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Hybrid Genetic Algorithm for the Location - Routing Problem with Emergency Referral

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Abstract

In this research, the location routing problem with emergency referral (LRPER) was defined to solve for (i) the number of local blood banks (LBBs) and their locations; (ii) the assignment of each hospital to each LBB; (iii) the routing from LBBs to hospitals for blood delivery. The mathematical model for LRPER was proposed to solve for the number of LBBs and their locations in such a way that the total cost is minimized and the emergency blood referrals are satisfied. LRPER, which is a special case of Location - Routing Problem, is NP-hard problem. Hybrid Genetic Algorithm (HGA) was developed to solve LRPER. A data set of 93 LBBs in the lower north-eastern provinces of Thailand was used as a case study in this research. The results shown that HGA is an appropriate method to solve LRPER giving the number of locations and routes that yield the lowest cost.

Keywords: Blood Banking; Emergency Referral; Location Routing Problem; Hybrid Genetic Algorithm; Neighbourhood Search

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Introduction

The health care system is one of the most important aspect of the developed countries. Health care logistics has been increasingly aware by professionals in the medical, business and engineering fields because it can be used to improve medical services as well as reduce operating costs. Moreover, the increasing demand for health care services coupled with their importance and higher costs make it necessary to better utilize the medical resources and facilities. The human blood is one of the most important components of a health care system. Human blood is a scarce resource. It is only produced by human beings and there are currently no other products or alternative chemical process that can be used to generate blood.

The rapid increasing demand for blood, criticality of the product, storage, handling, and distribution requirements and limitations, and the different geographical locations of hospitals and medical centers have made management of blood a complex and very important problem. Moreover, many countries face the problem of increasing gap between blood need for transfusion (demand) and donor recruitment (supply). Cost of blood transfusion has been increased due to strict measures in blood safety and logistics. Therefore, an efficient management of blood logistics can cause significant impact on medical operations improvement and maximize the utilization of blood supply.

One of the most important tasks of blood logistic managers is to design an efficient and effective distribution network in order to deliver blood and blood products to hospitals with the lowest cost and in the shortest possible time frame. Blood logistics is an approach to manage and use blood effectively and efficiently. Determining locations of blood banks and distribution of blood product is a strategic decision in the blood logistics. Salhi, S. and Rand, G. K. [1] described that locations of facilities and vehicle routing are critical in any application area. The overall system cost can increase if facility locations are not considered in routing decision. Moreover, in health care system if only a small number of facilities is utilized without the consideration of locations, it may result in increases in mortality and morbidity rates [2]. Blood bank locating and blood products distribution from these blood banks to hospitals are two key components in blood logistics. Therefore, it is necessary to incorporate and compute the locations of blood banks and the vehicle routing decisions simultaneously.

The Location-Routing Problem (LRP) is closely related to the Vehicle Routing Problem (VRP) and the Facility Location Problem (FLP), both of them are shown to be NP-hard [3] - [4]. The main difference of the VRP and the LRP is the decision variables, namely, the locations of depots are decision variables in LRP. Thus, the LRP can be considered as a combination of the FLP and the VRP. For both the LRP and the FLP the locations of the depots are decision variables. LRP considers the creation of routes when the allocation decision is made, the FLP etermines direct route between the customer locations and the depots. Perl, J. and Daskin, M. S. [5] shows how the facility location decision is comprised of three interdependent components; facility location, customer allocation, and routing.

The LRP integrates the decision process to determine the optimal number and locations of facilities to be open, an optimal assignment of customers to facilities, and an optimal set of vehicle routes from facilities to customers. The objective of the LRP is to minimize the total fixed and transportation costs. The LRP belongs to the class of NP-hard problems [6]. Therefore, even heuristic methods specialized in solving this problem require a considerable computation effort.

In this study we developed the location-routing problem with emergency referral (LRPER) model to solve the problem of blood logistics, with an objective to minimize the sum of the total fixed cost of local blood banks (LBBs), the total periodic delivery costs and the emergency delivery costs. The proposed model aims to determine (i) locations and number of LBBs, (ii) assignment of hospitals to LBBs, and (iii) vehicle routing for blood distribution.

