# LOCATION-ROUTING PROBLEM WITH EMERGENCY REFERRAL FOR REGIONAL BLOOD BANKING

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**A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Industrial Engineering**

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# ปัญหาการกำหนดที่ตั้งและเส้นทางการขนส่งสำหรับธนาคารเลือดระดับภูมิภาค กรณีมีความต้องการฉุกเฉิน

นายจารุพงษ์ บรรเทา

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต
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# LOCATION - ROUTING PROBLEM WITH EMERGENCY REFERRAL FOR REGIONAL BLOOD BANKING

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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งานวิจัยนี้ได้กำหนดปัญหาการกำหนดที่ตั้งและเส้นทางการขนส่งโดยพิจารณาความต้องการฉุกเฉิน (Location Routing Problem with Emergency Referral: LRPER) ซึ่งเป็นปัญหาที่แตกต่างจากปัญหาการกำหนดที่ตั้งและเส้นทางการขนส่งทั่วไป ปัญหา LRPER มีวัตถุประสงค์เพื่อหาจำนวนและที่ตั้งของธนาคารเลือดระดับภูมิภาค จัดสรรธนาคารเลือดระดับภูมิภาคให้แก่โรงพยาบาลแต่ละแห่ง และจัดเส้นทางการขนส่งเลือดจากธนาคารเลือดระดับภูมิภาคไปยังโรงพยาบาลแต่ละแห่งอย่างเหมาะสม ตัวแบบทางคณิตศาสตร์ของปัญหา LRPER ที่นำเสนอเป็นตัวแบบที่ทำให้ได้ผลของค่าใช้จ่ายรวมต่ำที่สุด การแก้ปัญหา LRPER ในงานวิจัยนี้จะพิจารณาปัญหาการกำหนดที่ตั้งของแต่ละธนาคารเลือด และการจัดเส้นทางการขนส่งเลือดพร้อมกัน แต่เนื่องจากปัญหา LRP เป็นปัญหาแบบ NP-hard จึงทำให้ปัญหา LRPER เป็นปัญหาแบบ NP-hard ด้วย ดังนั้นงานวิจัยนี้จึงพัฒนาวิธีการทางพันธุกรรมแบบผสม (Hybrid Genetic Algorithm: HGA) เพื่อแก้ปัญหา LRPER โดยใช้ชุดข้อมูลของโรงพยาบาลทั้งหมด 93 แห่ง ของจังหวัดในเขตภาคตะวันออกเฉียงเหนือตอนล่างของประเทศไทย ผลการแก้ปัญหาพบว่าวิธี HGA ที่เสนอเป็นวิธีที่แก้ปัญหาการกำหนดที่ตั้งและการจัดเส้นทางการขนส่งได้พร้อมกัน และให้ผลของคำตอบเริ่มต้นที่ดี แล้วยังนำมาปรับปรุงคำตอบให้ดียิ่งขึ้นได้ เมื่อใช้วิธีการหาคำตอบแบบใกล้เคียงคำตอบปัจจุบัน (Neighborhood search)



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JARUPONG BANTHAO : LOCATION - ROUTING PROBLEM WITH EMERGENCY REFERRAL FOR REGIONAL BLOOD BANKING. THESIS ADVISOR : ASST. PROF. PHONGCHAI JITTAMAI, Ph.D., 104 PP.

LOCATION ROUTING PROBLEM/BLOOD LOGISTIC/EMERGENCY REFERRAL/HYBRID GENETIC ALGORITHM

In this research, a variant of the Location - Routing Problem (LRP), defined as the LRP with Emergency Referral (LRPER), is considered. The LRPER aims to solve the number of local blood banks (LBB) and their locations, assign hospitals to each LBB, as well as determine vehicle routes from LBBs to hospitals with emergency referral. The mathematical model for LRPER is proposed in this study. The problem seeks to minimize the total cost by simultaneously locating each LBB and determining the vehicle routes that satisfy emergency referrals. The LRP is known as a NP-hard problem, hence, the LRPER is also NP-hard. The methodology based on Hybrid Genetic Algorithm (HGA) is developed to solve the problem. A data set composed of 93 hospitals in lower north-eastern provinces of Thailand is used. The algorithm is able to solve for locations and routes simultaneously and yields a decent initial solution. Solutions improvement is done by neighbourhood search.

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Jarupong Banthao

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# CHAPTER I

# INTRODUCTION

## 1.1 Significance of the Problem

The healthcare system has become one of the key development policy in developing countries. The aging society and the continuous improvement on medical treatments cause the healthcare budget to vastly rise. Moreover, there is also a growing requirement in providing cost-efficient healthcare services. Recently, the overall resources allocated to healthcare system in Thailand have significantly increased. The total health expenditure has steadily amplified at a faster rate than the growth of the gross domestic product (GDP). In 2011, the total health expenditure equalled 4.1% of the GDP. The public sector spent for 75.5% of the total cost, while the private sector disbursed for 24.5% (World Health Organization, 2014).

In the last few years, healthcare logistics study has begun with the blood logistics. Blood banking, which is an important part of the health service system and its applications, has a major impact on the success of the medical treatment procedures. Blood is a scarce resource, which is voluntarily supplied by donors. There is no substitute for human blood. Many countries face the problem of growing gap between blood need for transfusion (demand) and donor recruitment (supply). Blood transfusion cost has been augmented due to the new blood safety measures and blood logistics. Therefore, an efficient nationwide management for blood can lead to a significant improvement on medical operations and maximizing of blood supply utilization.

Current operations of the national blood bank in Thailand have some deficiencies in terms of economies of scale, blood safety requirements, self-sufficiency, and service quality. Hospital blood banks (i.e., transfusion centers) are responsible for the whole process of blood requisition, namely collecting, processing, testing, and storing blood and blood components. However, these tasks are yet to obtain the blood supply safely, reliably and efficiently. In Thailand, the latest blood and blood products bill was introduced in 2005, which has restructured tasks of all units related to the blood system of the country.

The Thai Red Cross Society (TRCS) has conducted blood services in Thailand since 1952. In 2010, TRCS received blood from donors for more than 1.7 million units. TRCS has started a project to reorganize the blood centers, which is compatible with the structure proposed in the draft bill throughout the country. Reorganization project is currently in the transition phase and there are still some problems in transforming to the new structure. TRCS allocates national blood services to 12 regions and locates Regional Blood Centers (RBC) in 12 major provinces. These provinces refer to regional blood operations center. Their main functions are blood procurement, processing, cross-matching, storage, distribution, recycling, quality control and outdating. Hospital blood banks, which are smaller blood centers in terms of size, capacity, and functions comparing to the regional blood centers, are capable of collecting, storing, distributing and testing the blood as immediately as required. Regional blood centers are responsible to fulfill all blood-related function to some demands in the regions. Blood components and plasma fractionation are produced at these locations. RBC utilizes a mobile unit to collect blood from donors and delivers either to a regional blood center or to a blood station at the end of the day.

In this study, we focus on the area of regional blood center V of TRCS, which consists of a single RBC and 123 hospitals. A few hospitals in the region ceased blood collection operations and made an agreement with the RBC for the supply of blood. Some of these hospitals order blood from RBC periodically. Each order quantity is determined by a hospital based on past experience and knowledge of professionals. Each request is sent from a hospital to RBC altogether with transportation to pick up blood and then return to the hospital, as shown in Figure 1.1. Practically, an RBC is located far from each hospital in the responsible area. This causes a lot of lengthy and inefficient trips, which lead to high transportation cost. Moreover, blood may not be available to the hospital in time of need especially for emergency requirements of patients.

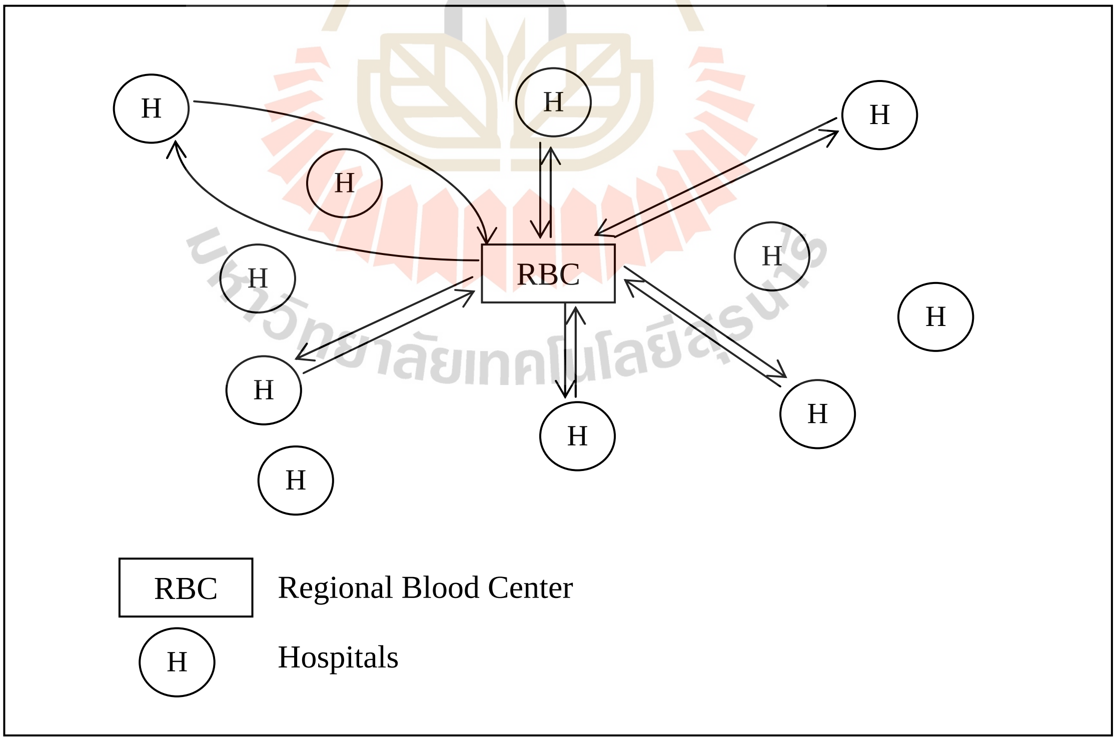


**Figure 1.1** Transport processes in the blood.

In recent years, there has been a considerable number of discussions on the issue of regionalization of the blood center systems. Regionalization is a process by which a set of blood centers within a given geographical area moves toward the coordination of its activities. (OR and Pierskalla, 1979). Such coordination may range from cases in which the blood centers merge into a large, centralized unit, to cases where the existing structure remains unaltered and only certain functions, such as donor recruitment, processing and distribution, are coordinated among the blood centers.

Decentralized mode of operations for blood center system has a disadvantage of high operating cost in establishing the facility and manpower. Another disadvantage of decentralized operations is non-uniform practices which may be adopted in the region. (Cohen and Pierskalla, 1975).The other, and perhaps most important, disadvantage of decentralized operation is the wasteful competition among the banks of a region due to limited supply of donors.

