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An Application of Multiple Trip Vehicle Routing Problem with Time Windows on Blood Collection

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Abstract

Blood donation program in Malaysia is organized by Pusat Darah Negara (PDN). Since blood donations events are performed during operating hours and there is a processing time limit, one cannot wait until all the donations completed especially when many sites with different operation hours are involved. Continuous pickups from the donation sites must be scheduled. The time elapsed from extraction to laboratory delivery is limited and thus, several trips to each donation sites are needed. Thus, this paper aims to study multiple trip vehicle routing problem with time windows in order to provide the optimal route for blood collection from each donation sites. A Mixed Integer Linear Programming (MILP) model is proposed to solve this problem. The objective is to minimize the total traveled distance while fulfilling the time constraints and collection of every single unit available at the donation sites. Result shows that there is an optimal multiple trip route with minimized total travelled distances for this problem.
Keywords: Blood donation, multiple trips, vehicle routing problem with time windows.

Introduction

Malaysia nationwide requires about 2,000 units (450ml per unit) of blood per day whereas, the National Blood Centre (NBC) (known as Pusat Darah Negara (PDN) in Bahasa Melayu), demand of blood by 500 units daily [1]. In order to cater the blood demand, blood supply is generally obtained through voluntary donations or blood donor programs held mostly by PDN across the country [1]. Due to equipment required and the necessary storage conditions, the donated blood are then delivered to a PDN and processed there. Considering real life implementation, blood donation event is held only during a certain operation hours and blood extracted must be analyzed within 6-hour donation time due to blood perishability [2]. Due to different operation hour per donation sites, which some can operate up to 12 hours straight, one cannot wait until all donations completed. Several trips to each donation sites need to be done.

In this paper, we aim to minimize the travelling distance for multiple trips of blood collection while observing the time window constraints of donation sites and spoilage time constraint of the blood. The problem is modeled as Multi Trip Vehicle Routing Problem with Time Windows (MTVRPTW), a variation of the Vehicle Routing Problem (VRP), which is defined as the problem of designing the optimum delivery or collection routes from one or more depots to a number of geographically dispersed locations, subject to limiting constraints. A Multi Integer Linear Programming (MILP) model for MTVRPTW is developed based on real event of donation program organized by PDN and will be solved using LINGO.

Materials and methods

The data and method used in this study are discussed in this section. Related data including general information about the blood donation program along with list of donation sites and operation hours, as well as specifics amount of donated blood, service time and the associated expenditures are referred from PDN official website. The model for the MTVRPTW in this study was formulated based on model proposed in a study by [3] and [4].

Let $G = (N, A)$ where $N = \{0,1,2,..N\}$ is the set of nodes, node 0 corresponds to depot and $A = \{(i,j): i,j \in N\}$ and $i \neq j$ is the set of arcs. Donation sites set is denoted by $N_o = N\{0\}$; where the total blood collected per sites referred as Q_i . Travel time form node i to j using vehicle k is denoted as T_{ijk} and service time per node i is S_i. A_i is the opening time for node i, while B_i is the closing time at node i. W_k is the total travelling time for vehicle k. $k = (1,2,\ldots,K)$ is the set of vehicles with maximum capacity. Cap_k is the capacity of vehicle k. $r = \{1,2,\ldots,R\}$ is the set of routes of each vehicle. NRK is the total number of vehicles available times the total routes available. Total routes are set arbitrary and assumed the same for all vehicles since there is a working hour restriction limits the number of routes a vehicle can travel. D_{ijkr} is the total distance from node i to node j using vehicle k at route *r*. Dur_{ijk} is the travelling time from node i to node j using vehicle k. Y_{ikr} is 1 if customer is visited by vehicle k at route r that is obtained from T_{ij}, 0 otherwise. U_{ikr} is the load of vehicle k at route r after visiting customer i. X_{ijkr} is 1 if from customer i to customer j is assigned using vehicle k at route r.

The mathematical model for MTVRPTW is constructed as follows.

Objective function:

$$Min\ \sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{k=1}^{N} X_{ijkr}D_{ijkr} \tag{1}$$

subject to:

$$\sum_{k=1}^{K}\sum_{r=1}^{R} Y_{ikr} = 1\ , \forall_i \in N\{0\} \tag{2}$$

$$\sum_{k=1}^{K}\sum_{r=1}^{R} Y_{0kr} \leq 0 \tag{3}$$

$$\sum_{j=1}^{N} X_{ijkr} = Y_{ikr}, \forall_i \in N\,; k = 1,\ldots,K; r = 1 \tag{4}$$

$$\sum_{j=0}^{N} X_{ijkr} = Y_{ikr}, \forall_i \in N\,; k = 1,\ldots,K; r = 1,\ldots,R \tag{5}$$