This paper is organized as follows: section 2 reviews of literature. Section 3 introduces the problem definition and assumptions. Section 4 presents the LRPER model. Section 5 proposes the HGA for solving LRPER. Computational results are given in section 6 and conclusion is given in section 7.

Literature Reviews

In the past, LRP was applied widely in various applications by Nagy, G. and Salhi, S. [7]. There are also following research that embraced LRP applications in their studies such as, parcel delivery [8] - [9], waste collection [10], newspaper distribution [11], distribution center [12], medical evacuation [13]. In the literature, the research on blood logistics focuses on the complexity of effective and efficient of blood location-allocation. Or, I. and Pierskalla, W. P. [14] considered a regional blood management problem where hospitals were assigned as regional blood banks and developed a location-allocation model to minimize the sum of the transportation and the system costs. One recent research by Şahin, G. et al. [15] presented a blood bank location model and developed several location-allocation models to solve the problems of regionalization based on a hierarchical structure method. However, both studies were carried out to demonstrate blood logistics, considering only the location of blood banks without incorporating the vehicle routing decision simultaneously in their consideration.

Incorporating the routing cost approximations in location models is an approach to solve the location routing problem (LRP). Using an integrated routing and locations mathematical to solve the problem. One of the first mathematical approaches to the location routing problem was introduced by Laporte, G. and Nobert, Y. [16]. This research involves an exact integer programming algorithm for solving a LRP without tour length restrictions and vehicle capacity constraints. The algorithm solve a relaxed model where the integrality and subtour elimination constraints were ignored. A study by Min, H. [17] provides an exact and a heuristic approaches. The exact algorithm is based on integer programming. The heuristic approach is based on the location-allocation-first and route-second approach. Customers are clustered in such a way that the demand for each cluster does not exceed the vehicle capacity. Subsequently, the customers in these clusters are sequenced using a traveling salesman problem (TSP) algorithm to form vehicle routes. Previous researches were carried out only to determine the feasibility of exact solution without incorporating comprehensive data on emergency cost. Perl, J. and Daskin, M. S. [5] proposed a tree-phase algorithm to solve a complex LRP which accounts for variable facility throughput costs and facility throughput capacities. This approach was tested on two problems. It yielded a total cost that is only 5 % higher than the LP lower bound for smaller one, and produced substantial savings for the larger problem. Wu, T. H. et al. [18] extended Perl, J. and Daskin, M. S. [5] model to solve the location allocation problem (LAP). In order to create initial vehicle routing problem (VRP) routes. The routes are treated as if they were one “node.” These “nodes” are used to solve a new LAP. This could potentially reduce the number of warehouses and fixed costs of warehouses. Several authors have proposed the use of metaheuristics to solve the multi-depot location routing problem (MDLRP). Su, C. T. [19] applied a genetic algorithm to the design of a physical distribution system where both the location of facilities and the routing of vehicles were considered. In addition to determining the number and locations of distribution centers, the author also developed a methodology to estimate the required number of vehicles and corresponding routing. Albaread-Sambola, M. et al. [20] developed a two phase tabu search heuristic for the MDLPR with one capacitated route from each depot. In the intensification phase, the routes are optimized while in the diversification phase the set of open depots is modified. Julia, R. et al. [21] presented the model of location-routing problem along with internal transportation processes inside hubs were taken into the consideration in this problem and the model mathematical formula with linear constrains were also considered.

After a thorough review, we have found that the methodology to solve the simultaneous location and routing problems has yet to be explored, especially in the topic of emergency referral. In this research, we proposed a mathematical model for LRPER. In addition, in order to get effective results we also proposed method to incorporate location and routing and solved them simultaneously.

Location Routing Problem with Emergency Referral Model (LRPER)

In this research, the mathematical model for LRPER has been proposed. The model is extended from the LRP by Or, I. and Pierskalla W. P. [14]. Two additional conditions have been incorporated into our model, which are the blood transportation with emergency referral (ER) and operating costs for the establishment of blood bank. The proposed model is call the "location routing problem with emergency referral." The solutions for the LRPER model are the numbers of blood banks, the sizes of blood banks, the locations of blood banks, the assignment of each hospital to appropriate blood bank and the result of the routing of blood transportation from blood banks to hospitals.