An analysis of regionalization of blood center systems should consider the balance between the aforementioned cost and benefit. Questions of optimal region size, central and local blood center locations, regional boundaries, and optimal distribution network configurations need to be answered.

Another vital issue on regionalization of blood center systems is the fixed facility cost for blood bank. Or (1976) dealt with the problem of locating regional blood banks to distribute blood to hospitals. Blood Transportation Allocation Problem (BTAP) is defined as a problem to determine the number, size, locations of regional blood banks, allocation of hospitals to those banks, and routing of the periodic supply operations in such a way that the sum of transportation and non-transportation costs were minimized. However, locations for regional blood banks were considered only from existing blood banks. Consequently, there is no fixed facility cost in the BTAP and the only transportation cost is the variable cost at regional blood banks.

In this research, we focus on transportation aspects of regionalization. Decision variables are local blood bank locations, regional boundaries, and blood distribution network configurations. The regionalization model with a two-level hierarchy is considered in this study. Regional blood banks are on one level and the local blood banks are on the other. Each local blood bank is to be assigned to one regional blood bank. A regional blood bank with all of the local blood banks assigned to its constitution a single region.

## 1.2 Problem Definition

The Location Routing Problem with Emergency Referral (LRPER) integrates the decision-making process to determine (i) the optimal number and locations for local blood banks; (ii) an optimal assignment of hospitals to local blood banks; (iii) an optimal set of vehicle routes from local blood banks to hospitals with emergency referral. The objective of the problem is to minimize the total fixed operating and emergency costs associated with local blood banks and vehicles. Capacity constraints on local blood banks and vehicles are incorporated in this problem. In particular condition that a set of potential local blood banks and set of hospitals locations are given, we seek to determine a subset of local blood banks required to be opened and a set of routing of vehicles to hospitals from available local blood banks in such a way that.

a) Each hospital is visited exactly once.

b) Each hospital is assigned to exact one local blood bank.

c) Each route starts and ends at the same local blood bank.

d) The total demand of the hospitals assigned to a route does not exceeded the vehicle capacity.

e) The total length of a route is no more than the maximum allowable route length.

f) The total demand of the hospitals assigned to a local blood bank does not exceed the capacity of the local blood bank.

In the context of this research, a route is a path that starts from a local blood bank and returns to the same local blood bank after visiting at least one hospital. Each hospital is allowed only a single visit at each delivery route. Figure 1.2 depicts an example of four different routes from RBC to LBB and hospitals in the area.

We develop a model LRPER associated with the known and fixed demand information and distance matrix. We also assume that each local blood bank has enough vehicles to serve all demands. Furthermore, we consider one class of vehicles, i.e. all having the same characteristics and working under the same conditions.

## 1.3 Research Objectives

In this research the following objectives will be fulfilled:

1.3.1 To propose a mathematical model for LRPER for determining local blood bank locations, boundaries and blood distribution network configuration, with an aim to decrease operating costs, shortages and outdates, without sacrificing blood quality.

1.3.2 To propose an efficient method for solving the location and routing problem simultaneously.

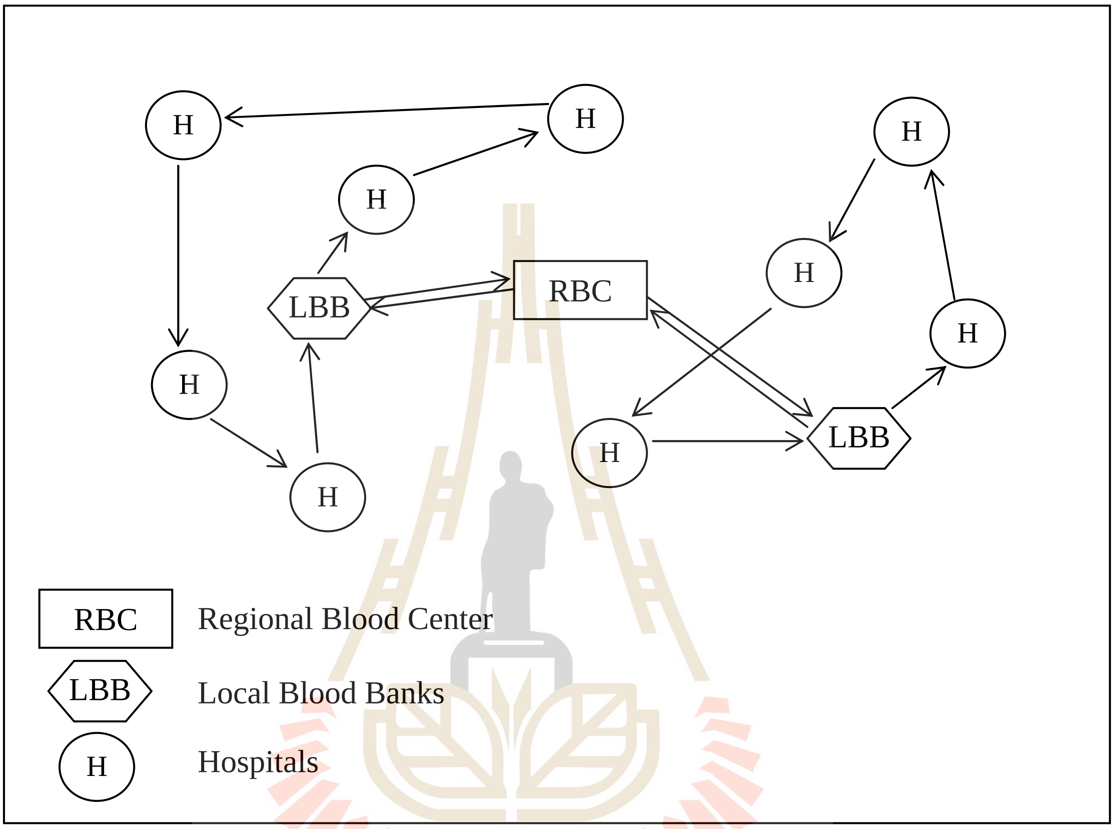


**Figure 1.2** Example of locations and routes of each local blood bank

## 1.4 Scope of the Study

To accomplish these objectives, the following issues will be considered.

1.4.2 The mathematical model for regional blood banks with two level hierarchies is considered. The regional blood banks are on one level and the local blood banks on the other.

1.4.3 Periodic deliveries are assumed. Hospitals will receive their expected requirements daily from the local blood bank. The blood deliveries will be made by a number of vehicles, starting from the local blood banks, then each hospital as scheduled to supply, and return to the local blood banks.

1.4.4 Emergency deliveries are extended in this study. Due to wide fluctuations of demand, hospital may run out of certain types of blood before the next delivery. In that case, a delivery vehicle will be dispatched immediately from its local blood bank. The delivery vehicle will make an emergency blood delivery to that hospital and return back to the local blood bank instantaneously.

1.4.5 There are three types of costs in each region for the operations of this system: (a) periodic delivery costs; (b) emergency delivery costs; and (c) operating costs.

## 1.5 Basic Assumptions

The basic assumptions of this research are:

1.5.1 Some local hospitals also function as local blood banks. The numbers of local blood banks are fixed.

1.5.2 All transportation costs are linear. The Euclidian distance is assumed. Considering the traffic congestion in downtown areas, which is the major highway, is an unrealistic assumption. A more reasonable assumption would be to assume linearity between transportation costs and the travel times between the hospitals. However, Euclidian distances or travel times influence neither the problem structure nor the solution procedure (they are just two different sets of parameters to the problem and, once determined, either set can easily be implemented in the solution procedure). So, although we are going to use the Euclidian distances, one could obtain a matrix of accurate travel time between all pairs of hospitals, and, using this matrix instead of the Euclidian distance matrix in the solution procedure one might produce more realistic results.

1.5.3 The delivery fleet consists of identical vehicles with the same capacity. This is a common assumption in dealing with routing problems. It avoids to add significant complexity that would otherwise result of the need to deal with the allocation of customers not only to routes but also to vehicle type.

1.5.4 There is no limit on maximum tour length. The constraint on maximum route length is not a physical constraint in the LRP, however it is imposed in some cases by labor contracts or other restrictions. This assumption is strictly computational and can be avoided at the expense of escalating a considerable computational effort.

1.5.5 If a delivery vehicle visits a hospital on its regular periodic supply operations, it delivers all of that hospital's expected blood requirement for the period. This assumption is very realistic for the model because it is a common practice in the regional blood bank.

## 1.6 Organization of Thesis

In this research is organized as follows. Chapter 1 illustrates the significance of the problem and research objectives. In Chapter 2, the relevant literature for location problem, vehicle routing problem, and location routing problem are discussed. Chapter 3, provides a mathematical formulation for the LRPER model and the Hybrid Genetic Algorithm (HGA) is proposed to solve the LRPER. The computational results and discussions are proposed in Chapter 4. Finally, in Chapter 5, summary, conclusion, and directions for future research are provided.

# CHAPTER II

# LITERATURE REVIEW

In this chapter, we provide a literature review for the topics that are used in more than one chapter. We first discuss the facility location problem. We describe the problem in section 2.1 and discuss the vehicle routing problem in section 2.2. In section 2.3, we describe the location routing problem. Solution approaches for the location routing problem is the focus of section 2.4. Section 2.5, we describe an overview of genetic algorithm.  Finally, described the applying genetic algorithm in section 2.6.

## 2.1 Facility Location Problem (FLP)

Facility location problem (FLP) arise in the context of many distribution and logistics systems design problems, whether it be the location of depots, plants, vehicles, people, or services. In general, the FLP may be defined as: Given a set of potential locations, select as facilities those which will satisfy the given constraints, while meeting the required objective. Because of the nature of involvement, location problem can occur both in manufacturing industries, for example, the location of warehouses in distribution systems, as well as in service and public sectors. Example of these would be emergency vehicle location, location of personnel (such as farm advisors, or medical advisors), and the location of blood banks.

Location models can be divided into two main structural categories. The first category is location on a continuous plane, or the infinite set approach. Classical location solution methods have taken this approach. Starting with the Weber location problem, the problem has been developed to include multiple facility location, and to consider stochastic factors such as customer demand. The usual problem is to find the location of facilities which minimize the sum of weighted Euclidean distances of customers from these locations. The objective may not be specifically distance but may be some surrogate thereof.

The second category is location on a network. This location problem is characterized by a finite solution space consisting of points on the network. This is especially true of transportation based location problem, where the underlying network may be highways or streets (Handler and Mirchadani, 1979). The distance measurement is according to the shortest paths between points on the network. In the past few years, more attention has been given to the problem of locating facilities on a network. Given a number of demand areas and alternative sites for the facilities the basic location problem is to determine where the facilities should be placed on the network, and which area is to be served by a given facility.

The location problems in the manufacturing sector and other private sector physical distribution systems share common characteristics. In the literature on location models, the objective of location has been considered mainly as economic in nature, whether minimization of costs or maximization of profits. There may be various other non-quantifiable factors that affect the location decision. Some of such factors might be the lab or market, the union climate, community support, and even personal preference of the decision maker. However, these are difficult to quantify and formalize in a mathematical model.

