A MIXED INTEGER GOAL PROGRAMMING (MIGP) MODEL FOR DONATED BLOOD TRANSPORTATION PROBLEM – A PRELIMINARY STUDY

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ABSTRACT

Blood Supply Chain (BSC) concerns with flow of blood products from blood collection by donors to transfusion of blood components to patients. BSC comprises of collection, testing, processing, storage, distribution and transfusion activities, which are normally responsibility of Blood Centre and hospitals. In Malaysia, National Blood Centre (PDN) is responsible to organize blood donation, collection and processing. Current procedure practised by PDN is to have vehicles sending staffs and equipment while one vehicle is assigned to collect donated blood from donation sites and transport the blood to PDN within six hours. As consequence, vehicles shortages are encountered and resources optimization unachieved especially when many blood donation sites involved per day. This paper presents the results of a preliminary study which aims at proposing blood collection optimal routes for blood collecting vehicles that adhere to all pre-determined time windows for blood collection at blood donation sites. A Mixed Integer Goal Programming (MIGP) model based on Vehicle Routing Problem with Time Windows (VRPTW) has been formulated. The MIGP model pursues four goals, namely, to minimize total distance travelled, to minimize total travel time, to minimize total waiting time of vehicles and to minimize number of vehicles (routes). The model was solved using preemptive goal programming approach and existing heuristics for the VRPTW. Based on the results, it can be concluded that the donated blood can be collected and transported using reduced number of vehicles as proposed by the MIGP model's optimal compared to the total number of vehicles used by current practice, Thus, the proposed VRPTW based MIGP model has promising significant impact for donated blood transportation in terms of resources optimization and costs savings. The model and approach could be easily extended to solve larger problem involving large number of donation sites with variants of time windows for the sites.

Keywords*: Donated blood, transportation, Mixed Integer Goal Programming (MIGP) model, multi-objective optimization, Vehicle Routing Problem with Time Windows (VRPTW).*

1. Introduction

Blood supply chain (BSC) problem is one of the crucial activities in the healthcare systems, where it can be categorized as a logistics as well as transportation problem, in ensuring sufficiency of blood supply. BSC is concerned with the flow of blood products from blood collection by donors to transfusion of blood components to patients (Ramirez *et al.*, 2018). BSC comprises of collection, testing, processing, storage, distribution and transfusion activities, which are normally the responsibility of Blood Centre and hospitals, in which blood is a scarce resource supplied by humans. Collection of blood donated by donors is the first echelon in the BSC network whereas the transfusion of blood components to patients signifies its final echelon. Blood transfusion is an essential component of healthcare to save lives of people involved in accidents, in need for urgent treatment or undergoing trauma care, surgeries or transplants, and for those suffering inherited blood disorder. For these reasons, the management of BSC has gained attention of many researchers worldwide.

Hospitals nationwide require about 2,000 units (450ml per unit) of blood per day whereas, in Klang Valley, demand of blood by hospitals is 500 units daily (Malay Mail, 2018). In Malaysia, National Blood Centre (in Malay, Pusat Darah Negara or PDN) is responsible to organize blood donation, collection and processing the donated blood. Any insufficient inventory in blood bank is mainly due to continuing shortfall of donations which could lead to fatalities if hospitals cannot provide blood transfusions needed. In addition, blood is also perishable in nature and has shelf life. Donated blood, when stored in refrigerator at required temperature, is only good for 42 days while platelets stored in required conditions have shelf life of five days and frozen plasma can only last for a year. Therefore, continuous replenishment of blood in blood bank must be carried out. Effective and efficient management of blood bank inventory is vital in ensuring the quality of blood and blood products and avoiding blood wastage due to deterioration.

Blood supply is generally obtained through voluntary donations or blood donor programs where donors either donate whole blood or its components (red blood cells, plasma, and blood platelets) in which each component has different shelf life and used according to different requirements concerning the patients. Fifteen minutes is required for whole blood donation process per person, a minimum of 45 minutes is taken for Apheresis donation process for plasmapheresis of a person and up to three hours for plateletpheresis per person (Charbonneau *et al.*, 2018). Donated blood is stored in blood packs that are kept in specially designed blood transport boxes. For maximum benefit, blood must be maintained at required temperature during transportation and storage to avoid spoilage or wastage, or reduced useful life. The system concerning storage and transport of blood and blood products that follows certain standard operating procedures (SOP) from the point blood is collected from donors to the point of transfusion and finally to patients is referred to as the blood cold chain.

Blood cold chain in BSC dictates that collected whole blood or its components must be shipped to the blood centre (PDN or identified hospitals) or to blood transfusion service in right temperature and in accordance to SOP of temperature, security and hygiene. Elapsed time between pre-processed blood collection to centrifugation for component preparation at blood centre should not be more than six hours whereas fresh frozen plasma (FFP) requires separation from the whole blood within six to eight hours of collection (WHO, 2019). Efficient blood cold chain is crucial to ensure blood quality while failure to adhere to the specified storage conditions, temperature or duration can affect viability of blood constituents and result in reduced clinical benefits with potentially harmful effect to recipients of blood or its products. Meanwhile, pickup/delivery efficiency of blood from donation sites to blood centre is influenced by time windows for collection and choices of routes.

In Malaysia, re-blood cold chain activities are managed by PDN. However, the blood donation programs are organized separately by certain organizers either at specified hospitals

or other venues. Besides vehicles used for transporting staffs and equipment, a vehicle is allocated for transporting collected blood from a donation site to PDN or other blood centre twice per day. The two collections or deliveries from donation sites to blood centre include one which is done half way through donation period and another one after donation program at site is completed. For remaining time, collection vehicles are idle and thus, not optimizing usage of vehicles and staffs and may cause shortages especially when many blood donation programs are held within same day. This motivates this study that is to determine more effective blood transportation (routing and scheduling), which is a critical component in the blood cold chain.