Notation

The subscripts, sets, parameters, and decision variables used in the model are described as follows:

a) Subscripts:

i = index of LBBs

j = index of hospitals

k = index of vehicles

b) Sets:

I = set of all LBBs

J = set of all hospitals

K = set of all vehicles

c) Parameters:

N = number of hospitals

d_{ij} = distance between points i and j

f_i = fixed cost for LBB i

e_j = number of the emergency referrals for hospital j

q_j = average number of blood units demanded by hospital j

Q_k = capacity of vehicle k

V_i = capacity of LBB i

c = cost per kilometer of a delivery vehicle

d) Decision variables:

x_{ijk} = 1, if point i precedes point j on vehicle k; 0 otherwise.

y_{ij} = 1, if hospital j is allocated to LBB i; 0 otherwise.

z_i = 1, if LBB i is established; 0 otherwise.

R_i are continuous variables used in the subtour breaking constraints.

Mathematical model formulation

The mathematical model formulation of the LRPER is:

$$\text{Minimize} \sum_{i\in I} f_i z_i + \sum_{k\in K}\sum_{i\in I}\sum_{j\in J} c\cdot d_{ij} x_{ijk} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} c\cdot e_j \cdot d_{ij} x_{ijk} \quad (1)$$

Subject to;

$$\sum_{k\in K}\sum_{i\in I} x_{ijk} = 1, \forall j \quad (2)$$

$$\sum_{j\in J} q_j \sum_{i\in I} x_{ijk} \le Q_k, \forall k \quad (3)$$

$$\sum_{i\in I}\sum_{j\in J} x_{ijk} \le 1, \forall k \quad (4)$$

$$\sum_{j\in J} x_{ijk} - \sum_{j\in J} x_{jik} = 0, \forall k, \forall i \quad (5)$$

$$\sum_{j\in J} q_j y_{ij} - V_i z_i \le 0, \forall i \quad (6)$$

$$\sum_{j\in J}\sum_{k\in K} x_{ijk} - z_i \ge 0, \forall i \quad (7)$$

$$\sum_{j\in J} x_{ijk} - z_i \le 0, \forall i, \forall k \quad (8)$$

$$\sum_{i\in I} x_{ijk} - \sum_{i\in I} x_{jki} = 0, \forall j, \forall k \quad (9)$$

$$R_i - R_j + (R+N)\sum_{k\in K} x_{ijk} \le R + N - 1, \forall i, i \ne j \quad (10)$$

$$x_{ijk} = \{0,1\}, \forall i, \forall j, \forall k \quad (11)$$

$$y_{ij} = \{0,1\}, \forall i, \forall j \quad (12)$$

$$z_i = \{0,1\}, \forall i \quad (13)$$

In this formulation, the objective function (1) minimizes the sum of fixed cost of LBBs, periodic delivery costs, and emergency referral delivery costs. Constraint (2) requires that each hospital has been assigned to a single LBB. Constraint (3) ensures that the vehicle capacity is not exceeded. Constraint (4) guarantees that each vehicle is routed from at most one LBB. The continuity of the routes and return to the original LBB is guaranteed through constraint (5). Constraint (6) ensures that the LBB capacity is not exceeded. Constraints (7) and (8) assure that vehicles must initiate from an opened LBB. Constraint (9) assures that a vehicle leaves and arrives in the same LBB. Constraints (10) are the subtour elimination constraints which guarantee that each tour must contain a LBB from which it originates. Finally, constraints (11), (12), and (13) specify the binary variables used in the formulation.

Hybrid Genetic Algorithm (HGA)

Genetic Algorithm for Location Routing Problem

As mentioned earlier, the LRP can be viewed as an integration of two NP-hard optimization problems where each individual problem is, by its own, difficult to solve. In this research, we propose a genetic algorithm (GA) to solve LRPER. GA is in fact a population-based metaheuristic, which has been proved very powerful to solve many large scale problems [11]. GA can avoid getting trapped in a local optimum by the aid of the genetic operations called mutation. The basic idea of GA is to maintain a population of candidate solutions that evolves under selective pressure. In recent years, GA has been applied successfully to a wide variety of hard optimization problems. The success is mainly due to its simplicity, easy operation, and great flexibility. These are the major reasons why GA is selected as a computation tool in this research.