The location problems in the service and public sectors have been treated somewhat differently in the literature. They differ from the problems in the manufacturing sector in that the goals and objectives may be different and not easily quantifiable. Examples of different objectives may be the maximum coverage of customers, or the minimization of maximum response time in the case of emergency services. However, cost may still be defined as an objective in many instances, especially as a surrogate objective to represent the more no quantifiable objectives. Services are further partitioned into those that are ordinary services, such as post offices and mail boxes, city bus stops, and those that are emergency services such as ambulance, fire and police. This is due to differing objectives and nature of constraints such as time and distance. Examples of emergency service sector location problems are location of fire stations to minimize the maximum travel time, location of ambulances to minimize response time, location of police stations to maximize the population covered.

Revelle et al. (1970) analyzed and differentiated between private and public sector models. In the private sector, the objective in most cases was to minimize the sum of the transportation cost and the amortized facility costs. A general mathematical formulation of the FLP in private sector is as follows.

Model 1: Location on a network

*Notations:*

$m$ = number of proposed depots.

$n$ = number of demand points.

$x_{ij}$ = quantity shipped from depot i to demand node j, i =1,…,m, j =1,…,n.

$y_i$ = total amount shipped from depot i, i =1,…,m.

$d_{ij}$ = distance shipped from depot i to demand node j.

$f_i$ = fixed and operating costs of depot i, i =1,…,m.

$D_j$ = demand at node j, j =1,…,n.

The model is formulated as:

$$\text{Minimize Z} = \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij}x_{ij} + \sum_{i=1}^{m} f_i y_i \tag{2.1}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} = y_i \qquad i = 1,\ldots,m \tag{2.2}$$

$$\sum_{i=1}^{m} x_{ij} = D_j \qquad j = 1,\ldots,n \tag{2.3}$$

$$x_{ij} > 0 \qquad i = 1,\ldots,m,\ j = 1,\ldots,n \tag{2.4}$$

$$y_i > 0 \qquad i = 1,\ldots,m \tag{2.5}$$



Model 2: The m-median problem.

*Notations:*

$m$ = number of facilities to be established.

$n$ = number of nodes in the network.

$a_i$ = demand at node i, i =1,…,n.

$d_{ij}$ = shortest distance from node i to node j, i=1,..,n j=1,..,n.

$$x_{ij} = \begin{cases} 1 \text{ if node i is assigned to center j, i =1,...,n, j =1,...,n} \\ 0 \text{ otherwise} \end{cases}$$

The model is formulated as:

$$\text{Minimize Z} = \sum_{i=1}^{n} \sum_{j=1}^{n} a_i d_{ij} x_{ij} \tag{2.6}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad i = 1,\dots,n \tag{2.7}$$

$$x_{ij} = m \qquad j = 1,\dots,n \tag{2.8}$$

$$x_{jj} > x_{ij} \qquad i = 1,\dots,n,\ j = 1,\dots,n,\ \text{i} \neq \text{j} \tag{2.9}$$

$$x_{ij} = \{0,1\} \qquad i = 1,\dots,n,\ j = 1,\dots,n, \tag{2.10}$$

The usual approach to the location problem has been solution by mixed integer programming. However, there are problems with this approach, such as presence of non-linearity in the cost functions in many cases. Also, the computer storage and time required to solve mixed integer programs grows very quickly with problem size, and therefore, such an approach cannot be used for large problems. The approaches taken to solve the problem are broadly classified as heuristics, exact methods, and simulation. First, the single facility location problem is analyzed.

Hakimi (1964)was the first to study the single facility location problem. He examined the problem with regard to locating a single switching enter in a communications network. He proved that there must exist an optimal location which is a node on the network and provided as algorithm to solve it. Mirchandani (1979) has shown that regardless of whether the network is oriented or not, an optimal solution exists on one node in the network.

Mirchandani (1980)has considered the case of location decisions on stochastic networks. In the context of locating public facilities, implicit in deterministic modelling is the assumption that people always true. Hence, there may be a need to model the stochastic nature. Further discussions on the probabilistic location problem on networks is provided in Handler and Mirchandani (1979)

## 2.2 Vehicle Routing Problem (VRP)

The routing and scheduling of vehicles and crews are of importance to both operations researchers and transportation planners. A well-structured and costly activity which is present in both the public and private sectors, it would appear to be a prime candidate for model-based planning and optimization (Toth P. and Vigo D., 2001). However, the combinatorial complexity of the routing problem has precluded the widespread use of optimization methods for this class of problems.

The problem considered is that in which a set of geographically dispersed customers with given requirements must be served by a fleet of vehicles stationed at given depots. It is assumed that all vehicles start and end at the depots. The vehicle routing problem is simply a generic name for a broad class of practical decision making problem, involving the visits of “customers” by “vehicles”. By vehicle route is implied a sequence of demand points which the vehicle must travel in order, starting and ending at a depot.

The vehicle routing problem has evolved from the travelling salesman problem. In order to review the vehicle routing model, it is necessary to first examine the travelling salesman problem and its solution procedures.

### 2.2.1 The Travelling Salesman Problem (TSP)

Most vehicle routing models are the extensions of the TSP. The TSP is the most basic version of the VRP, and also one of the most intensely studies areas of combinatorial optimization. The problem is very easy to state, and very difficult to solve. Given a set n nodes, the problem is to form a tour of the n nodes beginning and ending at the origin, say at node 1. A general mathematical formulation of the FLP in private sector is as follows.

Model 3: Travelling Salesman Problem (TSP)

The problem is to form a tour of the n nodes beginning and ending at the origin, say node 1.

*Notations:*

$s$ $= \{\mathrm{i} \mid i = 1,\ldots,n\}$ be the set of all nodes in the network.

$d_{ij}$ = distance between node i and j, $\forall \mathrm{i,j} \in \mathrm{s}$ .

$x_{ij}$ $= \begin{cases} 1, \text{ if arc i ,j is in the optimal tour } \forall \mathrm{i,j} \in \mathrm{s} \\ 0, \text{ otherwise} \end{cases}$

$X$ $= \{\mathrm{x_{ij}} \mid i, j = 1,\ldots,n\}$ is the set for all $\mathrm{x_{ij}}$

The model is formulated as;

$$\text{Minimize } Z = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij}x_{ij} \tag{2.11}$$

Subject to

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad j = 1,\ldots,n \tag{2.12}$$

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad i = 1,\ldots,n \tag{2.13}$$

$$V = \left\{ \left(x_{ij}\right) : \sum_{i \in Q} \sum_{j \in S} d_{ij} x_{ij} \geq 1 \text{ for every nonempty proper subset of Q of S} \right\}$$

$$X \in V \tag{2.14}$$

$$x_{ij} = \{0,1\} \qquad i = 1,\ldots,n,\ j = 1,\ldots,n, \tag{2.15}$$

There are many ways of obtaining solutions to the TSP. Exact solution procedures based on sequential tour building have been developed by Held and Karp (1971) and by Little et al. (1977). Held and Harp used a dynamic programming approach, while Little et al. have used a branch and bound approach. Some approximation algorithms which are sequential tour building methods are as follows:

(a) Nearest Neighbor Algorithm: Starting with any node, find the node closest to node last added and add to the path the edge between the two nodes. The tour completes when the first and the last nodes join. Rosencrantz et al. (1977).provides a bound on the worst case behavior of this algorithm.

(b) Clarke and Wright (1964) Savings Method: Saving is the distance travelling saved by visiting two customers joined in a link rather than visiting each of the two customers separately. The saving for all the links which can be formed are ordered, and starting from the largest savings the links are joined together to form a increasingly larger sub tour until a tour is formed.

(c) Insertion methods: The tour is constructed by inserting a node into a sub tour, thus increasing the sub tour until it is finally a tour. The insertion method could be the nearest insertion.

### 2.2.2 The Vehicle Routing Problem (VRP)

The TSP discussion has been in the context of a single depot, with no constraints on the vehicles, in terms of capacity, distance, or time. In a more realistic situation, there are likely to be multiple depots, and vehicles would have constraints imposed on them, capacity being the most common one.

The single depot VRP was first discussed by Dantzing and Ramser (1959), who developed a heuristic approach using linear programming and aggregation of nodes ideas. The problem is stated as: Find a set of delivery routes from a central depot to various demand points, each with known requirements, so as to minimize the total distance covered by the entire fleet of vehicles. It is assumed that all vehicles start and finish at the depot, thereby completing tours. A general mixed integer program formulation of the VRP based on Christofides and Eilon (1969) formulation is shown below.

Model 4: Vehicle Routing Problem (VRP)

*Notations:*

$X$ $= \{\mathrm{x_i} \mid i = 1,\ldots,N\}$ is the set of customers, $\mathrm{x_0}$ is depot.

$V$ $= \{\mathrm{v_k} \mid k = 1,\ldots,M\}$ is the set of vehiclea at the depot.

$q_i$ = quantity of product demanded by customer $x_i$, i=1,...,N

$u_i$ = time required by a vehicle to visit customer $x_i$ and unload

$q_i$, i=1,...,N

$Q_k$ = capacity of vehicle $k$, k=1,...,M

$T_k^s$ = start of working time for vehicle $k$, k=1,...,M

$T_k^f$ = end of working time for vehicle $k$, k=1,...,M

$C_k$ = fixed cost of vehicle $k$, k=1,...,M

$C_{ij}$ = least cost path from i to j, $i, j = 0,1,\ldots,n.,\ i \neq j$

$t_{ij}$ = travel time from i to j, $i, j = 0,1,\ldots,n.,\ i \neq j$

$y_i$ = arbitrary real numbers

$$x_{ijk} = \begin{cases} 1, \text{ if vehicle k visits customer j immediatly after visiting customer i} \\ 0, \text{ otherwise} \end{cases}$$

The model is formulated as;

$$\text{Minimize Z} = \sum_{i=0}^{M}\sum_{j=0}^{N} c_{ij}\sum_{k=1}^{M} x_{ijk} + \sum_{k=1}^{M}\left(c_k \sum_{j=1}^{N} x_{0kj}\right) \tag{2.16}$$

Subject to

$$\sum_{i=0}^{N}\sum_{k=1}^{M} x_{ijk} \leq 1 \qquad j = 1,\ldots,N \tag{2.17}$$

$$\sum_{i=0}^{N} x_{ipk} - \sum_{j=0}^{N} x_{pjk} = 0 \qquad k = 1,\ldots,M,\ p = 0,1,\ldots,N \tag{2.18}$$

$$\sum_{i=1}^{N}\left(q_i \sum_{j=0}^{N} x_{ijk}\right) \leq C_k \qquad k = 1,\ldots,M \tag{2.19}$$

$$\sum_{i=0}^{N}\sum_{j=0}^{N} t_{ij}x_{ijk} + \sum_{i=1}^{N}\left(u_i \sum_{j=0}^{N} x_{ijk}\right) \le T_k^f - T_k^s \quad k = 1,\dots,M \tag{2.20}$$

$$\sum_{j=1}^{N} x_{0jk} \le 1 \qquad k = 1,\dots,M \tag{2.21}$$

$$y_i - y_j + N\sum_{k=1}^{M} x_{ijk} \le N-1 \qquad i, j = 1,\dots,N., \; i \ne j \tag{2.22}$$

$$x_{ij} = \{0,1\} \qquad \forall i, j, k \tag{2.23}$$

This formulation also includes scheduling constraints. The objective function (2.16) minimizes the total cost. Constraint (2.17) implies that a customer can be visited at most once. Constraint (2.18) requires that a vehicle visiting a customer must depart from it. Constraint (2.19) and (2.20) are vehicle related constraints, which require that the total carried by a vehicle does not exceed the vehicle capacity, and the total working time does not exceed the allowable working time. Constraint (2.21) implies that a vehicle can be used only once. Constraint (2.22) is a sub tour breaking set of constraints, which force each vehicle route to pass through the depot. The last sets of constraints are integrity constraints.

