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Determination of a Fair Price for Blood Transportation by Applying the Vehicle Routing Problem: A Case for National Blood Center, Thailand

S. Pathomsiri, and P. Sukaboon

***Abstract*—**The National Blood Center, Thai Red Cross Society is responsible for providing blood to hospitals all over the country. When any hospital needs blood, it will have to send the vehicle to pick up at the NBC. There are a lot of vehicles to pick up blood at the NBC every day. Each vehicle is usually empty for inbound trip and a little loaded for outbound. The NBC realized such waste or loss and there have been the third party offered to distribute blood and charge for fee. This paper proposes to apply the vehicle routing problem (VRP) for estimating the fair price. The idea is tested with the real data during seven-day period of 6 – 12 July 2010 to estimate the fair price for transporting blood in Bangkok Metropolitan Region.

***Keywords*—**Blood Supply Chain, Vehicle Routing Problem, Heuristic, Saving Algorithm, Fair Price.

I. Introduction

LIKE other countries around the world, Thailand uses a large amount of blood every day. Blood service in Thailand is responsible by the National Blood Center (NBC) housed in Bangkok, the capital city. When a hospital needs blood for its patient, it has to request and send a vehicle to pick-up blood at the NBC. The incoming vehicle is always almost empty for the front-haul trip and little loaded for the back-haul because the amount of blood is very little as compared to the capacity of the vehicle. In addition, the drivers have to spend a long time waiting for only few blood units due to crowded queues from different hospitals at the NBC. Many vehicles are the ambulance which is very valuable for emergency case. From the logistic perspective, the current protocol incurs a lot of inefficiency in terms of excessive fuel and other resources as well as the opportunity loss to utilize the vehicle.

In fact, the NBC is well aware about this inefficient transportation system. However, it cannot do much due to the lack of expertise and understanding about transportation business. Although in the past, there have been a few third party logistic providers offered to take care of the blood transportation in exchange of fee, the NBC administrators could not make decision. On one hand, the NBC feels that the fee is too high and is very reluctant to add it to the price of blood. On the other hand, the NBC does not know the right or fair price for negotiation or bidding.

This research is aimed to supply the information on the fair price for the NBC to make an informed decision. We propose to determine the fair price for transporting blood by using the solution to the vehicle routing problem (VRP) as the basis. The idea is to treat blood just like other goods that usually required efficient route planning when the customers (or hospitals, in this application) are many. Then, we seek to re-route transportation of blood where the NBC is the distribution center (or depot in VRP terminology) and hospitals in the blood service network are customer points. Suppose that the carrier is somehow efficient, the least-cost solution to the VRP should be close to its cost. And if we allow for some overhead charge and profit, the NBC will be able to come up with the reasonable fair price for bidding. In this paper, we report the research results in six sections. Followed this introductory section, section II briefly provides the literature review on blood distribution issues, VRP mathematical model and transportation management. Section III explains about the research methodology. The analysis results and discussion are in section IV. Last, section V concludes the paper together with the recommendations.

II. Literature Review

A. Blood Distribution Problems

Daily, there are a large number of patients who need blood in their treatment, so it is vital that hospitals store sufficient blood. However, the life cycle of blood is relatively short; therefore, too many blood units should not be stored. Nonetheless, we cannot allow a blood shortage to happen as it will endanger lives of patients. Consequently, hospitals have to send their vehicles to the NBC for picking up blood. As a result, there is a transportation cost which mainly consists of the vehicle cost, gasoline, and the driver, etc.

Past researches show that analyzing the blood supply chain is difficult and complex. In particular, the problem of blood distribution [1] in developed countries such as the United States of America and England tried to schedule transportation and routes [2]. The best answer to this problem is the effective and most profitable or most economical distribution plan. The blood distribution problem can be viewed as the vehicle routing problem (VRP) which is an important problem in logistics management. The distribution concept is similar to milk runs (delivery problem) operation. Rather than the hospital arranges the vehicle to pick-up blood at the NBC, a vehicle may be dispatched to deliver the blood to a series of

P. Sukaboon is with the Department of Industrial Engineering, Faculty of Engineering, Mahidol University, Nakornpathom province 73170, Thailand (e-mail: p_sukaboon@yahoo.com)

S. Pathomsiri is with the Department of Civil and Environmental Engineering, Mahidol University, Nakornpathom province 73170, Thailand (phone: + 662-889-2138 ext. 6396-7; fax: +662-889-2138 ext. 6388; e-mail: Somchai.Pat@mahidol.ac.th).

hospitals along the route.