A. Chromosome representation

Surekha, P. and Sumathi, S. [22] indicated that the design of chromosomes is the first step, and it is one of the step of GA which is important because the design of chromosomes will have a direct effect on the speed in finding the optimal solution. In this research, the representation of a chromosome has to reflect the properties of the LRPER and describe the location of blood banks and the route of a vehicle. Figure 1 shows the representation of a chromosome (10 hospitals and 3 LBBs). Row A_1 represents the number of LBBs. And row B_1 represents the routing of the vehicle. For example, feasible hospitals to be served by LBB#1 are $a_6 = a_7 = a_8 = a_{10} = 1$, and routing for LBB#1 are 6 - 8 - 7 - 10 - 6.

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
A_1	3	2	2	3	3	1	1	1	3	1
B_1	4	6	8	2	3	1	5	7	9	10

Figure 1 The representation of a chromosome

B. Initial population method

The initial population method simultaneously both location set of LBBs and set of vehicle routes from LBB to hospitals by a random generation method. The random generation method gives solutions created from random numbers and a global search. Figure 2 shows three chromosomes an example of initial population generated.

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
A_1	3	2	2	3	3	1	1	1	3	1
B_1	4	6	8	2	3	1	5	7	9	10
A_2	1	3	1	3	3	1	2	1	1	2
B_2	9	10	3	7	6	8	2	4	5	1
A_3	2	1	1	3	2	3	1	3	3	1
B_3	5	8	2	1	10	4	3	6	9	7

Figure 2 An example initial population generated by random generation method

C. Fitness function

For the LRPER, the fitness function should minimize the total costs. The evaluation of fitness function F_{EVAL} is defined as the sum of three types of cost (based on objective function): i) fixed costs of LBBs (FC_{LBB}); ii) periodic delivery costs (PDC); and iii) emergency delivery costs (EDC). Therefore, $F_{EVAL} = FC_{LBB} + PDC + EDC$.

D. Selection

The roulette wheel selection operation is adopted to choose some chromosomes to undergo genetic operations. The approach is based on an observation that a roulette wheel which has a section allocated for each chromosome in the population, and the size of each section is proportional to the chromosome's fitness. The better fit the chromosome is the higher the probability of being selected will be.

E. Genetic Operation

The crossover operation swaps parts of two parents in the population in order to generate offsprings. The crossover is made in hope that an offspring will inherit good parts of old chromosomes. There are many ways to do crossover, and this approach is able to improve the problem by producing offsprings that yield better results. Our crossover operator is applied to both row A (location) and row B (routing). For row A, we randomly select a point to crossover. An offspring is then obtained by appending the beginning of the first parent to the end of the second parent. For row B, we follow the crossover procedure of [12]. First, we select one crossover point and the permutation is copied from the first parent to this point, then the second parent is scanned. If the hospital is not yet in the offspring, it will be added to the offspring. For clarity, let us consider an example as depicted by Figure 3.

F. Compare and replacement

Comparing the quality of two individual chromosomes is important in GA. The replacement of offsprings is the last phase in GA. It consists of maintaining the population size constant. Many existing methods are available in the literature to choose which individual to be removed from the population, such as random replacement or weak parent replacement. In the proposed algorithm, once a new offspring is created (using the GA operators), it is compared to the worst individual in the population. Then the best one is simply kept inside the population.

Hybrid Genetic Algorithm for Location Routing Problem with Emergency Referral

To solve a location-routing problem, there is a need to solve a facility location problem (FLP) and a vehicle routing problem (VRP). Both problems are classified as NP-hard problems [14]. Hence, the LRP is also NP-hard. The LRPER can be viewed as an extension of the capacitated LRP. Derbal, H. et al. [23] proposed a hybrid genetic algorithm (HGA) to solve capacitated LRP. Nevertheless, it is appropriate to develop HGA - based heuristic to solve LRPER.