The main shortcoming of this model and of other models formulated is that it is virtually impossible to introduce any of the additional practical constraints such as different types of products, subsets of vehicles that can be used to make deliveries to particular customers, and priorities of customers. Similarly, vehicles may have additional constraints, such as compartmentalization. There are various other underlying assumptions in different VRPs which need to be considered.

## 2.3 Location Routing Problem (LRP)

### 2.3.1 Relationship between Facility Location, Customer Allocation, and Vehicle Routing

The LRP is closely related to the VRP and the FLP. The main difference of the VRP and the LRP is the decision variables, namely, the location of depots are decision variable 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 determines direct route between the customer locations and the depots. Perl and Daskin (1985) shows how the facility location decision is comprised of three interdependent components; facility location, customer allocation, and routing.

The warehouse selection decision determines which customers are serviced from which warehouse, i.e., customer allocation. The customer-warehouse allocation, however, determines customers that are combined on a route. Going in the other direction, the customers' locations and demand requirements have direct effect on allocating customer to warehouse. Distribution activities typically involve shipping goods from multiple origins to multiple destinations. When there are a number of small shipments, i.e., less-than-truckload (LTL), consolidation may reduce the shipping costs. Typically, the unit freight rates for LTL shipments are two to three times higher than those for TL shipments (Min, 1996).

Servicing customers by way of delivery routes by ignoring the routing costs might lead to the increase of subsequent distribution costs (Salni and Rand, 1898). However, when customers orders are in multiple numbers of truckloads and the number is integer the solution to the FLP is optimal for the LRP, where routing can be ignored (OR and Pierskalla, 1979).

### 2.3.2 Class of Location Routing Problem

Min, et al. (1998) identifies two broad classes of the LRP; single stage and two-stage LRP. The single stage LRP focuses on the outbound delivery routes and the location of the depots. The two-stage LRP, or secondary facility LRP, adds a second dimension by considering both the outbound and inbound delivery routing. The various subcategories identified in their classification scheme include stochastic or deterministic demand, primary or secondary facility, and number of facilities.

Laporte, et al. (1986) proposes a classification scheme based on the number of layers and the distribution mode. Mode R refers to a return trip, which is a trip to and from a single location. Mode T refers to a tours, which is a round-trip that could visit to several locations before retuning. In this scheme, 2/R/T refers to large shipments that arrive at a secondary facility, then are broken up and shipped in smaller quantities to customers.

## 2.4 Approaches to solving the location routing problems

### 2.4.1 Exact Solution Procedures

Incorporating the routing cost approximations in location models is an approach to solve the LRP. Another approach is to use an integrated mathematical programming formulation to solve the problem in a simultaneous and interactive fashion. One of the first mathematical programming approaches to the location routing problem is by Laporte and Nobert (1981). This research involves an exact integer programming algorithm for solving a location routing problem without tour length restrictions and vehicle capacity constraints. The model solves LRP for the optimum location of a single facility which minimizes the sum of fixed facility location costs and routing cost. The algorithm solves a relaxed model where the integrality and sub-tour elimination constraints are ignored. Integrality is enforced using a branch and bound methodology, and the sub-tour elimination constraints are added iteratively when they are violated. The computational study reported in the paper is limited to problems with 20 to 50 customers due to the increasing computational difficulty with problem size.

Laporte, et al. (1983) developed an exact algorithm in an attempt to solve an incapacitated multi-facility location routing problem. Two different formulations were used for cases with Euclidean and non-Euclidean routing costs, and it has been shown that the difficulty of the problem is highly related to the nature of the routing costs. In a similar fashion to the previous study, the sub-tour elimination constraints are added only when violated. Computational results with up to 50 nodes (customers and facility sites both) are reported.

An exact algorithm for the capacitated non-Euclidean LRP is given in Laporte, et al. (1986). This algorithm also made use of constraint relaxation methods and obtained an initial solution by eliminating the integrality, sub-tour elimination, and chain barring constraints (cuts that are introduced to eliminate tours which start and finish at different facilities). These constraints are added during the solution procedure as they are violated. Vehicle capacity constraints are also forced by fixing certain variables at zero. This procedure is used to obtain the optimal solutions to problems with 20 customers and 8 possible facility locations.

In another paper, Bookbinder and Reece (1988) formulated a three-layer multi-commodity, capacitated distribution system as a non-linear, and mixed integer program. They used a solution procedure based on Benders decomposition, which decomposes the problem into two sub-problems. The master problem determined the location of warehouses and the allocation of customers to the warehouses and solves the routing problem for the optimal routing for each warehouse given the location-allocation decisions. Due to the computation requirements of the procedure, it was used to solve small problem in stances. One of the example problems has 12 customers, 3 plants (primary facilities), 4 facilities (secondary facilities) and 3 product types.

One recent study by Min (1996) provides an exact and a heuristic approach. 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 such that the demand for each cluster does not exceed the vehicle capacity. Subsequently, the customers in these clusters are sequenced using a TSP algorithm to form vehicle routes.

Each LRP has had a different objective function, such as to minimize periodic delivery costs, operating costs, and fixed facility costs. Although, the reported previous researches have been carried out to demonstrate the feasibility of exact solution, comprehensive data on emergency cost have not been presented.

### 2.4.2 Heuristics

Due to the exponential growth in problem size, optimal solution approaches to the location routing problem have been limited to small and medium size instances. As the problem size gets larger, heuristic procedures prove to be the only viable alternative. Some of these heuristic approaches will be reviewed next.

One of the earlier attempts to solve a practical location routing problem is given in Or and Pierskalla (1979). They considered the problem of locating regional blood banks to serve hospitals so that the sum of routing costs for periodic deliveries and “straight-and-back” emergency costs is minimized. The simplifying assumption in their paper is that the number of feasible combinations of facilities is limited, and all possible location alternatives can therefore be enumerated. The study ignores the location part of the problem, and concentrates on the allocation and routing decisions. They propose two routing algorithms, both of which ignore system costs and route length and vehicle capacity constraints. One of these algorithms uses a multiple traveling salesman type heuristic to minimize the periodic routing costs. The other algorithm tries to reduce the emergency routing costs by assigning each customer to its nearest facility. An iterative exchange procedure is performed to reduce the total cost by customer exchanges between facilities. Only those customers that are assigned to different facilities by the two routing heuristics are considered for an exchange.

Perl and Daskin (1985) proposed a tree-phase algorithm to solve a complex LRP which accounts for variable facility throughput costs and facility throughput capacities. The first phase is an initialization phase that heuristically constructs an initial set of routes assuming that all facilities are open. This initialization phase is followed by two phases that are to be opened. In phase 3, a multiple facility vehicle routing problem is solved for the facilities that are opened in phase 2. The solution to phase 3 is a new set of routes. If this set of routes result in a sufficiently large decrease in the total cost, the algorithm goes back to phase 2. 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.

Srivastava (1993) also suggests three heuristics for the LRP and explores the effects of several environmental factors. The first heuristic (SAV1) assumes all facilities to be open initially, and uses approximate routing costs for open facilities to determine the facility to be closed. The second heuristic (SAV2) takes the opposite approach, and considers adding facilities one by one, and is faster than SAV1 if a small number of facilities are to be chosen out of a large set of candidate sites. The last heuristic, CLUST, identifies cluster by generating the minimal spanning tree of customers and then separating it into a desired number of clusters using a density search clustering technique. When compared to the sequential approach, which first determines the facility location and then solves the multi-facility routing problem using the modified savings algorithm, all three perform significantly better. Computational results also show that SAV1 and CLUST are superior to the SAV2 heuristic.

One recent study by Wu, et al. (2002) extends Perl and Daskin (1985) by first solving the location allocation problem (LAP). They use these allocations to create initial 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 the costs.

Several authors have proposed the use of meta-heuristics to solve the multi-depot location routing problem (MDLRP). Albaread-Sambola,et al. (2005) develop 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.

After a thorough review, we have found that the area of heuristic approaches to solve the simultaneous location and routing problems has not yet been adequately addressed for solving emergency referral problems.

In this research, we will propose a mathematical model for LRP with emergency referral cost. In addition, in order to get effective results we will propose method to solve location and routing simultaneously.

## 2.5 Genetic Algorithm

Human being and all living creatures have evolution and have on going inherited variants. It starts from that each human chromosome is not the same, so human has different body size, face, and skin, and even character is not the same. In inherited variants, chromosomes of the parents are mixed together into a chromosome of the offspring. Some dominant and recessive genes of parents are kept, and some will be cut. In this procedure, it is based on the genetic hybrid method, or it is called genetic selection. This is the of creatures genetic process algorithm.

Holland J.H. (1992) described about Genetic Algorithm (GA) that it is the Heuristic simulated the procreate of creatures into the method's mechanism in order to select good or bad answer, and it has the evolution from generation to generation to develop the best answer which is the main goal of Heuristic algorithm development.

Dowsland K.A. (1996) described about the main elements of the genetic algorithm as consisting of four main components, i.e. Chromosome Encoding, Initial Population, Fitness Function, and Genetic Operator, which are detailed of as follows:

### 2.5.1 Chromosome Encoding

Chromosome Encoding is the stage to encode chromosome and make it comply with the real problems which require the solution development by GA. There are various kinds of chromosome encoding; only the following three are briefly discussed here:

1) Binary Encoding is the chromosome replaced with 0 or 1 only, as it is mentioned in Figure 2.1a. Characteristic of Binary Encoding is usually applied to the variables that determine the response in binary as well.

2) Permutation Encoding is the chromosome designed by using general numeric such as 1-10, and such numbers indicated the process of transit or manufacturing process as it is shown in Figure 2.1b.