Currently, research in blood transportation problem (BTP) in Malaysia is lacking. Hence, this study aims at establishing a model and method that reduces number of vehicles used, i.e., from a blood collection vehicle per site to lesser number of vehicles for all donation sites altogether. Through this, optimization in terms of maximum quantity of blood carried per vehicle and minimum number of vehicles used can be achieved. Prior to solving BTP for larger scale problem where more efficient algorithms will be employed, a preliminary study was conducted to get insights of problem. This study involved several blood donations sites and PDN (depot) and used the VRPTW approach to solve the BTP. A Mixed Integer Goal Programming (MIGP) model was formulated to find optimal schedule and routes for vehicles which comply with time windows for collection at blood donation sites and vehicles scheduling horizon and to arrive at PDN within stipulated time. The study focuses on donated whole blood transportation from blood collection sites (hospitals, health institutions and other donation sites) within Kuala Lumpur to PDN. The model, solution and findings of this study are intended to provide strategies useful to PDN or other blood centres in enhancing blood transportation from collection points to PDN to be processed and stored for immediate or future use.

This paper presents the overview of the problem, review of past studies, the model and methods, and results of this preliminary study conducted. The remaining of the paper is organized as follows: Section 2 provides the Literature Review; Section 3 describes the Methodology; Section 4 presents the Results and Discussion and finally, Section 5 is the Conclusion, that wraps up the whole discussion on this preliminary study.

2.   Literature Review

Transportation is a critical component of logistics with substantial economic values in production and delivery system where even a small percentage improvement in fleet management could yield sizeable savings. Considering BSC as essential service in health care systems, donated blood transportation specifically requires effective planning. Mathematical optimization models have played central roles in solving BTP either in transporting blood from blood donation sites to respective collection facilities, or from these facilities to hospitals and transfusion centres, to guarantee quality of blood, efficient transportation management as well as on-time delivery and satisfying demand for the required blood. Many studies have been conducted to address diverse variants of BTP. Cheraghi *et al.* (2016), for example, put forward a Mixed Integer Linear Programming (MILP) model for BTP which addresses unpredictability of blood supply and aims at minimizing total transportation costs of main centres, relocation of provisional blood services facilities and total distribution costs for specified duration. GAMS was used to solve the model. Optimal results based on MILP model showed that the robust model is superior compared to deterministic one in handling uncertainty as well as robustness of the problem. Sibuea *et al.* (2017) formulated a Stochastic Integer Programming (SIP) model based on model proposed by Gunpinar and Centeno (2015) to solve BSC problem. The problem focused on blood group and blood age that can be used by PMI Blood Transfusion Unit (UTD) of Pekanbaru. The SIP model includes constraint which guarantees blood demand is satisfied while reducing risks and mistakes in delivery of blood for patients. Data involved demand scenarios from January to April 2017 of PMI UTD Pekanbaru blood group data. Microsoft

Excel 2010 and LINGO 16 were used to solve the model. Solutions were utilized as basis for simulation of 14 days platelets distribution and blood wastage data for months involved which could be useful in preventing wastage and avoiding blood shortages.

Meanwhile, Taweeugsornpun and Raweewan (2017) carried out a case study in Thailand for determining optimal routes for blood delivery vehicles of third-party logistics (3PL) service provider, where the vehicles are alternatives for hospital ambulances. An Integer Programming (IP) model has been formulated and used to determine exact solution which consists of optimal routes for vehicles. The primary goal of the IP model is to minimize total travel time from the National Blood Centre (NBC) to hospitals. The model was solved using IBM ILOG CPLEX. Two vehicles of a 3PL service provider have been designated to serve 10 hospitals in Bangkok metropolitan area and other provinces with airport nearby. Based on results. a maximum of 30 minutes length of stay at hospital must be complied. Otherwise, additional vehicle is required for optimal routes and higher idle time incurred for vehicles. On the other hand, Heidari-Fathian and Pasandideh (2017) designed a novel BSC network consisting of three main echelons. which are donors, collection facilities and demand points. That involves main blood centres as permanent facilities, and two mobile facilities, mobile blood facilities and demountable collection centres. The proposed Mixed Integer Programming (MIP) model has one objective function that is to minimize total costs of BSC network using certain numerical examples. Sensitivity analyses conducted through changes on main parameters of the model investigate effects on the objective function. Heidari-Fathian and Pasandideh (2018) formulated a multi objective MILP model to minimize total costs of supply chain, to maximize satisfaction by minimizing total amounts of expired blood products and also shortage of blood products, and to minimize total GHG emissions of transportation activities. The bounded objective function method was used to transform the model into a single objective model while Lagrangian relaxation heuristic algorithm based on sub gradient approach is proposed to handle the complexity of the model. Numerical experiments using small and large sizes data showed that results are produced within reasonable time as compared with results of exact methods.

Asadpour *et al*. (2020) conducted a study concerning BSC problem in disaster situation where blood groups and expiration dates are considered. The network involved comprises of blood collection centres, labs for quality assurance and producing blood products, and hospitals. An MIP model was proposed in which the objective function is to minimize the total cost of network, including establishment cost of facilities, cost of transportation, and cost of holding inventory. The model was implemented on three randomly generated sample problems in different dimensions (small, medium, large), with uncertainty in demand considered, and solved using GAMS software. The objective function value increases as dimension gets larger while increasing computational time was observed with larger dimension. Jin *et al.* (2021) proposed a four-echelon blood supply chain model involving blood donors, blood donation houses, blood centres, and hospitals, focusing on BSC operation-related problems in emergencies. The objective function of the proposed dynamic stochastic optimization model is to minimize composite costs including shortage cost incurred in blood centres, cost of opening a blood donation house, and the operating cost. Computational experiments are based on data in Chengdu, China involving Chengdu Blood Centre, 10 blood donation houses and 20 blood donation groups. Model is solved using Lingo and results show that by changing average blood supply, the blood shortage situation is alleviated. Increase in proportion blood apheresis collection results in a significant decrease of total RBC shortage and RBC shortage cost, thus lowering the number of blood donation houses. In addition, increasing distance acceptable to donors lead to participation of new blood donors while proper adjustment of donation frequency of donor groups is necessary with respect to time interval requirements.

The study by Karadağ *et al*. (2021) concerns with location-allocation model for a BSC network design problem that has four echelons - Mobile Blood Donation Vehicles (MBDVs), Blood Donation Centres (BDCs) as permanent blood collection locations, Regional Blood

Centres (RBCs) that perform all duties of laboratories, storage facilities and distribution centres, and supply/demand points. A multi objective mathematical programming model is proposed in which objective functions are to minimize distance between BDCs and RBCs, to minimize distance between RBCs and demand points, and to minimize the travel lengths of MBDVs routes. These goals (objectives) are combined in an objective function by multiplying different priority coefficients found by prioritizing objectives using Analytical Hierarchical Process (AHP) with experts' help. Model is tested based on real data from the Eastern Anatolia region of Turkey for various supply demand scenarios. Results indicate that proposed model gives at least 25% more effective solutions as compared with current situation in the region.