The procedure of the HGA considers the initial population by using random generation and heuristic techniques. The flowchart of two algorithms, HGA1 and HGA2, for the LRPER is shown in Figure 4. The difference between HGA1 and HGA2 is that HGA1 also hybridizes the greedy random and nearest heuristic to generate initial population. HGA2 hybridizes an improved heuristic, called the neighborhood search. The procedures of HGA1 and HGA2 are described as follows: The HGA generates the initial chromosomes of the problem. Each chromosome contains two sets, A is the set of locations and B is the set of routing in the LRPER. In HGA1, the chromosomes are generated by greedy random and nearest heuristic. Each chromosome is then measured by an evaluation function. The roulette wheel selection operation is adopted to select some chromosomes for the genetic operations, including the order crossover, and the inversion mutation. For HGA2, after new chromosomes or offspring are produced, these chromosomes are improved by the neighborhood search (insertion method and two-opt method). The fitness of the offspring is measured and the offspring may become a member of the population if it possesses a relatively good quality. Then, the roulette wheel selection is performed again to repeat the whole iterations. The HGA will not stop unless the predetermined number of iterations is completed.

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
A_1	3	2	2	3	3	1	1	1	3	1
A_2	1	3	1	3	3	1	2	1	1	2
$A_{offspring}$	3	2	2	3	3	1	2	1	1	2

B_1	4	6	8	2	3	1	5	7	9	10
B_2	9	10	3	7	6	8	2	4	5	1
$B_{offspring}$	4	6	8	2	9	10	3	7	5	1

offspring

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
A_1	3	2	2	3	3	1	2	1	1	2
B_1	4	6	8	2	9	10	3	7	5	1

Figure 3 Crossover operations for the permutation row.

Fitness function

For the LRPER, the fitness function should minimize the total costs. The evaluation of fitness function F_{EVAL} is defined as the sum of three types of cost (based on objective function): i) fixed costs of LBBs (FC_{LBB}); ii) periodic delivery costs (*PDC*); and iii) emergency delivery costs (*EDC*).

$$F_{EVAL} = PDC \tag{14}$$

$$F_{EVAL} = FC_{LBB} + PDC + EDC \tag{15}$$

Problem instances are evaluated using (14) and the test problems as well as real problems are evaluated by (15). Then, the selected initial population are evaluated by roulette wheel method in order to obtain location chromosomes and routing chromosomes.

Computation Results of HGA in LRPER

This section explains the heuristic test in the real problem, which has already been mentioned in some parts of section 1. Real problem used as the case study is the case of Regional Blood Bank V (RBC V). There are 4 provinces that are under the responsibility and care of RBC V. The number of population of these four provinces is approximately 6,740,000 or 10.36 % of the whole population in Thailand. RBC V serves blood approximately 1,200 units per week.

Computational experiments were performed using various data sets from RBC-V of the Thai Red Cross Society, consisting of 93 hospitals. All hospitals are candidate LBBs. The proposed HGA described in the previous section was coded in MATLAB on a computer with Intel Core i5-3210 CPU 2.50 GHz and 4 GB memory.

The first step of this heuristic test method is to compare results similar to section HGA. It is to compare the results of real problem solving done by GGA, HGA1 and HGA2. Then, the computation results will be shown. Details of results include the following information.

Results Comparison

Test results received from solving the LRPER problem, which is the real problem, done by GGA, HGA1 and HGA2 methods are not different from the test results received from solving the problem instances and test problems. It can be said that HGA2 is the algorithm that yields the best result and can be used to solve LRPER with efficient results.

Results Description

From the results shown in table 1 indicating that HGA2 is the heuristic approach that yields the best solution, therefore further result description received from HGA2 will be explained in this section. This includes the list of hospitals chosen to be setup as LBBs, the list of hospitals allocated for each LBB, and the routes for transportation. See more explanation below:

i) Hospitals chosen to be setup as LBBs. With the result of solving LRPER problem done by HGA2, it is found that there are 14 hospitals chosen to be setup as LBBs. 5 in Nakhon Ratchasima and 3 in Chaiyaphum, 3 in Buriram and 3 in Surin. Further details can be seen in table 2.

ii) Allocation of hospitals for each LBB. Results of hospital allocation for each LBB are arranged according to the province area as shown in table 3. For example in Nakhon Ratchasima, LBB 2 is responsible to transport blood for hospital 1, 3, 10, and 13.

iii) Blood transportation route arrangement of each route. Results of blood transportation route from LBBs to each of hospital, allocated for each LBB, is arranged according to the province area as shown in table 4. An example of the route arrangement result is as follows. In Nakhon Ratchasima, blood transportation route 1 start from LBB 7, then out to deliver blood to hospitals 8 - 17 - 4 - 6 respectively. After the completion, the blood delivery vehicle returns to LBB 7.