3) Value Encoding is the chromosome which used real number or alphabets as the representative of real answer to replace value encoding in chromosome as it is presented in Figure 2.1c. It is applied with the variable which has value in numbers such as number of parts to be produced, etc.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |

***a. Binary Encoding***

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | 9 | 10 | 3 | 1 | 4 | 8 | 7 | 2 | 6 |

***b. Permutation Encoding***

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 50 | 35 | 100 | 5 | 75 | 40 | 85 | 70 | 25 | 65 |

***c. Value Encoding***

**Figure 2.1**Chromosome Encoding

Surekha P. and SumathiS. (2011) indicated that the design of chromosomes is the first step, and it is one of the steps of GA which is important because the design of chromosome will have a direct effect on the speed in finding the optimal solution.

**2.5.2 Initial Population**

Initial population is to create the model population and use as the initial point of the process of evolution. This is the first step which occurs before entering to the process of GA. The first group of population or initial population might come from randomly chosen method or other methods in order to obtain numbers of model population. The used method can be the same of different. The created model population is a parameter set up before the start of the initial population of the GA. There are several methods to find initial population such as:

1) Random: the random will have the same possibility

2) Greedy Random is the random method with different possibilities. Each choice has different possibilities as it depends on each variable. For example, VRP will randomly select customers who have to transfer goods in the next stage, and the customers with more numbers of transferred goods shall have high possibility to transfer goods than other customers.

**2.5.3 Fitness Function**

The equation for the answer is the function used to determine the appropriateness to provide scores for all possible answers. The result of the appropriate assessment may be the answer of the problem which is needed to be solved directly, or it may be the other functions used to evaluate the appropriateness only to vary answers in order to obtain the optimal answers. The following details are the method to identify the fitness Function.

2.5.3.1 Fitness function in penalty type is an appropriate fitness function for answers which cannot be used for the answers to the questions that required solution. However, it is acceptable to be a model chromosome to obtain new answer or to improve specific answer for the better final answer.

2.5.3.2 Fitness function which is objective function and this type of fitness function might change some objective functions or it might not been changed. The more adjustment has been made on objective function, the more advantages it will get to search for solutions in many areas. However, fitness function will not change much from objective function, but it will change in some rhythm in repeated cycle.

**2.5.4 Genetic Operator**

Osman, et al. (2003) and Geonwook,et al. (2007) defined the meaning of genetic operator accordingly that genetic operator is the operator to transfer from generation to generation such as selection, crossover, and mutation with the following details.

2.5.4.1 The Crossover Operator

The crossover operator takes two chromosomes, separates them at a random site (in both chromosomes), and then swaps the tails of the two, resulting in two new chromosomes. Cutting the chromosome at one location, called single-point crossover, is not the only possibility. Multipoint crossover can also be used (see Figure 2.2a and 2.2b).

The crossover operator does not create new material within the population but inter-mixes the existing population to create new chromosomes. This allows the genetic algorithm to search the solution space for new candidate solutions to solve the problem. The crossover operator is generally accepted as the most important operator. Though it is important, the next operator provides for the introduction of new material within the population.

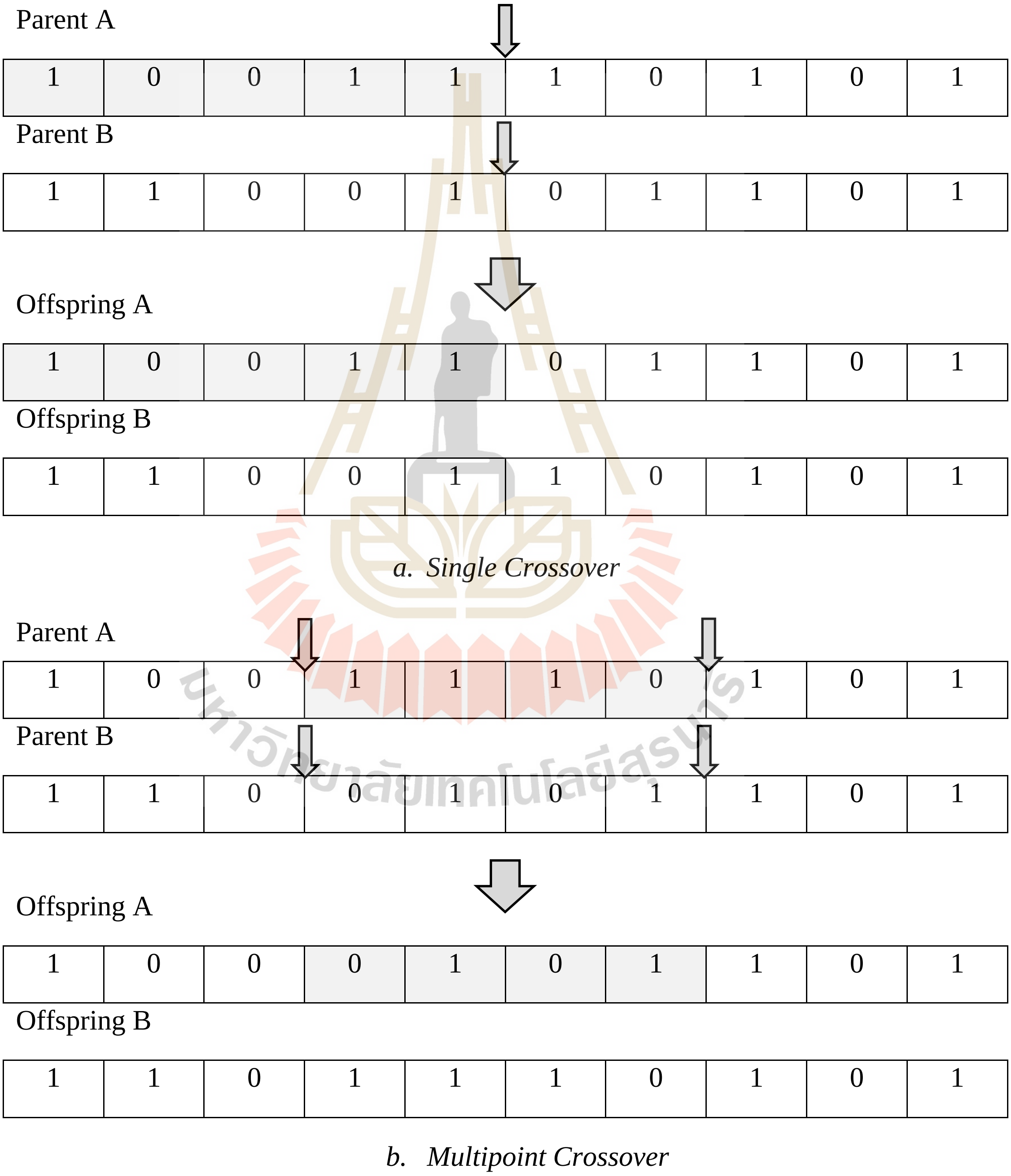


**Figure 2.2** Single and multipoint crossover

2.5.4.2 Mutation

The mutation operator introduces a random change into a gene in the chromosome (sometimes more than one, depending on the rate of application). The mutation operator provides the ability to introduce new material into the population. Because chromosomes intermix with existing chromosomes, mutation provides the opportunity to "shake up" the population to expand the solution space (See Figure 2.3).

Parent

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 |

Offspring

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 |

**Figure 2.3** Inversion mutations

# CHAPTER III

# RESEARCH METHODOLOGY

This chapter presents discuss the research concept and the research process which will explain about the mathematical model, the presented heuristic method, the testing of heuristic with a sample of problem, the computer and program used for calculation, the comparison and selection of the searching for answer starting from heuristic method as well as the improvement of answer by a meta-heuristic method. This research has chosen the genetic algorithm method with the following details:

## 3.1 Research Conceptual Framework

According to the aforementioned problem of blood transportation at regional blood centres as stated in Chapter 1, it is discovered that the inefficient blood transportation has both direct and indirect effects. Direct effect is the high cost of blood transportation caused by one-way trip while indirect effect is the inadequate service for users. Therefore, we have came up with an approach to solve such problem and improve the transportation method for maximum efficiency.

The proposed model of location routing problem with emergency referral (LRPER) incorporates the literature of Or and Pierskalla (1979) as the foundation to define our problem due to some common characteristics of the location routing problem (LRP). Still, there are some factors that Or and Pierskalla did not consider, such as the operating cost for the facility of blood bank and the cases of urgent blood requirement. This research will investigate these two important factors in LRP.

Moreover, the method to solve problem proposed by Or and Pierskalla was a two-stage solution, i.e., to find the location of blood bank first and then arrange the routing for blood transportation. This lead to some limitation that their proposed algorithm cannot handle large problem well. Therefore, the aim of this study is to extend the work of Or and Pierskalla (1979) by adding conditions of operating costs of blood banks and emergency referral.

The newly-defined LRPER will be able to find three solutions: i) appropriate numbers and locations of blood banks; ii) assigning each hospital to appropriate blood bank and iii) appropriate routing for blood transportation. The main objective of LRPER is to minimize the sum of total costs of operating the blood banks, blood transportation and blood transportation in emergency referral cases.

Besides, this research will develop the solutions which make it possible to consider two problems simultaneously. However, since the LRP is a NP-Hard problem as and, the LRPER is extended from the LRP. Thus, LRPER is also a NP-Hard problem. Hence, this research will focus on the study of the appropriate heuristic method and comparing the results of the test with the known problems. Then, the proposed heuristic approach will be applied to solve the LRPER. The results will be analyzed and then concluded.

## 3.2 Research Procedure

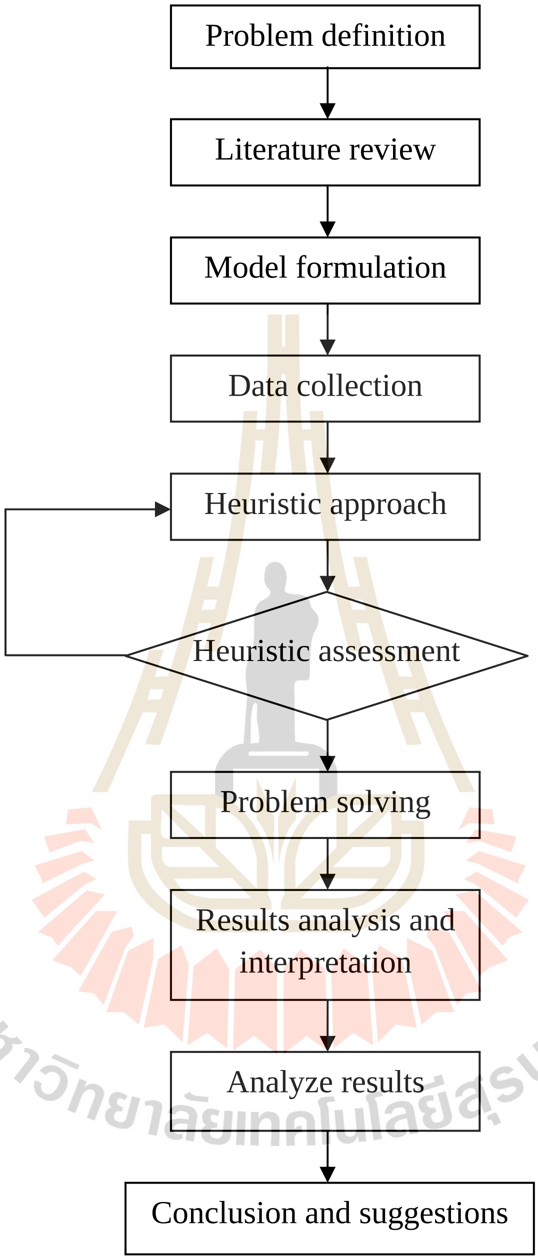


**Figure 3.1** Research procedure

The method to conduct this research is displayed in Figure 3.1, starting from the study of LRP and the review of related researches in order to define the problem in the form of mathematic model. Related data are also collected. Since the mathematic model is the NP-Hard, it is appropriate to solve the problem by the heuristic method. In this research, there will be a test of the proposed heuristic with a data set before applying it to the real study cases, followed by the conclusion.