B. Mathematical Model for Vehicle Routing Problem

The VRP occurs in many types of businesses such as mail, raw milk, auto parts, oil transporting, etc. Mathematically, the vehicle routing problem is the NP-Problem which is very difficult to find an optimal solution, especially when the problem in terms of the number of customer nodes is large. Finding the best answer may take a very long time to calculate or it may be impossible to find an answer. There are two possible solution approaches to tackle the VRP; i.e., exact and approximation methods.

1) Exact Method

First of all, the VRP is formulated as the mixed integer linear program (MILP). This method solves such the mathematical formulation by using the sophisticated algorithm to explore all possibilities until it finds the optimal solution. Intuitively, this method is very time-consuming, so it is ideal for a small problem which has a small number of customers. However, it also requires very high efficient solver.

2) Approximation Method

This method uses heuristic to define some steps to solve the problem. The solution does not guarantee to be the optimal. If an algorithm is efficient, it will be able to solve the large problem quickly. One of well-known heuristics is saving algorithm [3 - 4] etc.

Zanakis and Evan (1981) [5] suggested using a heuristic to find a solution when the nature of the problem is complex like a problem that has so many practical terms that the exact method takes too long time to find the solution. Having learned from previous research, here the saving algorithm is adopted. Although the algorithm may be old, the research idea is simply to get the fair price, not the optimal one. Therefore, the algorithm is suitable to obtain the solution in a short period of time [4], [6]. Another good thing is that it is not difficult to code. This makes it convenient and easy to apply in the real implementation.

C. Transportation Management

An important objective of transportation is to deliver products to customers according to their requirements with the minimum total cost. If the problem of route management and distribution are solved effectively, the total transportation cost can be reduced to as much as 5 - 20% [7]. For the success of their businesses, entrepreneurs should try to reduce all involved costs as much as possible, particularly the transportation cost, which is the highest logistics cost of most businesses. Regarding the transportation management, the owners of goods have two options; namely, to deliver the merchandise by oneself, or to hire a carrier for the transportation task.

At present, the NBC is analogous to a merchandise (blood) owner. However, the NBC is currently not taking responsibility of delivering blood to hospitals in Bangkok Metropolitan Region. Thus it does not have so much pressure or motivation to improve the blood distribution. Since it does not carry the cost of transportation, the NBC does not have to worry much about the expense. However, there is the possibility for upcoming future that stakeholders of blood distribution will realize the necessity of enhancing efficiency of blood distribution. There used to be a few carrier companies contacted the NBC and offer their services for blood distribution. These companies suggested charging for transportation cost as the percentage of blood price delivered to hospitals. However, the NBC perceived that the charge was quite high, and it would incur criticism of taking too much profit if the cost is transferred to hospitals. This would contrast with the operational philosophy of the NBC, which was founded as a non-profit organization. Thus the NBC has not taken any decisions regarding this matter, although it recognizes the persistent problems of blood distribution. If, in the future, the NBC make a decision that it should administer blood distribution, the likelihood is that the NBC will hire a carrier company for transportation services. This is due to its inadequacy of transportation skill. The analyses on route administration presented in this paper will reveal costs of efficient blood transportation, which should be useful for the NBC. With the guidance of these resulting costs, the NBC should be able to determine a fair price for considering about hiring a company.

III. Research Methodology

A. Scope of the Study

This research analyzes blood distribution between the NBC and the network hospitals in Bangkok Metropolitan Region. There are totally 131 member hospitals in the network. Fig. 1 shows location arrangement of the network hospitals on a digital Geographic Information System map within Bangkok Metropolitan Region.