$$\sum_{i=1}^{N} Q_i Y_{ikr} \leq Cap_k,\ \ \forall k = 1,\ldots,K; r = 1,\ldots,R \tag{6}$$

$$A_i \leq T_{ijk} \leq B_i \tag{7}$$

$$T_{ijk} + S_i \leq B_i \tag{8}$$

$$T_{ik} + S_i + Dur_{ijk} - T_{jk} \leq M\left(1 - X_{ijkr}\right), \forall i,j \in N, i \neq 0, k \in K \tag{9}$$

$$A_1 \leq W_k \leq B_1\, , \forall k \in K \tag{10}$$

$$\sum_{i \in N} T_{ijk}X_{i0kr} + S_i X_{i0kr} + Dur_{i0kr}X_{i0kr} = W_k \quad , \forall k \in K \tag{11}$$

$$W_k - \sum_{j \in N} X_{1jkr}T_{jk} \leq \tau \ \ , \forall k \in K \tag{12}$$

$$r_i \leq U_{ikr} \leq Cap_k\, , \forall i \in N, i \neq 0, k \in K \tag{13}$$

$$U_{ikr} - U_{jkr} + Cap_k X_{ijkr} \leq Cap_k\, , \forall i,j \in N, i \neq 1, j \neq 0, i \neq j, k \in K \tag{14}$$

$$Y_{ijkr} \in \{0,1\} \ \ , \forall i \in N; k = 1,\ldots,K, r - 1,\ldots,R \tag{15}$$

$$X_{ijkr} \in \{0,1\} \ \ , \forall i \in N; k = 1,\ldots,K, r - 1,\ldots,R \tag{16}$$

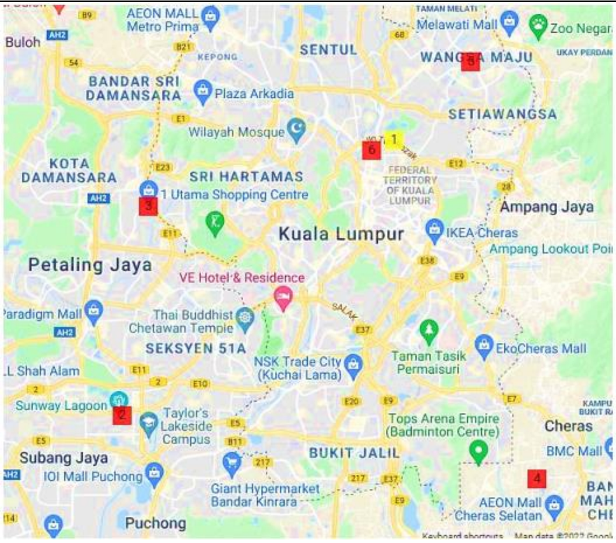
(17)

(18)

The objective function in (1) is to minimize the total distance travelled, while constraints (2) ensure that every node is visited only once. Constraints (3) show that the maximum number of routes and vehicles can be used. Constraints (4) and (5) guarantees the same vehicle and route enters and leaves a given nodes. Constraints (6) ensure that every trip does not exceed the vehicle capacity. Constraints (7) ensure that the vehicle arrived at each node must be within their respective opening and closing time. Constraints (8) restrict the arrival time of vehicle and service time at each node does not exceed its closing time. Constraints (9) make the time sequence of arrival of vehicle at node j is more than the time arrival at previous node added with service time at node i and travelling time from node i to node j. Constraint (10) ensure the total travelling time of vehicle does not exceed closing time of depot. Constraint (11) calculate the total travelling time per vehicle. Constraint (12) ensure vehicle to arrive at depot before blood spoilage time limit. Constraint (13) and (14) ensure there are no subtour. Constraints (15) and (16) define the solution space of the decision variables.

Results and discussion

Figure 1 shows the locations and coordinate for blood donation sites managed by Pusat Darah Negara (PDN). These locations have been frequently selected as blood donation sites within the selected area for this study. Table 1 shows the travel time from donation sites to Pusat Darah Negara and one another. Average travel time from one point to other is around 20-30 minutes. Table 2 shows different operation hours for each donation sites and PDN.



1. Pusat Darah Negara (3.173280, 101.706413)
2. Sunway Pyramid (3.07230, 101.60630)
3. Pusat Komuniti St John Ambulans Malaysia (3.14925, 101.61606)
4. AEON Big Bandar Tun Hussein Onn (3.04893, 101.75877)
5. AEON - Alpha Angle Wangsa Maju (3.20222, 101.734271)
6. Yayasan Keusahawanan Sosial(YKS) (3.16969, 101.69801)

Figure 1. Locations and coordinate for blood donation sites managed by Pusat Darah Negara (PDN)

Table 1: Travelling time (in minutes) between respective donations sites to central laboratory, Pusat Darah Negara (PDN) and one another.