## 3.3 Assumption and Problem Characteristics

The assumption and problem characteristics of the LRPER are as follows:

3.3.1 All blood bags are considered identical in terms of quantity and quality assurance.

3.3.2 The quantity of blood demand to be transferred in each round is known.

3.3.3 The quantity of urgent blood demand can be considered from the past records.

3.3.4 In case of urgent request, the transportation from blood banks to hospitals in need must be done immediately.

3.3.5 The blood bank establishment costs are proportional to the sizes of the blood banks.

3.3.6 The size of each blood bank that has been established must be big enough to facilitate the fundamental needs of the allocated hospitals.

3.3.7 There are enough vehicles to transport blood.

3.3.8 All vehicles are in the same size with the same capacity.

3.3.9 There is no limitation in terms of number of clients in each route and maximum distance in each route for normal blood delivery.

## 3.4 Mathematical model

In this research, the mathematical model for LRPER has been proposed. The model is extended from the LRP by Or and Pierskalla in 1979. Two additional conditions have been added into our model, which are the blood transportation with emergency referral (ER) and the operating costs for the establishment of blood bank. The proposed model is called the "location routing problem with emergency referral (LRPER)." 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.

All parameters and variables of the LRPER model are defined below.

3.4.1 Indices

$i$: the $i^{th}$ blood bank in the area $i \in I$

$j$: the $j^{th}$ hospital in the area $j \in J$

$k$: the $k^{th}$ vehicleused for blood transportation $k \in K$

3.4.2 Sets

$I$ is the set of all blood banks in the area

$J$ is the set of all hospitals in the area

$K$ is the set of all vehicles for blood transportation

3.4.3 Parameters

$d_{ij}$ distance between the $i^{th}$ blood bank and the $j^{th}$ hospital

$o_i$ operating costs for the establishment of blood bank the $i^{th}$

$c$ transportation cost per unit distance

$e_j$ number of emergency demands for blood from the $j^{th}$ hospital

$q_j$ average of blood demands of the $j^{th}$ hospital

$N$ number of all hospitals in the area

$Q_k$ the maximum capacity to carry blood for the $k^{th}$ vehicle

$V_i$ blood storing capacity for the $i^{th}$ blood bank

3.4.4 Decision variables

$x_{ijk}$ = 1 when the $k^{th}$ vehicle travels from the $i^{th}$ blood bank to the $j^{th}$ hospital; 0, otherwise

$y_{ij}$ = 1 when the $j^{th}$ hospital receives blood from the $i^{th}$ blood bank; 0, otherwise

$z_i$ = 1 when the $i^{th}$ blood bank is assigned as a blood bank; 0, otherwise

$R_i$ variables to eliminate sub tours

3.4.5 The mathematical model formulation of the LRPER

Minimize $\sum_{i\in I} O_i z_i + \sum_{k\in K}\sum_{i\in I}\sum_{j\in J} c \cdot d_{ij} x_{ijk} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} c \cdot e_j \cdot d_{ij} x_{ijk}$

Subject to;

$$\sum_{k\in K}\sum_{i\in I} x_{ijk} = 1 \quad ,\forall j \tag{3.1}$$

$$\sum_{j\in J} q_j \sum_{i\in I} x_{ijk} \le Q_k \quad ,\forall k \tag{3.2}$$

$$\sum_{i\in I}\sum_{j\in J} x_{ijk} \le 1 \quad ,\forall k \tag{3.3}$$

$$\sum_{j\in J} x_{ijk} - \sum_{j\in J} x_{jik} = 0 \quad ,\forall i, \forall k \tag{3.4}$$

$$\sum_{j\in J} q_j y_{ij} - V_i z_i \leq 0 \qquad ,\forall i \tag{3.5}$$

$$\sum_{j\in J} \sum_{k\in K} x_{ijk} - z_i \geq 0 \qquad ,\forall i \tag{3.6}$$

$$\sum_{j\in J} x_{ijk} - z_i \leq 0 \qquad ,\forall i, \forall k \tag{3.7}$$

$$\sum_{i\in I} x_{ijk} - \sum_{i\in I} x_{jki} = 0 \qquad ,\forall j, \forall k \tag{3.8}$$

$$R_i - R_j + (R + N) \sum_{k\in K} x_{ijk} \leq R + N - 1 \qquad ,\forall i, i \neq j \tag{3.9}$$

$$x_{ijk} = \{0, 1\} \qquad ,\forall i, \forall j, \forall k \tag{3.10}$$

$$y_{ij} = \{0, 1\} \qquad ,\forall i, \forall j \tag{3.11}$$

$$z_i = \{0, 1\} \qquad ,\forall i \tag{3.12}$$

The objective function is to determine the locations of blood banks and the routing of vehicles in such a way that the costs for establishing and operating the blood banks, blood transportation costs and blood transportation costs in emergency referralcases are minimized.

Constraint (3.1) indicates that each hospital will receive blood from only one source, i.e., each hospital can get blood from only one blood bank and cannot get blood from any other blood bank. Constraint (3.2) specifies that the blood which will be transferred to each hospital must be prepared and loaded from only one blood bank, and the loading quantity of blood must not exceed the maximum capacity of the vehicle ($Q$).Constraint (3.3) specifies that each vehicle can travel to only one hospital. Constraint (3.4) specifies that the total number of vehicles travelling to each hospital or each blood bank must equal the number of vehicles departing such hospitals or blood banks. Constraint (3.5) indicates that the quantity of blood transferring to each hospital on each route must not exceed the ability to store blood at each blood bank. Constraints (3.6) and(3.7) specify that each blood delivery vehicle must travel to designated hospital only. Constraint (3.8) specifies that each vehicle must depart from a blood bank and return to the same blood bank after finishing each delivery. Constraint (3.9) aims to eliminate sub tours by specifying that each route must have a blood bank as the starting point. Constraints number(3.10), (3.11) and(3.12) define the binary values of the decision variables.

## 3.5 Hybrid Genetic Algorithm

### 3.5.1 Genetic Algorithm for location routing problem

As mentioned earlier, the LRPER can be viewed as an integration of two NP-hard problems with additional conditions of blood bank operating costs and emergency referral. In this research, we propose a genetic algorithm (GA) to solve LRPER. GA is in fact a population-based meta-heuristic, which has been proved very powerful to solve many large scale problems. 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 evolve 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 tool to compute for solutions in this research.

3.5.1.1 Chromosome representation

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 3.2 shows the representation of a chromosome (10 hospitals and 3 LBBs). Row A1 represents the number of LBBs. Row B1 represents the routing of the vehicle. For example, feasible hospitals to be selected as LBB#1 are a6 = a7 = a8 = a10 = 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 3.2**The representation of a chromosome

3.5.1.2 Initial population method

The initial population method generates simultaneously both set of locations 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 3.3 shows three chromosomes which are of initial population to be modified in the step of genetic operation.

| | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 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 3.3**An example initial population generated by random generation method

3.5.1.3 Fitness function

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

3.5.1.4 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 has a section allocated for each chromosome in the population, and the size of each section is proportional to the chromosome's fitness. The fitter the chromosome, the higher the probability of being selected.

3.5.1.5 Genetic Operation

The crossover operation swaps parts of two parents in the population in order to generate off springs. The crossover is made in such a way 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 offspring 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 Murata and Ishibuchi (1994). 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 3.4.

| | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 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 3.4**Crossover operations for the permutation row



3.5.1.6 Compare and replacement

Comparing the quality of two individual chromosomes is important in any GA. The replacement of offsprings is the last phase in GA. Population size needs to be controlled to be constant. In the proposed algorithm, once a new offspring is created (using the GA operators), it is them compared to the worst chromosome in the population. Then the best chromosome is simply kept inside the population.

### 3.5.2 Hybrid Genetic Algorithm

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 (OR and Pierskalla, 1979). Hence, the LRP is also NP-hard. The LRPER can be viewed as an extension of the capacitated LRP. Debel et al, (2012) 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 3.5. 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 location 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 againtorepeatthe whole iterations. The HGA will not stop unless the predetermined number of iterations is completed.