Vehicle Routing Problem (VRP), proposed by Dantzig and Ramser (1959), concerns with servicing a set of customers using vehicles fleet based at a depot where customers' locations and demands are known. The goal of VRP is to determine a set of routes in which each route must start at depot, visit a subset of customers and must return to depot. A customer can only be served by a vehicle and visited by the vehicle once. The common objective of VRP's mathematical model is to minimize total distance travelled. Some examples of VRP variants are Capacitated VRP (CVRP), VRP with Backhauls (VRPB), Inventory Routing Problem (IRP) and Multi-Depot Vehicle Routing Problem (MDVRP). In the presence of customers' time windows and depot time window (scheduling horizon), the VRP is known as VRP with Time Windows (VRPTW). According to Lenstra and Rinnooy Kan (1981), the VRP and VRPTW are classified as NP-hard combinatorial optimization problems which means due to their complexity, finding exact solutions is difficult even for moderate size instances. Although exact optimal solutions of VRP and VRPTW can be obtained by exact method, heuristic and metaheuristics approaches are more promising approaches in producing near optimal solutions in reasonable times for large size problems.

An example of VRP's application in BTP is a study by Sukaboon and Pathomsiri (2011) who employed Clarke and Wright Savings algorithm to determine routes for a network consisting of Thailand National Blood Centre (NBC) and 131 surrounding hospitals within Bangkok Metropolitan Region, where vehicles are managed by NBC. They proposed an MILP model which minimizes total distance and minimizes total travel time of routes for vehicles by placing a maximum travel time as constraint whereas a cut down by more than 50 percent on total distance is imposed to maintain an average distance of 960 km/day. Two rounds of blood collection were by vehicles and 12 vehicles were used. Proposed routes were able to lessen number of empty trips and save energy. Meanwhile, Pathomsiri and Sukaboon (2013) concerned with number of vehicles utilized to transport blood from NBC every day in which each vehicle carries little load outbound and comes back (inbound) empty while at the same time there are third party vehicles which can handle the blood transportation with certain fee. VRP approach was used to determine estimated total transportation cost (fair price) for blood distribution that enables NBC to make an informed decision, either to use own vehicles or hiring third party. The savings algorithm was coded in Visual Basic 2008 with user interface. Meanwhile, Sahinyazan *et al.* (2015) proposed the Selective VRP (SVRP) with integrated tours that aims at maximizing quantity of blood collected by mobile blood collection vehicles under large blood collection activities at reasonable total operations cost. Blood was collected and brought back to depot spoil free by shuttles that visits blood mobiles at sites, allowing continuous blood collection by blood mobiles without them having to return to depot every day. Optimal routes of shuttle and blood mobiles were determined by solving a two-stage IP model using heuristic algorithm in reasonable computational time. The IP model was tested using past actual data of blood donation drives under Turkish Red Crescent in Ankara and data developed using GIS data of Istanbul's European part. Computational results on both datasets indicate that proposed method reduces the current logistics costs.

VRPTW for BTP from venues of donation programs to the blood bank was implemented by Yi and Scheller-Wolf (2003), who proposed the model and solution method that concern

with variable rewards and freshness constraints. The VRPTW approach was applied to solve BTP of the American Red Cross (ARC). Collected blood must be brought back to blood bank in less than six hours to retain blood quality if it is to be decomposed into platelets. The amount of blood collected depends on the arrival and departure times of vehicles where more blood can be collected if collecting vehicles arrive at blood donation sites later in the day. Blood collection routes were established using three main steps, routes generation, individual route optimization, and route selection. An IP model has been proposed and solved optimally using CPLEX. Meanwhile, Yu *et al.* (2018) introduced Blood Pickup Routing Problem (BPRP), an extension of VRPTW, which constraints include blood's spoilage time restriction. BPRP aims to minimize total length of routes for blood bag collection between a blood bank and donation sites that are subject to time window constraints that must be adhered to. BPRP follows VRPTW attributes and assumptions adapted to this problem. Time windows for all nodes are set to [60, 660], vehicle capacity is set ranging from 50 to 140 while spoilage time is fixed as 360, where time unit is in minutes. Simulated annealing heuristic with restart strategy (SA_RS) was implemented in C++ and tested on small instances based on Solomon's (1987) VRPTW instances and also tested using some newly generated BPRP instances. Results compared with those obtained by CPLEX indicates SA_RS metaheuristic effectively solved BPRP.

The VRP and VRPTW of the BTP have also been formulated using the nonlinear programming models. For example, Iswari *et al*. (2018) formulated a Mixed Integer Nonlinear Programming (MINLP) model for problem known as Blood Mobile Collection Routing Problem (BMCRP). The model aims at achieving the minimum total distance of blood collection routes, where time window and service time have been set for each blood collection site. The MINLP model has been evaluated using eight hypothetical data sets of small cases VRP and solved using LINGO to determine the optimal routes. In addition, Ghasemi and Bashiri (2018) proposed a two-stage stochastic Selective-Covering-Inventory-Routing (SCIR) model. The goal of the model is to handle the distribution of whole blood under uncertainty involving the identified blood centre and blood mobile facilities. The solution of the SCIR model were obtained using CPLEX solver in which the impact of parameters variations has been analyzed based on model's outputs and costs. A study by Normasari and Muallifah (2020) concerned with the Maximum Blood Collection Routing Problem (MBCRP), an extension of VRPTW, to determine the location of blood donation sites to be visited by the blood collection vehicles in which blood spoilage time limitation is considered. MINLP model was proposed and the model was coded in AMPL and solved using CPLEX. The objective function of the MINLP model is to maximize quantity of blood collected from donation sites. Each donation site can only be visited by a collection vehicle at most once. The model was tested using small case of one depot (the blood centre), five blood donation sites and two vehicles, where capacity of blood collection vehicle is 40 blood bags and the spoilage time is 360 minutes (six hours). The MINLP model performed effectively with optimal routes found. In addition, a review concerning blood collection distribution based on VRP can be found in Azezan *et al.* (2017). The survey paper analyses the models, algorithms and solution methods which were used by some past studies. Although there have been many studies which solve VRP and VRPTW related to BTP from donation sites to blood bank or from blood bank to hospitals or transfusion centres conducted in many countries in the world, studies on BTPs in Malaysia are still lacking.

