend less time on the bus. Same goes for the second bus where the route where the distance of the route already decreased. At the same time, the number of stops reduced to two stops only. Thus it helps to reduce the service time. Therefore, the passenger will have quicker time travel on the bus.

Hence if this route is established, it will be an advantage to the passenger and also the government and PAJ. The passenger will spend less time on the bus as well as helping them to arrive earlier to any place they want to go. As for PAJ, the less distance travelled means less cost incurred. Not only that, the number of buses needed to cover the route will be only two. Thus it will also help to reduce the total number of buses use. However, if the number of the bus is one, the solution will become infeasible since it cannot arrive at the stops within the time windows and if we consider the number of buses more than two, then higher cost needed to operate the buses. We can conclude in order to achieve an optimal solution, the number of buses must be two.

5. CONCLUSION

The main objective of this research is to model and solve the VRPTW problem involving the Muafakat Johor bus routing problem in order to minimize the distance travelled by bus. Our hypothesis is that by having an optimal bus route, Johor government and PAJ are able to reduce their operation cost. By solving the developed model, it provides us with the optimal route for the buses. Through comparison of the cost and time between the previous route and the new route, we can conclude that the new route obtained is more efficient and cost-effective as the shorter distance is travelled by the buses at the same time it reduces the travel time of the passenger in the bus. The optimal number of buses is obtained to be two. By considering the time window constraint, the current practice of one bus covering all the stops is found to be infeasible.

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