Location	Pusat Darah Negara	Pusat Komuniti St John Ambulans Malaysia	Yayasan Keusahawanan Sosial(YKS)	AEON Big Bandar Tun Hussein Onn	AEON Alpha Angle Wangsa Maju	Sunway Pyramid
Pusat Darah Negara (PDN)	0	25	10	35	15	30
Pusat Komuniti St John Ambulans Malaysia	2	0	16	41	21	17
Yayasan Keusahawanan Sosial(YKS)	10	16	0	39	18	24
AEON Big Bandar Tun Hussein Onn	35	41	38	0	43	37
AEON - Alpha Angle Wangsa Maju	15	21	18	43	0	37
Sunway Pyramid	30	17	24	37	37	0

Table 2. Operation hours for Pusat Darah Negara (PDN) and each donation sites.

Location	Starting time	Closing time
Pusat Darah Negara (PDN)	7.30 AM	8.00 PM
Pusat Komuniti St John Ambulans Malaysia	11.00 AM	7.00 PM
Yayasan Keusahawanan Sosial (YKS)	9.00 AM	3.00 PM
AEON Big Bandar Tun Hussein Onn	11.00 AM	5.00 PM
AEON - Alpha Angle Wangsa Maju	11.00 AM	5.00 PM
Sunway Pyramid	10.00 AM	5.00 PM

The real service time has been at most 15 minutes or less at each site [3]. For convenience in computing the solution, service time is considered to be constant in this study, which is 15 minutes per donation site. Figure 2 illustrates the expected results of the optimal routes for blood collection from each donation sites. The routes for the 1st trip are PDN→ Yayasan Keusahawanan Sosial (YKS) → Pusat Komuniti St. John Ambulans Malaysia → Sunway Pyramid → AEON Big Bandar Tun Hussein Onn → AEON Alpha Angle Wangsa Maju → PDN with total time travelled is 2 hours and 13 minutes including service time. If trip 1 starts at 10.00am (1 hour after blood donation event at YKS starts), trip 1 will be completed by 1.00pm. Second trip is needed in order to collect the remaining blood package at each donation sites. For trip 2, the blood collection starts from PDN → YKS → AEON Alpha Angle Wangsa Maju → AEON Big Bandar Tun Hussein Onn → Sunway Pyramid→ Pusat Komuniti St John Ambulans Malaysia → PDN with total time travelled of 2 hours and 20 minutes including service time. To ensure every blood is collected, trip 2 is recommended to start at 3.00pm, considering all donation sites' crew will stay after closing time until all blood package is transferred to vehicle.

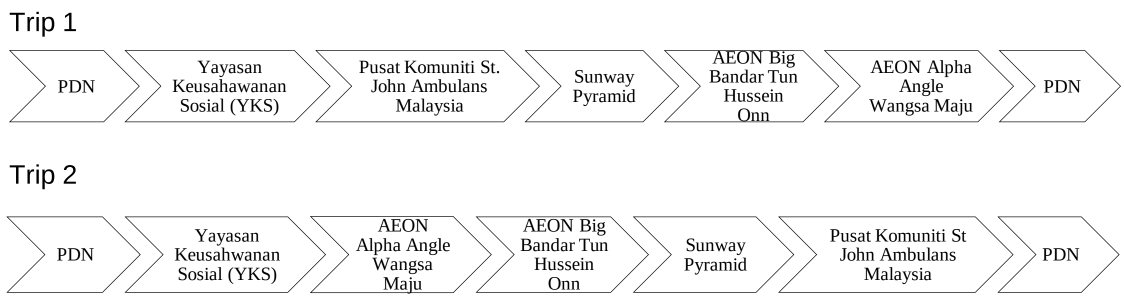


Figure 2. Optimal multiple trip solution for blood collection.

Conclusion

This study addresses a Multiple Trip Vehicle Routing Problem with Time Windows and was applied to a specific case study that fits the human health sector, more specifically the clinical analysis. The purpose is to create a model capable of improving the collection of blood from several donation sites and carried to a central laboratory. A MILP model was applied and afterwards implemented in LINGO to solve the problem. Deeper study on the model is executed to ensure solution obtained is reliable and accurate. This work will help the clinical analysis sector not to waste blood samples and consequently reduce the negative impact on the environment because if 6-hour time limit to collect, transport, and deliver the blood after extraction is guaranteed, no additional extractions need to be done. This time limit imposed in our model is a big improvement for the daily work regarding companies of this sector.

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