3. Methodology

This section discusses data and methods used in this preliminary study. Data from PDN include general information on PDN's blood donation programs and activities, details of donation sites and operations, resources involved (vehicles, staffs, beds, equipment, etc.), volume of donated blood, and related costs involved. According to PDN, for every 100 donors at a donation site, one clerk, one doctor, three nurses and one lab technician are needed. In other words, resources

required vary based on number of donors at blood donation sites. Vehicles are used mainly to transport the equipment and staffs while one vehicle is allocated to collect donated blood from donation sites and transport them to PDN within six hours.

The MIGP model for the VRPTW of BTP in this study was formulated based on a VRPTW models proposed in Shuib (2007) and Shuib and Muhamad (2018). The MIGP model has four goals pursued which are to minimize total distance travelled by vehicles, to minimize the vehicles' total travel time, to minimize total waiting time of vehicles at locations and to minimize number of vehicles (routes). VRPTW involves a fleet of homogeneous vehicles, a directed graph $G(N, A)$ and a set of customers, C where $C = \{1, 2, \dots, n\}$. The set N has $n + 2$ vertices, $N = \{0, 1, 2, \dots, n, n + 1\}$, in which n denotes number of customers. The depot is represented by node 0 (driving-out depot) while node $n + 1$ (returning depot), where "driving-out" and "returning" depots are assumed identical. Arcs set A represents links between depot and customers and connections between a pair of customers. For each arc (i, j). $i \neq j$, c_{ij} denotes the cost (distance) associated to this arc while t_{ij} represents the direct travel time from i to j. The capacity of a vehicle is denoted by Q_k, $k = \{1, 2, \dots, K\}$ whereas d_i represents the demand of any customer i. The earliest and latest time for service for customer i is indicated by time window $[a_i, b_i]$. The earliest a vehicle is allowed to serve customer i is at time a_i. If arriving earlier than a_i, the vehicle has to wait until this earliest time and waiting time (w_i) incurred. Vehicle must arrive and serve customer i the latest by b_i. The depot time window is $[a_0, b_0]$ where $[a_0, b_0] = [a_{n+1}, b_{n+1}]$ and this is known as vehicle's scheduling horizon. Vehicles cannot leave depot earlier than a_0 and must arrive back at depot before or by b_{n+1}. The triangular inequality is assumed to be satisfied for both c_{ij} and t_{ij}. VRPTW's target is to determine a set of minimal cost routes, one route per vehicle where each customer is serviced exactly once and every route starts at node 0 and finishes at $n + 1$ while the time windows and capacity constraints must be adhered. MIGP model for the VRPTW is formulated as follows:

Notations:

n	:	number of donation sites
K	:	number of vehicles
C	:	set of donations sites, $C = \{1, 2, \dots, n\}$
N	:	set of nodes including PDN (depot)
i, j	:	indices for nodes where $i = 0, 1, 2, \dots, n$; $j = 1, 2, \dots, n, n + 1$; $i \neq j$
k	:	index for vehicles, $k = 1, 2, \dots, K$
c_{ij}	:	distance travelled from i to j
t_{ij}	:	direct traveling time from i to j
d_i	:	demand at i (quantity of donated blood at i)
f_i	:	service time, (15 minutes for donation site and 0 min or no service at depot)
Q_k	:	vehicle capacity (Q_k is 50,000 ml for any vehicle k)
r_k	:	maximum travel time of any vehicle k
$[a_i, b_i]$	:	service time window, $i = 1, 2, \dots, n$. Note: $[a_0, b_0] = [a_{n+1}, b_{n+1}]$ is depot time window.

Decision Variables:

x_{ijk} : decision variable that represents whether traveling from i to j in vehicle k where

$$x_{ijk} = \begin{cases} 1, \text{if vehicle } k \text{ travels from } i \text{ to } j, \ i \neq j. \\ 0, \text{otherwise.} \end{cases}$$

and $i, = \{0, 1, 2, \dots, n\}$, $j = \{1, 2, \dots, n, n + 1\}$

w_i :   waiting time at i, $i = \{0, 1, 2, \dots, n\}$ and $w_0 = 0$ (no waiting time at depot)

s_{ik} :   vehicle k start time of service at i, $i, = \{0, 1, 2, \dots, n\}$, $k = \{1, 2, \dots, K\}$. At depot, $s_{0k} = 0$ for all k.

MILP Model Formulation for the VRPTW:

$$\text{Minimize} \quad \sum_{k=1}^{K}\sum_{i=0}^{n}\sum_{j=1}^{n+1} c_{ij}x_{ijk} \qquad\qquad , i \neq j \tag{1}$$

$$\text{Minimize} \quad \sum_{k=1}^{K}\sum_{i=0}^{n}\sum_{j=0}^{n+1} (t_{ij} + w_i + f_i)x_{ijk} \quad , i \neq j \tag{2}$$

$$\text{Minimize} \quad \sum_{k=1}^{K}\sum_{i=0}^{n}\sum_{j=0 \; i\neq j}^{n+1} w_i x_{ijk} \qquad\qquad , i \neq j \tag{3}$$

$$\text{Minimize} \quad \sum_{k=1}^{K}\sum_{j=1}^{n+1} x_{0jk} \tag{4}$$

subject to:

$$\sum_{j=1}^{n+1} x_{0jk} = 1 \qquad\qquad k = 1, 2, \dots, K \tag{5}$$

$$\sum_{i=1}^{n} x_{i,n+1,k} = 1 \qquad\qquad k = 1, 2, \dots, K \tag{6}$$

$$\sum_{k=1}^{K}\sum_{j=1}^{n+1} x_{ijk} = 1 \qquad\qquad i = 0, 1, 2, \dots, n, \; i \neq j \tag{7}$$

$$\sum_{k=1}^{K}\sum_{i=0}^{n} x_{ijk} = 1 \qquad\qquad j = 1, 2, \dots, n+1, i \neq j \tag{8}$$

$$\sum_{i=0}^{n} x_{ipk} - \sum_{j=1}^{n+1} x_{pjk} = 0 \qquad\qquad i \neq p, \; p \neq j, \; k = 1, 2, \dots, K \tag{9}$$

$$\sum_{i=0}^{n} d_i \sum_{j=1}^{n+1} x_{ijk} \leq Q_k \qquad\qquad k = 1, 2, \dots, K \tag{10}$$

$$s_{ik} + t_{ij} - M(1 - x_{ijk}) \leq s_{jk} \qquad i \neq j, k = 1, 2, \dots, K \tag{11}$$

$$a_i \leq s_{ik} \leq b_i \qquad\qquad i \in N, k = 1, 2, \dots, K \tag{12}$$

$$\sum_{i=0}^{n}\sum_{j=1}^{n+1} (t_{ij} + f_i + w_i)x_{ijk} \leq r_k \quad i \neq j, k = 1, 2, \dots, K \tag{13}$$

$$x_{ijk} = \{0,1\}, w_i \geq 0, s_{ik} \geq 0 \qquad i = 0, \dots, n, j = 1, \dots, n+1, i \neq j, k = 1, \dots, K \tag{14}$$