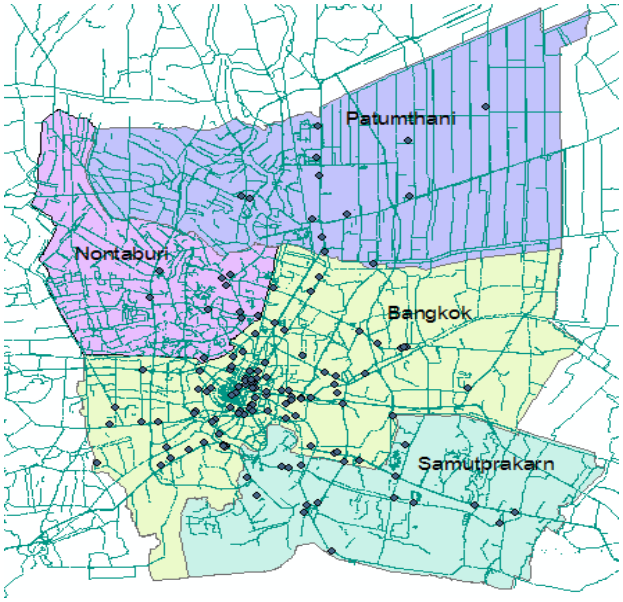

Fig. 1 Locations of the network hospitals in Bangkok Metropolitan Region

B. Data Collection

This research collected a great deal of relevant data regarding general characteristics of blood services by the NBC. The procedures of data collection started from preliminarily reviewing a good number of international journals and national symposiums/workshops regarding blood distribution services. Then a series of field observations were conducted to collect detailed data. The field observations began by interviewing the NBC's staff. Names and locations of hospitals that are network members of the NBC were collected. Photos were taken in order to study procedures of receiving blood at the NBC. Types and number of vehicles sent from hospitals as well as their containers used for receiving blood were recorded. Quantity of daily blood demand of the network hospitals was also collected. Data collection regarding daily blood demand took place at the NBC for a period of seven days, during 6 to 12 July 2010.

C. Data Preparation

The first set of data needed for solving the VRP is the distance matrix, which represents all distances along the roads from all nodes to all nodes in the network. These nodes refer to the NBC and all the network hospitals. For distance calculation, a GIS software package called ArcMap 9.3 was used. The distances were recorded in a form of Travel Distance Matrix, d_{ij}. Some part of the matrix is shown as an example in Table I.

TABLE I
AN EXAMPLE OF THE DISTANCE MATRIX

d_{ij}	0	1	2	..	..	131
0	0	163	3,406	..	..	18,870
1	377	0	3,244	..	..	18,930
2	3,759	3,383	0.00	..	..	20,285
..	..	..		..	..	..
..	..	..		..	..	..
131	18,863	19,026	20,544	..	..	0

Set 0 = the NBC
1 = Hospital 1
2 = Hospital 2
…
131 = Hospital 131

The second set of data is blood demands of the hospitals. The data were collected during a period of seven days. The mean value of daily blood demand by hospital was calculated. The results were then used as the figures of blood quantity delivered to the network hospitals. This will allow VRP ready to be solved. Characteristics of daily blood demand data are presented in Table II.

TABLE II
BLOOD DEMAND DURING JULY 6-12, 2010

number	Hospitals	Blood Volume (bags)								
		6	7	8	9	10	11	12	Total	Average
1	Hospitals 1	346	481	251	438	75	116	330	2037	291
2	Hospitals 2	43	25	107	28	22	24	76	325	46
..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..
131	Hospitals 131	0	0	0	0	0	0	0	0	0
	Total	2,324	2,453	2,465	2,417	1,577	1,176	2,824	15,236	2,177

D. Mathematical Modeling

The problem of blood distribution has a characteristic that correspond to a pattern of VRP. Since the problem size is very large, by containing over 100 customers (network hospitals), a saving heuristic is then adopted for solving the VRP in the reasonable amount of time. The algorithm is coded in Visual Basic 2008. Procedures for calculation of the algorithm are as follows;

I. Choose the central depot, which is the NBC

II. Calculate for saving values that will be resulted from integrating multiple routes into the same one between each pair of node i to node j. The saving cost (S_{ij}) is equal to $d_{oi} + d_{jo} - d_{ij}$, where:

O = the central depot (the NBC)
d_{oi} = distance from the NBC to hospital i
d_{jo} = distance from the hospital j to the NBC
d_{ij} =distance from hospital i to hospital j

TABLE III
AN EXAMPLE OF SAVING DISTANCE VALUES (M.)