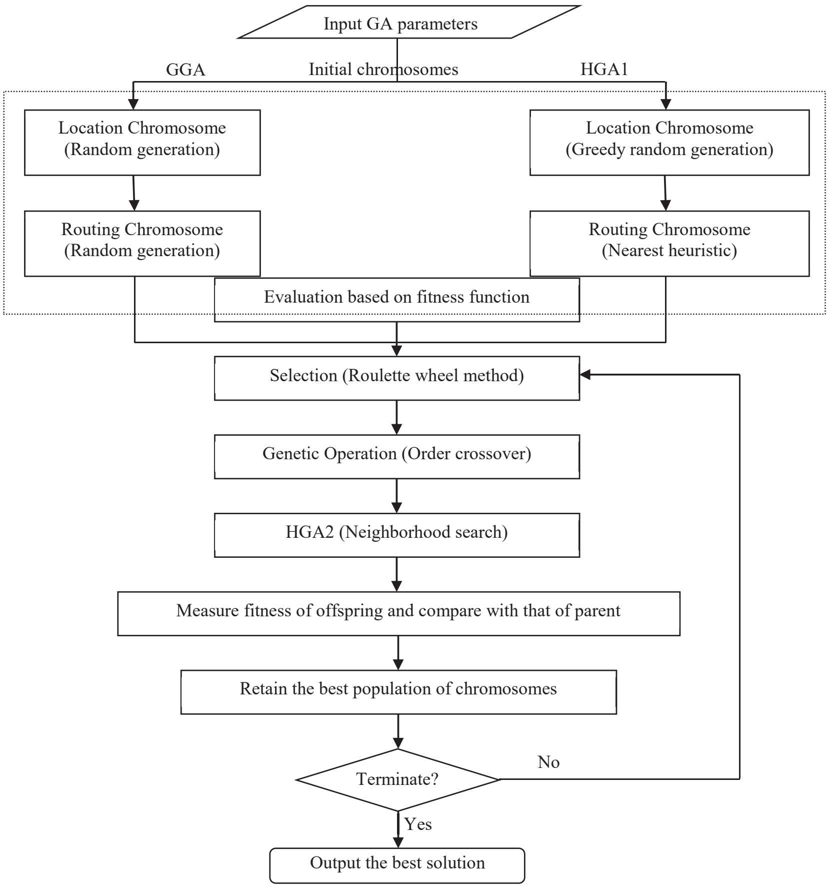

Figure 4 The flowchart of HGA1 and HGA2

Table 1 Computation results compared between GGA, HGA1 and HGA2 in real problem

Province	Min. Cost			%Gap1	%Gap2	%Gap3
	GGA	HGA1	HGA2			
Nakhon Ratchasima	23,049	20,695	17,532	10.21	23.94	15.28
Chaiyaphum	9,025	7,864	7,804	12.86	13.53	0.76
Buriram	13,207	10,564	10,350	20.01	21.63	2.03
Surin	8,529	8,213	7,932	3.71	7.00	3.42
Total Min. Cost	53,809	47,335	43,617			
Average				**11.70**	**16.52**	**5.37**

Table 2 Hospitals chosen to be setup as Location Blood Banks

Province	Hospital to be setup as LBB	Total LBBs
Nakhon Ratchasima	2, 14, 7, 21, 29	5
Chaiyaphum	11, 2, 5	3
Buriram	3, 20, 9	3
Surin	9, 12, 11	3