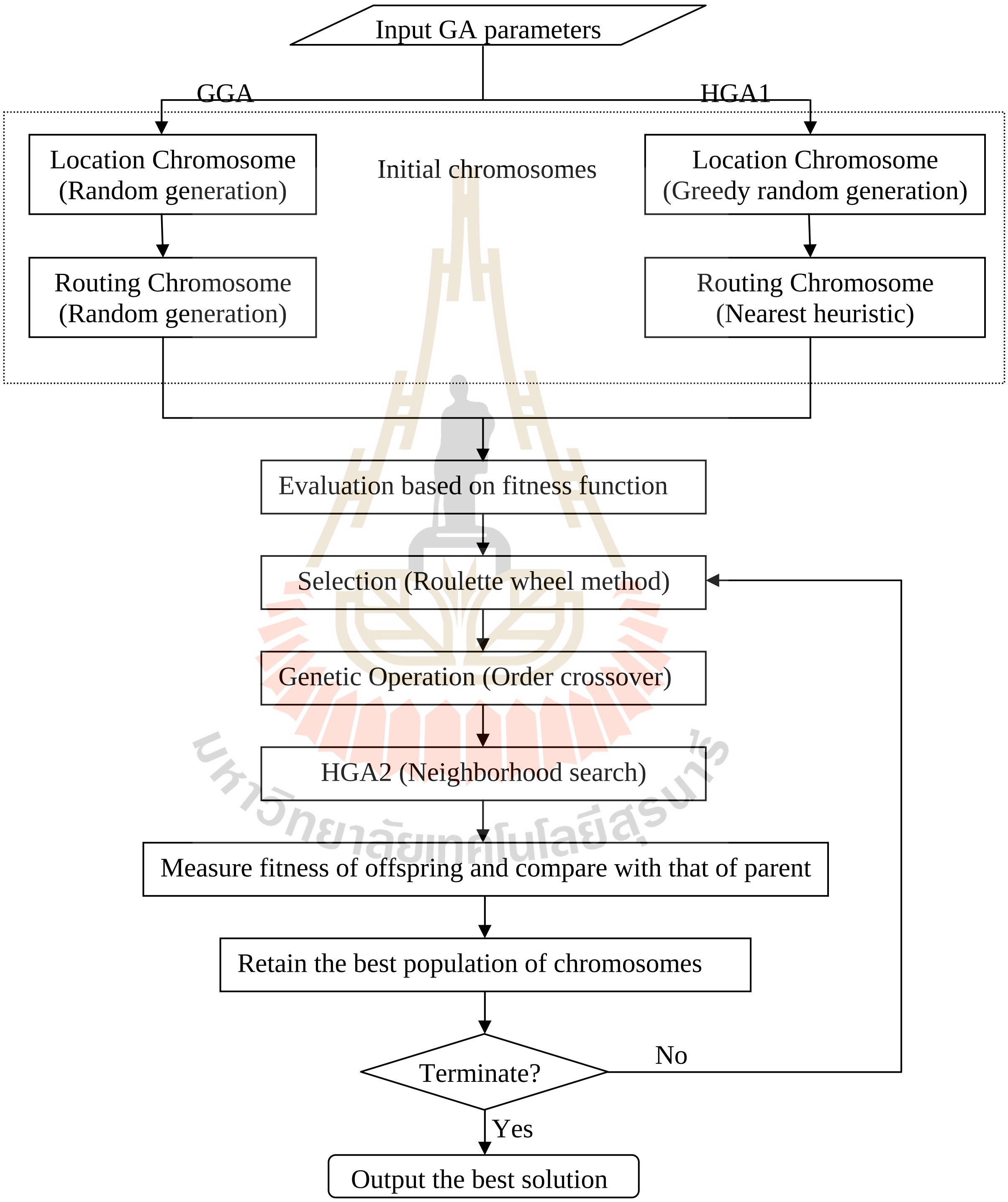


**Figure 3.5** The flowchart of HGA1 and HGA2

# CHAPTER IV

# RESULTS AND DISCUSSIONS

This chapter described the information related to the heuristic development which was used to solve the problem of location routing problem. This new heuristic is called Hybrid Genetic Algorithm or HGA. HGA test results, problem instances and test problems, real problems will be described, and the results obtained from HGA are presented, analyzed and concluded in the last section.

## 4.1 The Test Procedures

In the test procedure, the proposed heuristic has the following procedures:

4.1.1 Test on initial population which can be created from greedy random and nearest heuristic.

4.1.2 Select the solution of initial population by comparing fitness function. The initial population with the least value of fitness function should be considered first according to the population size in each identified model, and then chromosome would be selected according to the Roulette wheel method.

4.1.3 Identify the genetic operator. In this research, there are two ways to test on the chosen genetic operator, single point crossover and two-point crossover.

4.1.4 Identify the solution improvement to obtain the solution with the neighbourhood search. In this research, the solution improvement is taken by the customers' movement. In this research, two methods can be used, insertion method and two-opt method.

4.1.5 Bring the designed algorithm to create the model by using MATLAB and test the developed program with the problem instance. Then, analyze and compare the test results.

4.1.6 Bring the developed program to solve the real problem, analyze and make conclusions for the research.

## 4.2 Problem Instances and Test Problems

The problem instances and test problems are prepared in order to test the proposed heuristic. In the location routing problem related research, there are various known problem instances that many researchers use to find solutions and compare the results. Ten problem instances are selected to test the heuristic in this study as illustrated in Table 4.1.

For the test problems in this study, we defined the problems with specifications that are similar to the real problem by adding the operating costs for the establishment of blood bank sand the transportation costs in emergency referral cases, namely *ER*. There are 3 different levels of problem sizes, the problem with small number of hospitals (10 hospitals), the problem with medium number of hospitals (25 hospitals), and the problem with large number of hospitals (50 hospitals), as shown in Table 4.2.

**Table 4.1** Problem instances for this study

| No. | Problem Instance | Problem Size | | Min-Max Demand (Units) | Min-Max Distance (km.) |
|---|---|---|---|---|---|
| | | No. Customers | No. Warehouses | | |
| 1 | Gaskell 67-21×5 | 21 | 5 | 100 – 2,500 | 3 - 83 |
| 2 | Gaskell 67-36×5 | 36 | 5 | 25 - 25 | 10 - 71 |
| 3 | Christofides 69-50×5 | 50 | 5 | 3 - 41 | 5 - 86 |
| 4 | Christofides 69-75×10 | 75 | 10 | 1 - 37 | 2 - 85 |
| 5 | Christofides 69-100×10 | 100 | 10 | 1 - 41 | 1 - 101 |
| 6 | Daskin 95-88×8 | 88 | 8 | 8,247 – 7,322,564 | 1 - 53 |
| 7 | Min 92-27×5 | 27 | 5 | 1 – 273 | 1 - 682 |
| 8 | Or 76-117×14 | 117 | 14 | 7 - 52,567 | 4 – 2,264 |
| 9 | Perl 83-12×2 | 12 | 2 | 20 | 4 - 29 |
| 10 | Srivastava 86-8×2 | 8 | 2 | 54 - 145 | 18 - 170 |

## 4.3 Initial Populations

Initial population are determined first and used to calculate solution using Genetic Algorithm (GA). Good initial population may lead to better results with less computing time. Greedy random method and nearest heuristic are used to generate initial population for Hybrid Genetic Algorithm (HGA). For the test of the proposed heuristics on initial population, we compare with the random initial population, which is according to the procedure of the General Genetic Algorithm (GGA). Summary of initial population for GGA and HGA is shown in Table 4.3.

**Table 4.2**Test problems for this study

| No. | Problem Instance | Problem Size | | Min-Max Demand (Units) | Min-Max Distance (km.) |
|---|---|---|---|---|---|
| | | No. Hospitals | No. Blood Banks | | |
| 1 | Small Size | 10 | 2 | 1 - 41 | 1- 101 |
| 2 | Medium Size | 25 | 5 | 1 - 41 | 1 - 101 |
| 3 | Large Size | 50 | 10 | 1 - 41 | 1 - 101 |

**Table 4.3** The specification of initial population of GGA and HGA

| Chromosome | GGA | HGA | |
|---|---|---|---|
| Location | Random | Random | Greedy Random |
| Routing | Random | Random | Nearest Heuristic |

Location and routing chromosomes can be generated using the following procedures:

Step 1 Specify the number of warehouses. For example, 2 warehouses were specified from 10 customers.

Step 2 Sequence the customers' demands from the highest to the lowest.

Step 3 Generate random number of each warehouse into location chromosome.

Step 4 Choose customers with the highest demands according to the number specified in Step 1 in order to establish or specify as the warehouses. If the number of customers with the highest demands exceeded the number of warehouses specified in Step 1, warehouses will be selected randomly among those customers with the highest demands.

Step 5 Assign a random number to each vehicle route in the routing chromosome.

Step 6 Improve vehicle routes according to the nearest heuristic. In this case, the goods should be delivered to the customer with the shortest route to the warehouse first. Then deliver to next customer in the same fashion until all customers have been served.

The heuristic can be simply illustrated using a small set of data in the following example. There are two warehouses and ten customers and demand requirements are shown in Table4.4.

**Table 4.4** Sample of identified initial population

| Customer | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Demand | 2 | 4 | 1 | 6 | 3 | 7 | 5 | 3 | 6 | 4 |

Step 1: Assign 2 warehouses and insert into the location chromosome.

Step 2: Sort the demand of customers from the highest to the lowest.

| Sort | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Customer | 6 | 4 | 9 | 7 | 10 | 2 | 5 | 8 | 1 | 3 |
| Demand | 7 | 6 | 6 | 5 | 4 | 4 | 3 | 3 | 2 | 1 |

Step 3: Generate random number of each warehouse into location chromosome

| Sort | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Customer | 6 | 4 | 9 | 7 | 10 | 2 | 5 | 8 | 1 | 3 |
| Random | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 2 |

Step 4: Customer numbers 6 and 9 were chosen to be warehouse 1 and 2, respectively, and the following location chromosomes would be obtained.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Customer | 6 | 4 | 9 | 7 | 10 | 2 | 5 | 8 | 1 | 3 |
| Location Chromosome | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 2 |

Step 5: Sort the routing of the vehicles by inserting random number into routing chromosome as follows:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Routing Chromosome | 6 | 4 | 7 | 8 | 1 | 9 | 10 | 2 | 5 | 3 |

Step 6: Generate route by using nearest heuristic. This may cause some changes to the routing chromosome.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Routing Chromosome | 6 | 7 | 8 | 1 | 4 | 9 | 3 | 10 | 5 | 2 |

Now the result of the initial population is obtained. It is pairs of chromosomes with location and routing information.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location Chromosome | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 2 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Routing Chromosome | 6 | 7 | 8 | 1 | 4 | 9 | 3 | 10 | 5 | 2 |

## 4.4 Fitness Function

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

$$F_{EVAL} = PDC \quad (4.1)$$

$$F_{EVAL} = OC_{LBB} + PDC + EDC \quad (4.2)$$

Problem instances are evaluated using (4.1) and the test problems as well as real problems are evaluated by (4.2). Then, the selected initial population are evaluated by roulette wheel method in order to obtain location chromosomes and routing chromosomes.

## 4.5 Genetic Operation

This step aims to improve fitness function value by using genetic operator. Genetic Operation is an important step of GA. In this research, two genetic improvement method are used, single point crossover and two-point crossover as described in section 2.5.4. Moreover, in the step of genetic operation, inversion mutation is used to adjust genetics inside the location chromosome, and it makes a huge different in location chromosome. However, inversion mutation could not be applied with routing chromosome as routing chromosome is not the binary encoding chromosome.

## 4.6 Neighbourhood Search

After obtaining location chromosome and routing chromosome from the step of genetic operator, the next step is to improve the solution in order to obtain better result. In this research, neighbourhood search is incorporated with the proposed HGA. This is the unique step in this research as there are no such work in the literature that uses this technique for LRP.

Neighbourhood search is used to improve solution by changing and transferring position of customers in each route in both intra-route and inter-route techniques. The results from neighbourhood search would lead to the global optimum. Two types of neighbourhood searches are used, insertion move and two-opt move.

### 4.6.1 Insertion move

It is the action that customers move from its original location to a new location. For the insertion movement in this research, each customer would be selected and move to locate in various positions within the same route or on different route. Then, this algorithm will record the total distance of the customer. In Figure 4.1, the customer 3 from Route 2 was moved and inserted in front of customer 1 on route 1.