S_{ij}	d_{oi}	d_{jo}	d_{ij}	Saving distance
$S_{1,2}$	377	3,406	3,244	377 + 3,406 +3,244 = 539
$S_{1,3}$	377	3,485	3,323	377 + 3,485 + 3,323 = 539
$S_{1,4}$	377	4,830	4,963	377 + 4,830 + 4,963 = 244
..	..	..	..	..
..	..	..	..	..
$S_{131,129}$	18,863	27,391	32,948	18,863 + 27,391 - 32,948 = 13,307
$S_{131,130}$	18,863	42,093	47,649	18,863 + 42,093 - 47,649 = 13,307

Table III Show example of saving valuesIII. Sort the saving values (S_{ij}) descending

IV. Choose the highest saving value from each pair of node i to node j, without any repetition of node i and node j. Then create sub-routes by connecting between each pair of node i and node j.

V. Repeat step 3) and step 4) until all nodes are completed.

The solution to the VRP can be used to estimate the transportation costs. These costs can be regarded as the most efficient costs. A professional carrier company should adopt this method of vehicle routing for proposing a plan to support the distribution service for the NBC. After adding costs incurred in other tasks and percentage of profit to these costs, such company can obtain the total cost to propose to the NBC. Alternatively, the NBC may set this total cost as a fair price for arranging an auction to find an appropriate carrier.

IV. RESULTS

A. Results of Re-Designed Route

The saving algorithm was coded by Visual Basic 2008 with the user-interface (Fig. 2) specially designed for easy and convenient access. The user is only required to select from the name-list hospitals in need of blood transport, assign the demanded amount as well as other constraints such as distance, loading capacity, number of stops, travel time, etc.

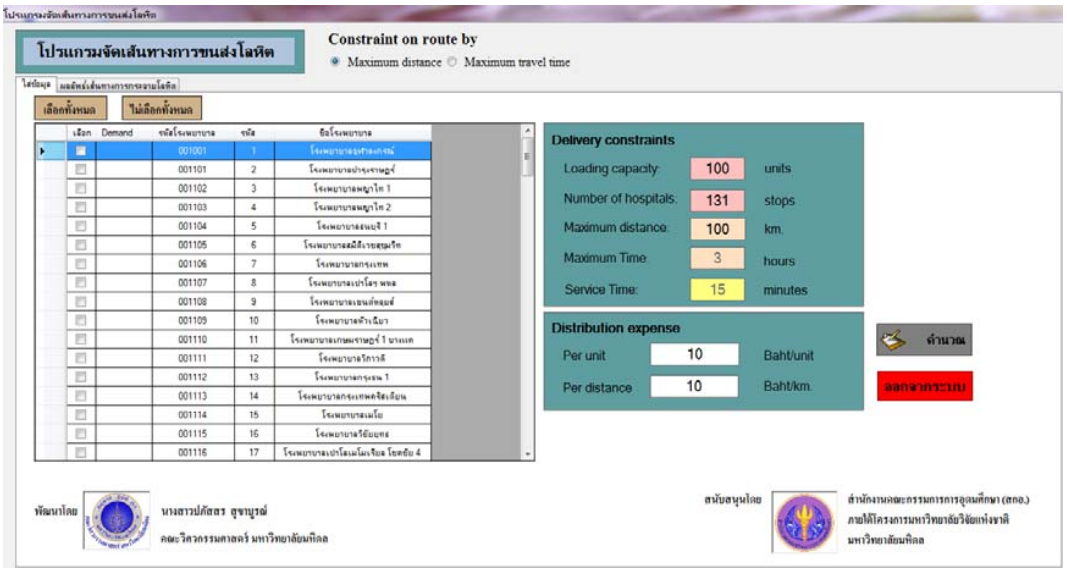

Fig. 2 User interface of the program for designing blood distribution routes

Once all inputs are in, the program will calculate the routes for transport. The analysis was conducted base on blood distribution data during seven days and determined constraints regarding loading capacity 600 units and maximum travel time three hours. For each trip, the number of stops is added by 1, starting from 1,2,3,…., to 10 stops, in order to observe the performance of the problem and find the proper number of hospitals in the trip. Table IV shows results of the calculation.