3.1   Model Description

Objective functions (1), (2), (3) and (4) represent the goals of the model where their order is based on lexicographic method and has been pre-specified. The primary goal, given by Eq. (1), is to minimize total distance travelled. Meanwhile, the second goal, Eq. (2), is to minimize total travel time that is by adding waiting time and service time at i to traveling time from i to j. The third goal or objective function (3) is to minimize total waiting time of vehicles. Equation (4) represents the fourth goal that is to minimize the number of vehicles (routes). Equation (5) guarantees that exactly one outgoing arc from the depot for any vehicle. The constraint denoted by Eq. (6) dictates that, for each vehicle, there is exactly one arc into the depot. A complete tour for each vehicle is guaranteed by constraints (5) and (6). Equation (7) is constraint that restricts for each vehicle k, only one arch emanates from each node i. On the other hand, Eq. (8) ensures that for each vehicle k, only one arc enters j. Both constraints (7) and (8) are necessary to ensure each vehicle visits each node exactly once. Constraint given by Eq. (9) controls the vehicle such that it leaves the depot, arrives at a customer and serves this customer, leaves this customer and proceed similarly until finally going back to depot. Equation (10) represents constraint that ensures that a vehicle does not exceed its capacity whereas Eq. (11) indicates a vehicle k cannot arrive at j before $s_{ik} + t_{ij}$ when travelling from i to j and M represents large scalar. Constraint (12) guarantees time windows are adhered to and Constraint (13) ensures total travel time for vehicle does not exceed maximum route time. Eq. (14) specifies binary integer values for x_{ijk} and non-negativity constraints for w_i and s_{ik}.

3.2   Methods

VRPTW model has been applied to solve BTP in this preliminary study which involves Time Oriented Heuristics (TOS) and adopting some concepts described by Yi and Scheller (2003). The first phase is the clustering stage where locations of donation sites (nodes) are represented by polar coordinates. Once the centre of "gravity" is fixed, locations of donation sites are ordered by their coordinates. A cluster is established by assigning sites to vehicles using counter clockwise sweep and ensuring vehicle capacity is not exceeded. The second phase concerns with establishing route for vehicle schedule for the cluster that has been formed. Note that few customers in this cluster possibly may not be able to be scheduled in the route due to time window constraints. Similar clustering process is carried out for the remaining unrouted nodes using next vehicle by another counter-clockwise sweep starting from the line that bisects the region of the previous cluster. Then routing is done. The steps are repeated until all sites have been included. The main steps for the blood transportation's VRPTW are as follows:

i)   establish Cartesian coordinates for donation sites and depot with the depot at the origin;
ii)   convert the locations' Cartesian coordinates into polar coordinates;
iii)   perform clustering of sites using counter-clockwise sweep approach by adhering to the vehicle capacity;
iv)   establish the route by first selecting the first site using certain criterion;
v)   perform insertion of one site at a time, as many sites as possible, but satisfying all associated time window constraints; and
vi)   repeat steps iii) until v) until all sites have been scheduled in which another vehicle is used whenever a new cluster is formed.

TOS starts a route by using either: a) the farthest node which is not yet routed; b) the earliest deadline unrouted node; or c) the unrouted node with minimum equally weighted route-time and distance criteria combined. In this study, the first blood donation's site to be visited for a vehicle is decided using b). Two measures, $c_1(i, u, j)$ and $c_2(i, u, j)$ have been used at every iteration for choosing and inserting a blood donation's site, one at a time, into the currently constructed route as follows. Let $(i_0. i_1, i_2, ..., i_m)$ be the route, i_0 and i_m denotes the

depot (beginning and end of route), where $m = n + 1$. The best feasible insertion place (i_u, j_u) for unrouted site u in this route is determined by: $c_1(i_u, u, j_u) = \min_{p=1,...,m} c_1(i_{p-1}, u, i_p)$. The insertion of u in between i_{p-1} and i_p may influence the start times at sites $i_p, ..., i_m$. The begin times for remaining sites may be affected by delays at any prior sites with the possibility that the route could become infeasible (starting time at these sites are after the latest start times). Hence, sequential inspection must be done to each site, until $PF_i = 0$, i.e., the following sites will not be affected by the push forward or time infeasibility. Once the best insertion place is found, the best site u^*, to be inserted between i_u and j_u. is selected as described in Eq. (15) in which u is unrouted and feasible.

$$c_2(i_{u^*}, u^*, j_{u^*}) = \max(c_2(i_u, u, j_u)) \qquad (15)$$

The step is repeated until no more sites with feasible insertion can be found. Then, a new route in similar manner until all sites have been routed. Solomon (1987) Insertion Type (I) heuristic, represented as c_{11}, is considered the most successful sequential insertion heuristic and has been applied extensively in the heuristics for VRP and VRPTW. Its criteria are as given by Eq. (16), Eq. (17), Eq. (18) and Eq. (19), where b_{ju} is the new begin time of service at j, given u is in the route while d_{ij} is distance from i to j. Parameter μ controls the savings in distance. The best feasible insertion place for an unrouted site is decided using $c_1(i, u, j)$ that minimizes the measure of extra distance and time required to visit the site. Meanwhile, α_1 and α_2 are factors representing how much the best insertion place for the unrouted site depends on extra distance and time required to visit the site by the current vehicle. The parameter λ indicates how much the best insertion place for this site depends on its distance from depot. Solomon (1987) used the combinations of these parameters as given in Eq. (20), where this insertion heuristics maximizes the benefit derived from servicing a site on the partial route being constructed rather than on a direct route.