Table 3 Allocation of hospitals for each LBB

Province	LBB No.	Hospital No.
Nakhon Ratchasima	2	1, 3, 10, 13
	7	4, 6, 8, 17
	14	5, 11, 12, 16, 18, 19, 24, 25, 26, 27, 28
	21	9, 15,20, 22
	29	23, 30, 31, 32, 33, 34, 35, 36
	11	12, 15, 14, 17, 16, 10, 9, 8, 7
Chaiyaphum	2	3, 4, 6
	5	13
	3	2, 5, 6, 7, 12
Buriram	20	14, 1516, 17, 18, 21, 22, 23, 24
	9	1, 4, 8, 10, 11, 13, 19
	9	1, 2, 3, 4, 5, 6, 8
Surin	12	7, 13, 14, 15, 16
	11	10

Table 4 The route for transportation

Province	Route No.	Route Arrangement
Nakhon Ratchasima	1	7-8-17-4-6-7
	2	21-20-22-15-9-21
	3	29-31-30-23-33-32-34-36-35-29
	4	2-1-3-10-13-2
	5	14-18-16-19-12-11-24-25-26-27-28-5-14
Chaiyaphum	1	11-12-15-14-17-16-10-9-8-7-11
	2	2-3-4-6-1-2
	3	5-13-5
Buriram	1	3-2-5-12-6-7-3
	2	20-18-17-14-16-15-21-23-24-22-20
	3	9-8-10-11-4-1-13-19-9
Surin	1	9-8-5-4-3-2-6-1-9
	2	12-15-13-14-16-7-12
	3	11-10-11

Conclusions

Blood logistics is an approach to manage and use blood effectively and efficiently. Determining locations of blood banks and distribution of blood products are crucial for a strategic decision making in the blood logistics. Locations of facilities and vehicle routing planning are critical in any application area. The overall system cost will increase if facility locations are not considered in routing decision. Moreover, operating a small number of blood banks without considering the locations may lead to increasing of mortality and morbidity rates. Thus, blood bank locating and blood product distribution from these blood banks to hospitals are two key components in blood logistics. Therefore, it is necessary to incorporate and compute the locations of blood banks and the vehicle routing decisions simultaneously.

The LRP integrates the decision process to determine the optimal number and locations of facilities, an optimal assignment of customers to facilities, and an optimal set of vehicle routes from facilities to customers. In this research, we propose a mathematical model for location-routing problem with emergency referral (LRPER), which is an integer programming model. The objective is to minimize the total cost of fixed costs of LBBs, periodic delivery costs, and emergency referral delivery costs. We introduced a Hybrid Genetic Algorithm (HGA) to solve the LRPER. HGA can solve the location of blood banks and vehicle routing for blood distribution decisions simultaneously. HGA is based on chromosomes representing both the number of LBBs and the routing of the vehicles. Our HGA include HGA1 and HGA2. GA1, was developed based on GGA procedure with added greedy and nearest heuristics into location chromosomes and routing chromosomes, respectively. HGA2 was developed based on HGA1 procedure and additional solution improvement procedure using neighborhood search method (insertion move and two-opt move). This research also compares the results of HGA1 and HGA2 to GGA using known problem instances and our test problems. Results indicate that the HGA2 yields a stability that shows better solutions on average.

We developed genetic algorithm-based heuristic procedure to solve LRPER. We tested the performance of this heuristic by comparing it to the general genetic algorithm for problem instances and test problems. We find genetic algorithm-based heuristic procedure to be very efficient. It can be easily extended to other classes of the location routing problem. However, direct comparisons with other meta-heuristics could not be made due to lack of available of data or code.

The primary objective of this research has been the development of a location-routing framework which can be used to improve distribution system design. The complexity of this problem has resulted in a lack of solution techniques to the problem. Almost all of the previous research in the area has concentrated on solving either the location problem or the vehicle scheduling problem. The need to provide solution procedures to the actual problem of simultaneous location-routing exists. It is hoped that this research covers some of that ground and provides some impetus to move further in that direction.

As a consequence of these studies, several points of interest have been brought out for further study. First is an investigation of the application of hybrid genetic algorithm to large-scale location routing problems. Second, we recommend incorporating modification HGA with other heuristic techniques to generate a population of initial chromosomes and comparing solution with other meta-heuristics for robust and efficient evaluation. Finally, further improvements in the LRPER model may be brought by considering uncertainty in future operating costs and vehicle travel times.

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