TABLE IV
COMPUTING TIME FROM REDESIGNING FOR BLOOD DISTRIBUTION BY USING SAVING ALGORITHM

D/M/Y	Trips	Computing time (Sec)									
		1	2	3	4	5	6	7	8	9	10
1	72	30.7	16.8	16.8	16.6	15.3	16.8	16.6	16.8	15.8	15.6
2	84	38.4	20.8	20.2	20.1	19.4	19.7	19.8	20.1	20.2	19.9
3	83	37.0	21.9	21.7	21.5	21.3	21.4	21.5	21.3	20.5	20.8
4	80	35.4	20.3	19.3	19.6	18.4	18.6	18.5	18.5	18.2	18.4
5	69	28.1	16.2	15.6	15.4	15.4	15.6	16.7	16.7	15.7	15.8
6	54	18.8	11.5	11.7	10.9	10.9	11.6	12.3	11.3	11.7	14.2
7	78	33.1	18.8	18.4	18.2	18.2	17.6	18.0	17.9	18.4	18.3
Average	82	31.6	18.0	17.7	17.5	17.0	17.3	17.6	17.5	17.2	17.6

From testing with real implementation of more than 100 hospitals, the program seems to prove effectively functional, be able to design route in a short period of time (less than 40 seconds). It can be concluded that there is no calculation-related difficulty. The average time for processing is only within 20 seconds. In reality, the problem posed might not be technical, but could be caused by the transport management which either be operated by the NBC itself or a third party service. But due to the lack of expertise in transportation business, the NBC should not be able to develop efficient transport routing plan, such as how the routes should be re-designed, how many stops should be placed on a route. This inability suggests that the NBC is likely to hire the third party. There comes another problem when the NBC cannot make a decision on which carrier it should hire. This research provides a solution to such a situation. The simplest means is to assess the cost first and then determine a fair price.

B. Calculation for Proper Transportation Hiring Cost

Table V shows the results on routing calculated by the computer for 6 July, 2010. It can be seen that totally 17 trips (routes) are required in order to guarantee that every hospital receives desired amount of blood. The total distance is 885 km., compared to the current situation where hospitals need to take 72 rounds or 1,957 km. in total. It is obvious that the VRP solution can potentially reduce the energy consumption dramatically by (1,957 – 885) = 1,072 km. per day. Provided the transport cost, the fixed cost (e.g. vehicle, registration, insurance, driver, etc.), and the variable cost (fuel, engine oil, maintenance, depreciation, etc.) are 21 Baht/km., saving value by transport routing is 1,072 km./day x 21 Baht/km. = 22,512 km./day.

TABLE V
RESULTS FROM THE PROGRAM FOR DESIGNING BLOOD DISTRIBUTION ROUTES

Route no.	Delivery route	Demand (Units)	Distance (km)	Travel Time (hours)	Expense by unit (Baht)	Expense by distance (Baht)
1	0-99-98-60-15-0	78	60.6	3.0	15,600	1,273
2	0-55-63-73-94-87-0	93	107.7	2.8	18,600	2,262
3	0-116-119-124-122-58-0	64	97.0	2.9	12,800	2,038
4	0-93-78-67-51-0	189	67.6	2.9	37,800	1,420
5	0-89-6-46-21-34-0	63	51.4	2.2	12,600	1,080
6	0-8-57-95-102-24-0	165	60.0	2.6	33,000	1,260
7	0-5-28-96-11-0	114	102.4	2.9	22,800	2,150
8	0-88-62-50-66-13-0	197	61.7	2.2	39400	1,295
9	0-82-91-16-74-72-0	143	20.2	1.6	28,600	423
10	0-30-6-22-59-92-0	33	28.6	2.0	6,600	601
11	0-70-79-76-71-20-0	381	13.7	1.1	76,200	287
12	0-10-83-0	67	8.8	0.7	13,400	185
13	0-80-84-69-0	148	17.5	0.9	29,600	368
14	0-14-29-9-116-35-0	77	34.1	1.6	15,400	715
15	0-3-68-4-2-1-0	481	14.2	1.2	96,200	297
16	0-109-0	6	61.8	3.4	1,200	1,298
17	0-110-0	25	77.9	3.6	5,000	1,637
	Total	2,324	885.2	42	464,800	18,589