$$c_{11}(i, u, j) = d_{iu} + d_{uj} - \mu d_{ij} \quad , \mu \geq 0 \qquad (16)$$

$$c_{12}(i, u, j) = b_{ju} - b_j \qquad (17)$$

$$c_1(i, u, j) = \alpha_1 c_{11}(i, u, j) + \alpha_2 c_{12}(i, u, j) \quad , \alpha_1 + \alpha_2 = 1, \ \alpha_1, \alpha_2 \geq 0 \qquad (18)$$

$$c_2(i, u, j) = \lambda d_{0u} - c_1(i, u, j) \quad , \lambda \geq 0 \qquad (19)$$

$$(u, \lambda, \alpha_1, \alpha_2): (1,1,1,0), (1,2,1,0), (1,1,0,1), (1,2,0\ 1) \qquad (20)$$

Figure 1 provides an illustration on VRPTW scenario of donated blood collection, with time windows. $[a_i, b_i]$ represents the time windows at each site i and $[s_{ik}, h_{ik}]$ represents the range of service time at site i, where $i = 1, 2, ..., n$. If any of the time windows is violated, the route becomes infeasible. Similarly, if depot time window is violated, then time restriction for blood to arrive at the blood centre within six hours is exceeded, thus, route is also infeasible.
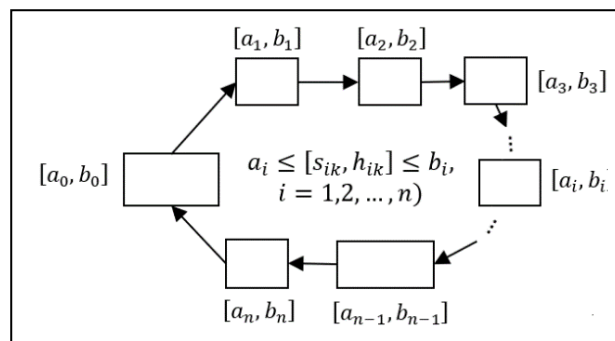

Figure 1. Time Windows for the Blood Collection Sites

4.   Results and Discussion

Table 1 displays the locations coordinates of blood donation sites and PDN (the depot) in xy-Cartesian coordinate system. where PDN coordinates of is (0, 0). These donation sites shown are the most common locations selected by organizations and private health institutions in organizing blood donation campaigns within the area specified by this study. Locations of PDN and blood donation sites are as shown in Figure 2.

Table 1. Locations Coordinates

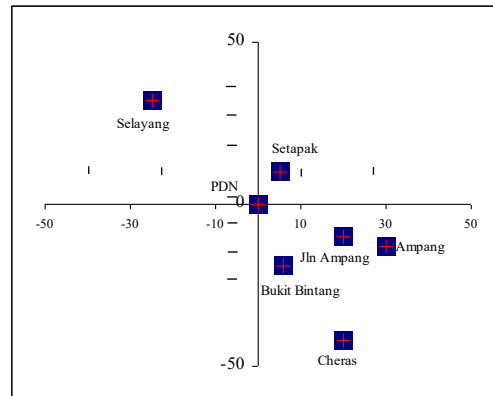| Blood Collection Sites	Location Coordinates	
	x	y
PDN	0	0
Ampang	30	-13
Jln. Ampang	20	-10
Cheras	20	-42
Selayang	-25	32
Setapak	5	10
Bukit Bintang	6	-19

Figure 2. Blood Donation Sites

Table 2 shows Euclidean distances from PDN to blood donation site and between any pair of blood donation sites. Distance is taken as travel time (in minutes) where 1 kilometre represents 1 minute travel time. Actual service time has been approximated as 15 minutes or less at each site. However, for simplicity, service time is assumed constant, which is 15 minutes per collection site. Table 2 also shows two sets of time windows (in minutes) representing first and second round of blood collection in a day at each site, denoted as TW1 and TW2, respectively. The earliest a vehicle can depart from PDN is at 9.00 a.m (minute 0) while latest time to arrive back at PDN is at 3.00 p.m. (minute 360), thus, PDN's time window is [0, 360]. Time windows for donation sites are set based on number of donors for these sites in which the site with less number of donors is given earlier beginning time window. For example, time windows for Ampang which is [260, 290] refers to [1.20 p.m., 1.50 p.m.]. Range for each time window at donation site is between 20 to 60 minutes for TW1 and 20 to 240 minutes for TW2. A vehicle is allowed to collect blood only within given time windows at each site, say i, represented by $[a_i, b_i]$. If vehicle arrives too early (before a_i), then waiting time encountered. After collecting blood at site i, the vehicle's departure time at this site should not exceed latest time window, b_i. Otherwise, time window is violated. Total schedule time for blood collection cannot exceed six hours. The MIGP model was solved using the TOS heuristic algorithm coded using Fortran. The MIGP model utilized preemptive goal programming technique described by Taha (2017) based on a strict dominance order of goals (objective functions) where highest priority is minimizing total distance travelled, second priority is minimizing total travel time, minimizing total waiting time for the fleet of vehicles is the third priority and minimizing number of vehicles or routes is last priority. Homogeneous vehicles, which can transport up to Q_k = 150,000 ml of blood, are utilized. Data on amount of blood to be collected at each donation site (based on past data of PDN) are as shown in the last column of Table 2.

Figure 3a illustrates the optimal routes obtained by solving the model using TW1. These routes are PDN → Setapak → Jln. Ampang → Cheras → Bukit Bintang → Ampang → PDN (Vehicle 1) and PDN → Selayang → PDN (Vehicle 2). Vehicle 2 is required because the time window of PDN will be violated if Selayang was included in the first route (Vehicle 1). For Vehicle 1, Departure Time (DT) from PDN is 108.8 (10.49 a.m.), Total Distance (TD) =

152.5, Total Waiting Time $(WT) = 0$, Total Service Time $(ST) = 75$, Total Travel Time $(TT) = 227.5$ (3 hr. and 47 min.) and Arrival Time (AT) at PDN is 336.3 (2.36 p.m.). Total amount of blood collected by Vehicle 1 is 27,000 + 27,450 + 34,200 + 24,750 + 26,100 = 139500 ml. Meanwhile, Vehicle 2's DT from PDN is at 254.4 (1.14 p.m.) with one collection site at Selayang, $TD = 81.2, WT = 0, ST = 15, TT = 96.2$ (1 hr. and 36 min.) and AT at PDN is 336.3 (2.50 p.m.). Amount of blood collected using Vehicle 2 is 38,250 ml.

Table 2. Euclidean Distance between Blood Collection Sites (c_{ij})

Site i	PDN	Amp	JA	Ch	Sg	Sk	BB	Time Windows $[a_i, b_i]$		Blood Collected (ml)
								TW1	TW2	
PDN	0	32.70	23.36	46.52	40.61	11.18	19.92	[0,360]	[0,360]	
Amp		0	10.44	30.68	71.06	33.97	24.74	[260,290]	[260,330]	26,100
JA			0	32.00	61.55	25.00	16.64	[150,190]	[150, 210]	27,450
Ch				0	86.61	54.12	26.93	[200,235]	[235,270]	34,200
Sg					0	37.20	59.68	[295,325]	[110,330]	38,250
Sk						0	29.02	[120,140]	[120,180]	27,000
BB							0	[240,295]	[240,295]	24,750

Note: Amp: Ampang, JA: Jln. Ampang, Ch: Cheras, Sg: Selayang, Sk: Setapak, BB: Bukit Bintang
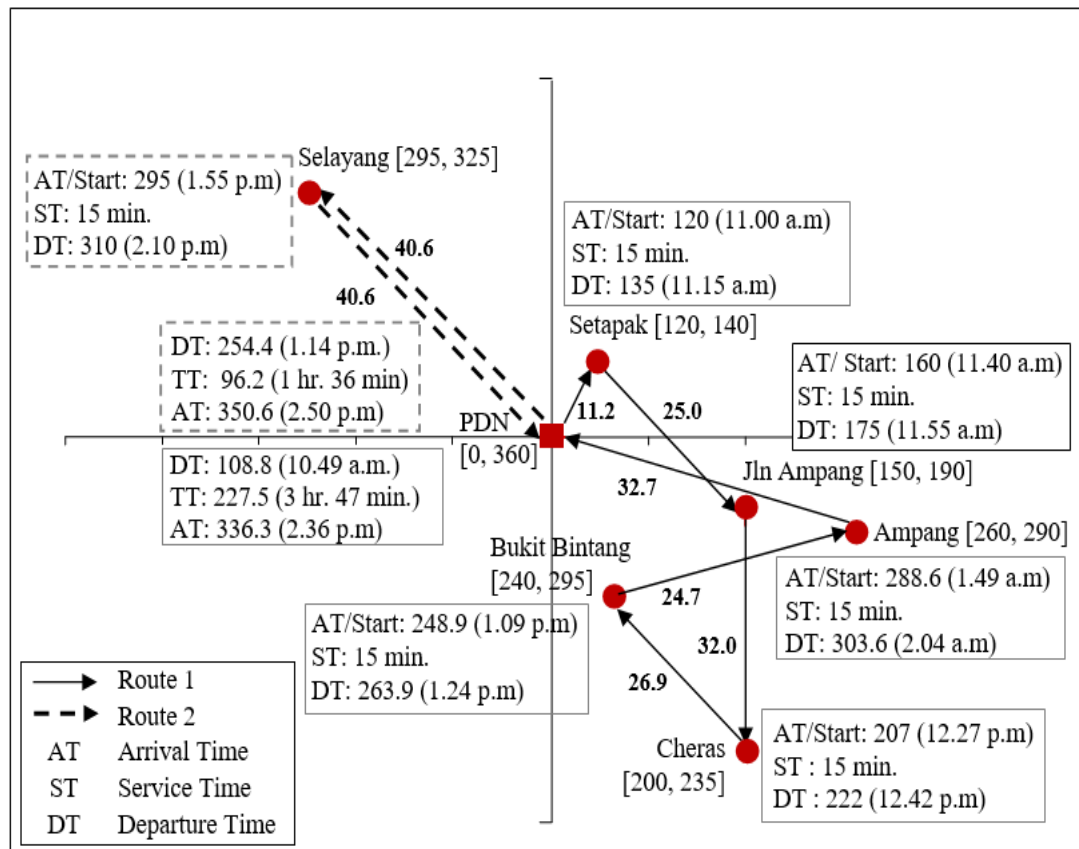

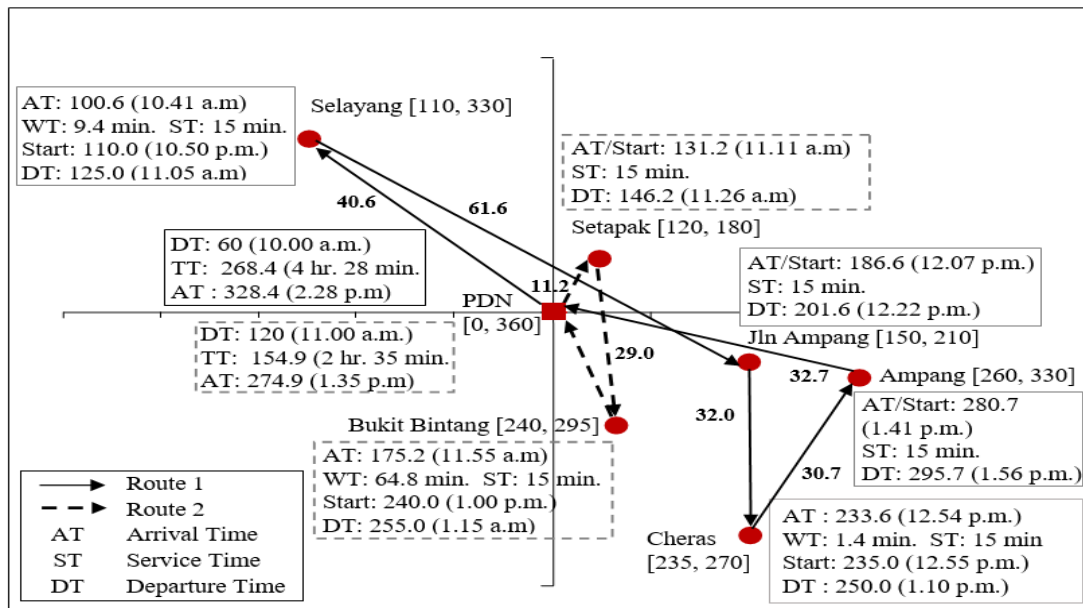Figure 3a. Blood Transportation based on TW1