The saving value of 22,512 Baht/day is contributed to all hospitals received blood service on the sample day. This money might be sufficient for paying the third party to take responsibility for blood distribution. According to the NBC,

there have been several companies offered their services. Some charge for 10% of the blood value. This may result in the higher cost of blood, affecting the end-consumers, the patients, who will have to face more medical fees. To prevent this, a fair price is set in order to select the most proper transportation service provider, and can be applied in an auction.

This sample calculation is only conducted for 6 July 2012. The transport cost per blood bag, provided the average cost of blood is 2,000 Baht/unit. The charge is 10% of the blood value. For route 1, the expense can be calculated as follows.

Expense by unit = The number of units x 200 (Baht/unit) x 10%
= 78 x 2,000 x 0.1
= 15,600 Baht

If the total cost is calculated with transport cost, fixed cost (e.g. vehicle, registration, insurance, driver, etc.), and the variable cost (fuel, engine oil, maintenance, depreciation, etc.) are 21 Baht/km. The results are as follows;

Expense by distance = Cost per km. (Baht/km.) x Distance (km.)
= 21 x 60.60
= 1,273 Baht

Routes 2-17 are calculated in the same way. Table V shows the summary of transport cost on 6 July 2010. As seen in the table, each route takes no longer than three hours. Thus the new blood distribution system can be designed to have two trips per day, three hours per trip, and working hour from 09.00 – 12.00 a.m. and from 01.00 – 04.00 p.m. However, there are two routes that take longer than three hours. These are routes No. 16 and 17, which go to Phatara-Thonburi Hospital and Pathum Thani Hospital respectively. These two hospitals are located relatively very far from the NBC, comparing to other hospitals in the network. In practice, the vehicle assigned for either the route No. 16 or No. 17 can be allowed to spend more than 3 hours for the trip. After arriving back at the NBC, the vehicle can be assigned for another short route, such as the route No. 12 or No. 13.

It is seen that if the transportation cost is calculated by percent, the cost may be as high as 464,800 Baht per day. It is possible that the NBC or the network hospitals will altogether bear so much expense. Another choice is to estimate cost by distance, which should be more reasonable as the transport cost depends on distance. This way, the transport cost is 18,589 Baht/day or about 1,100 Baht per round trip. This number is much lower than the current cost (1,957 x 21 = 41,097 Baht).

Provided that a carrier has expertise in route planning and is able to design the route not less efficiently than reported herein, the transportation cost should be around 18,600 Baht, plus 30% for operating cost and 20% for profit. The fair price for the carrier should be 18,600 x 1.30 x 1.20 = 29,000 Baht. This can be used as the fair price to start the auction. On the other hand, if all hospitals reach an agreement to cooperate, the money saved can be spent on hiring third party transport service provider to offer more efficient blood distribution.

V. Conclusion

From the view of transportation people, solving the VRP is only an effort to meet the need of clients for the best efficiency, especially for the least-cost transportation plan. However, from the view of the NBC, the product (blood) owner, it is something more. It is about the proper and fair cost of transport if it is necessary to hire a third party to take responsibility for distributing blood to hospitals. This paper suggests that the analysis of vehicle routing problem by transport businesses can be also used for the interests of the owner of products in order to set up a proper price for hiring. If the third party can manage the transport routes efficiently, and calculate cost properly, along with reasonable operating cost and profit, they will have a proper price for themselves. The NBC can possibly use this final price as a 'fair price' for hiring transport carrier to distribute blood in Bangkok Metropolitan Region in the future.

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