Figure 3b. Blood Transportation based on TW2

Meanwhile, Figure 3b displays optimal routes based on TW2. Two vehicles are employed for blood transportation. These routes: Vehicle 1: PDN → Selayang → Jln. Ampang → Cheras → Ampang → PDN and Vehicle 2: PDN → Setapak → Bukit Bintang → PDN. For Vehicle 1, DT from PDN is at 10.00 a.m. overall $TD = 197.6$, $WT = 10.8$ (at Selayang and Cheras), $ST = 60$ (4 sites), $TT = 268.4$ (4 hr. and 28 min.) and AT at PDN is 328.4 (2.28 p.m.). Amount of blood collected using Vehicle 1 is 126,000 ml, that is 38,250 + 27,450 + 34,200 + 26,100 ml. As for Vehicle 2, DT from PDN is at 11.00 a.m., $TD = 60.1$, $WT = 64.8$ (1 hr. and 4.8 min.), $ST = 30$ (2 sites), $TT = 154.9$ (2 hr. and 35 min.) and AT at PDN is 274.9 (1.35 p.m.). Total amount of blood collected is 27,000 + 24,750 ml or 51,750 ml. In TW2, time windows at donation sites can be larger, between 20 minutes to 240 minutes. Note that Selayang site has a wide time window for collection. Advantage of this larger time window is Selayang will be easily scheduled. However, if there is no other site with earlier beginning time window, then Selayang will be likely scheduled as first site to be visited by the collecting vehicle. Thus, amount of donated blood collected at this site cannot be optimized. Another disadvantage is the beginning time window for second round collection for Selayang need to be early to ensure blood arrives at PDN within six hours. Nevertheless, optimal solutions obtained based on TW1 and TW2 ensured that six hours restriction has been complied.

Two more variants of time windows, namely TW3 and TW4, for all the donation sites have been used to further explore the model and investigate possible scenarios concerning the blood collection transportation from sites to PDN. The time windows and results are as shown in Table 3. Based on results, variants of time windows may produce different optimal solutions concerning routing and scheduling of vehicles for collection of donated blood. In general, it is observed that one vehicle is likely to be able to collect blood from five sites without violating time window restrictions. However, six sites or more would require more than one vehicle.

Table 3. Results based on Other Variants of Time Windows at Donation Sites

Label	Sites (i)	TW3	Optimal Solution	TW4	Optimal Solution
0	PDN	[0, 360]	Vehicle 1 0→4→2→3→1→0 $TD = 197.5$; $ST = 60$; $WT = 50.2$; $TT = 307.7$; Blood collected: 126,000 ml Vehicle 2 0→5→6→0 $TD = 60.1$; $ST = 30$; $WT = 76.0$; $TT = 166.1$; Blood collected: 51,750 ml	[0, 360]	Vehicle 1 0→5→2→3→6→1→0 $TD = 152.5$; $ST = 75$; $WT = 0.0$; $TT = 227.5$; Blood collected: 139,500 ml Vehicle 2 0→4→0 $TD = 81.2$; $ST = 15$; $WT = 0.0$; $TT = 96.2$; Blood collected: 38,250 ml
1	Ampang	[260, 290]		[260, 290]	
2	Jln. Ampang	[150, 190]		[150, 190]	
3	Cheras	[200, 235]		[200, 235]	
4	Selayang	[0, 360]		[185, 240]	
5	Setapak	[120, 140]		[120, 140]	
6	Bukit Bintang	[240, 295]		[240, 295]	

As proposed by optimal solutions found using VRPTW MIGP model and TOS heuristic, instead of having six vehicles to transport donated blood from six blood donation sites (one vehicle per site) to PDN, number of vehicles can be reduced to two vehicles. Thus, the optimal solutions have the potential to contribute towards more costs savings in transporting the donated blood from all donation sites. In terms of computational time, the output is produced within a very short time, which is less than one minute. It is expected that the computational time will increase with the increase in the number of blood collection sites. In addition, the same approach using the same model can be proposed to determine the route and schedule of vehicles for the second round of blood collection for the day. However, emphasis must be given on the earliest collection time so that amount of collected blood could be optimized based on the first-round collection for the day at the respective sites while at the same time ensuring the blood donated can arrive at PDN within six hours from the time they were donated.

In general, when solving the VRPTW for transportation of blood collected at donation sites to PDN, the following aspects should be considered:

- Having almost similar time windows at many sites can cause violation in time windows for service due to push-forward insertions. This can also cause an increase in the number of vehicles utilized because of inability to schedule as many sites serviced by any collecting vehicle due to time window limitations.
- The time windows for each site should not be too tight, i.e., difference between the earliest (begin) time window, a_i, and the latest (end) time window, b_i, should be sufficiently large.
- Place restriction on the earliest time windows for the blood donation sites to ensure that the collected amount of blood donation at each site is optimized.
- Avoid combination of open time windows, in this case [0,360], or large time windows together with tight time windows at blood collection sites, because this might lead to more vehicles being used due to limited choices for insertions in routing.

5.   Conclusion

Based on results of the preliminary study, it can be concluded that number of vehicles assigned to blood collection sites in one day can be reduced. From the current blood collection practice, one vehicle is needed at each site to collect the blood, thus, in the case of six blood donation sites, six vehicles are utilized. However, based on the proposed MIGP model and optimal solution found, number of vehicles required could be decreased to two vehicles. Thus, reduction in number of vehicles used would imply possible reduction in costs and resources required for transportation of donated blood to PDN. However, the complexity in scheduling and routing the vehicles to transport the donated blood would increase when a larger number of blood donation campaigns are organized, hence larger number of sites, in one day. Thus, our study will work on the formulation of an enhanced mathematical model with additional constraints

to represents more restrictions imposed and to solve this model using heuristics or metaheuristics. These model and approaches and better strategies entailed will be useful for PDN especially when it is responsible not just overseeing blood donation campaigns but also managing the strategic, tactical and operational decision in terms of blood collection from donation sites to blood collection centres and distribution of blood from PDN or these blood collection centres to hospital or any blood transfusion centres. Thus, initiatives that could optimize the costs and resources required, such as proposed in our preliminary and further study, should be explored further. The model and method of this study can be extended by considering multi-depot (involving PDN and other blood centres).

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