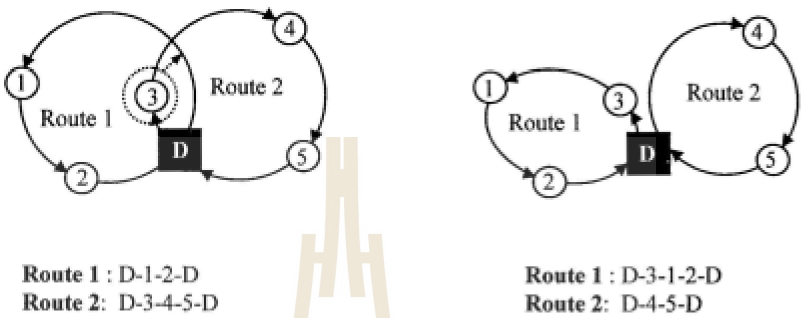


**Figure 4.1** An operation of Insertion Move Method

### 4.6.2 Two-opt move

The two-opt move is the move of customers within intra-route. It starts by choosing two non-adjacent routes between customers, and these routes are switched. In this case, the sequence of customers between the two chosen points is in reverse order. The customers could be moved in this manner if there are more than two customers in the route.

For the example of Two-opt customer movement, it could be presented in Figure4.2. If there is a two-opt between customers 1 and 4. Two chosen customers and the next customers (customers 2 and 5.) would be connected (ranking in adjacent position). For customers who are in between customers 1 and 4, they would be ranked in the reverse order. For example, the sequence is modified from customers 2→3 to customers 3→ 2.

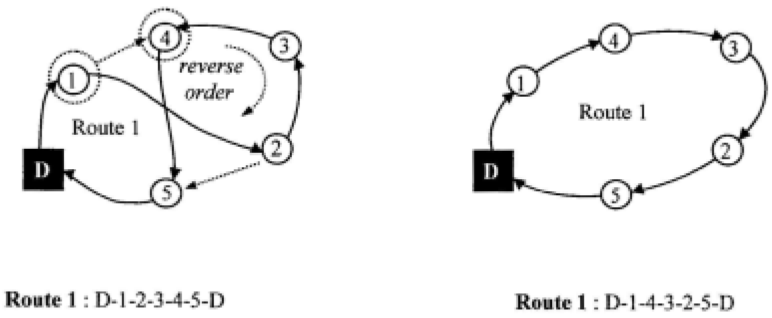


**Figure 4.2** An operation of Two-opt Move Method

## 4.7 The Results of Genetic Operation for Problem Instances and Test Problems

In this section, test results will be presented under the proposed HGA method in order to solve the location routing problem. This test will compare the results received from GGA and HGA. Problem instances and test problems are used to test with both algorithms. Test results are be demonstrated below.

### 4.7.1 Results for Problem Instances

Problem instances chosen for this test are commonly used in the test. Ten instance problems with different sizes are selected to test the proposed heuristic (as shown in table 4.1). In addition, there are also the conditions of individually unique customer product requirements and individually unique customer location distances. Both conditions are regarded as the critical conditions for location routing problem solving.

According to the test procedure in this section, computation result will be shown in three different parts as follows:

i) GGA results

ii) HGA1 results are computed from the proposed HGA1 heuristic. This heuristic is developed based on GGA procedure by incorporating initial population selection as explained in section 4.4. Moreover, genetic operator method as explained in section 4.6is also added in HGA1. In genetic operator procedure, single point crossover and two point crossover methods are chosen to be used in HGA1.

iii) HGA2 results are computed from the proposed HGA2 heuristic. This heuristic is developed based on HGA1 procedure by incorporating solution improvement based on neighbourhood search technique (insertion move method and two-opt move method).

Parameters used in the computation are the following:

- Initial population = 500 chromosomes
- Crossover rate = 80%
- Mutation rate = 1%
- Number of chromosomes that are selected = 20% of initial population size
- Condition of program running stop= 1000 iterations

In order to compare results from GGA, HGA1 andHGA2 heuristics using the selected problem instances, the positive results are considered on the basis of cost minimization. The different results received from GGA, HGA1 and HGA2 (in %Gap) are considered. These are calculated in percentage according to the equations 4.3 – 4.5.

$$\%Gap1=\frac{(\text{Min.Cost of GGA})-(\text{Min.Cost of HGA1})}{(\text{Min.Cost of GGA})}\times 100 \tag{4.3}$$

$$\%Gap2=\frac{(\text{Min.Cost of GGA})-(\text{Min.Cost of HGA2})}{(\text{Min.Cost of GGA})}\times 100 \tag{4.4}$$

$$\%Gap3=\frac{(\text{Min.Cost of HGA1})-(\text{Min.Cost of HGA2})}{(\text{Min.Cost of HGA2})}\times 100 \tag{4.5}$$

Table 4.5 shows the results of GGA, HGA1 and HGA2in problem instance solving. Comparison results are divided into 3 different parts as shown below:

i) Comparing between GGA and HGA1, it is found that the average of %Gap1 is 4.88%. That is, problem instances solved by HGA1 yield the better result than those solved by GGA. The best result is obtained from “Christofides69-75x10”, of which %Gap1 is 7.90%. This is the highest value comparing to the other problems while the computation time is less than one minute (see Table 4.6**)**.

ii)Comparing between GGA and HGA2, it is found that the average of %Gap2 is 31.97%. This can be interpreted that on average the problem instances solved by HGA2 yield the better result than those solved by GGA. The best solving result can be received from the problem of “Or76-117x14” of which %Gap2 is 59.03%. This is the highest value comparing to the other problems while the computation time is less than one minute (see Table 4.6**)**.

iii) Comparing between HGA1 and HGA2, it is found that the average of %Gap3 is 28.49%.On average the problem instances solved by HGA2 yield the better result than those calculated by HGA1. The best solving result can be received from the problem of “Or76-117x14” of which %Gap3is 57.38%.This is the highest value comparing to the other problems while the computation time is less than one minute (see Table 4.6**)**.

**Table 4.5** Computation results of GGA, HGA1 and HGA2 in problem instance.

| No. | Instances | Min. Cost | | | %Gap1 | %Gap2 | %Gap3 |
|---|---|---|---|---|---|---|---|
| | | GGA | HGA1 | HGA2 | | | |
| 1 | Gaskell67-21x5 | 789 | 752 | 627 | 4.69 | 20.53 | 16.62 |
| 2 | Gaskell67-36x5 | 1,145 | 1,117 | 919 | 2.45 | 19.74 | 17.73 |
| 3 | Christofides69-50x5 | 1,537 | 1,435 | 1,097 | 6.64 | 28.63 | 23.55 |
| 4 | Christofides69-75x10 | 2,619 | 2,412 | 1,288 | 7.90 | 50.82 | 46.60 |
| 5 | Christofides69-100x10 | 3,373 | 3,307 | 1,684 | 1.96 | 50.07 | 49.08 |
| 6 | Daskin95-88x8 | 2,017 | 1,867 | 1,071 | 7.45 | 46.91 | 42.64 |
| 7 | Min92-27x5 | 6,715 | 6,436 | 4,087 | 4.15 | 39.14 | 36.50 |
| 8 | Or76-117x14 | 68,736 | 66,073 | 28,158 | 3.87 | 59.03 | 57.38 |
| 9 | Perl83-12x2 | 328 | 308 | 324 | 6.10 | 1.22 | -5.19 |
| 10 | Srivastava86-8x2 | 443 | 427 | 427 | 3.61 | 3.61 | 0.00 |
| Average | | | | | 4.88 | 31.97 | 28.49 |

According to Table 4.5, comparing the values of %Gap of those three heuristics, on average HGA2 performs better than both GGA and HGA1.The lowest cost can be obtained from the problem of “Or76-117x14” which is the large problem comparing to the other problem instances. Namely, HGA2 yields the best result when used in solving the large problem.

**Table 4.6** Number of iterations and running times that yield the lowest costs for the problem instances solved by GGA, HGA1 and HGA2.

| No. | Instances | No. iterations | Running Time (min.) |
|---|---|---|---|
| 1 | Gaskell67-21x5 | 119 | 0.3373 |
| 2 | Gaskell67-36x5 | 112 | 0.1574 |
| 3 | Christofides69-50x5 | 716 | 0.1360 |
| 4 | Christofides69-75x10 | 971 | 0.3059 |
| 5 | Christofides69-100x10 | 717 | 0.2785 |
| 6 | Daskin95-88x8 | 722 | 0.2293 |
| 7 | Min92-27x5 | 38 | 0.1410 |
| 8 | Or76-117x14 | 796 | 0.4504 |
| 9 | Perl83-12x2 | 317 | 0.0743 |
| 10 | Srivastava86-8x2 | 289 | 0.0944 |
| Average | | 480 | 0.22 |

### 4.7.2 Results for test problems

Results tested on problem instances by HGA1 and HGA2 yield better result than those calculated from GGA. However, it is not sufficient to conclude that these two heuristics can solve the LRPER because there are additional costs (warehouse operating costs and emergency delivery cost) that are not appeared in the problem instances. These two costs are essential because they appear in real situation.

In order to test the proposed heuristics with problem instances that are similar to the real situation, Christofis problems are modified by incorporating operating cost and emergency delivery cost. Christo ides problems compose of three different sizes - small, medium and large problems as can be seen in table 4.2. The modified test problems have the following details:

- Operating costs of warehouse based on different warehouse sizes: According to the real situation, it is found that operating costs of warehouse are directly relative to warehouse sizes. That is, larger warehouse has higher operating cost than smaller warehouse. In addition, warehouse sizes in the real problem are categorized into three different sizes – small, medium and large, with capacities of 50, 70 and 100 units, respectively. Therefore, capacities of 50, 70 and 100 units are also specified in test problems. Capacities of warehouses will be determined using the random method.

- Transportation cost for emergency delivery is directly relative to the number of emergency transportation. That is, if the number of emergency need is high then the emergency transportation cost will also be high. In the opposite, if the number of emergency need is low then the emergency transportation cost will also be low. Real problem information also shows that the number of emergency needs is between

0 – 9 times. Therefore, the number of emergency need in test problems will be specified at between 0 – 9by using the random method.

Table 4.7shows the minimize cost comparison received from GGA, HGA1 and HGA2in modified test problems. The results show that HGA2 yields the better %Gap2 and %Gap3 values than those obtained from both GGA and HGA1 with computation time less than one minute. The lowest cost result can be received from the large problem, which is in line with the test in section 4.7.1.

**Table 4.7** Computation results of GGA, HGA1 and HGA2 in test problems.

| No. | Problems | Min. Cost | | | %Gap1 | %Gap2 | %Gap3 |
|---|---|---|---|---|---|---|---|
| | | GGA | HGA1 | HGA2 | | | |
| 1 | Small Size | 1,537 | 1,494 | 1,411 | 2.80 | 8.20 | 5.56 |
| 2 | Medium Size | 2,795 | 2,697 | 2,546 | 3.51 | 8.91 | 5.60 |
| 3 | Large Size | 5,836 | 5,543 | 5,176 | 5.02 | 11.31 | 6.62 |
| Average | | | | | 3.77 | 9.47 | 5.93 |

According to results of the problem instances and the modified test problems, it can be claimed that both HGA1 and HGA2 yield better results than GGA. Moreover, HGA2 yields the best results with lower costs when used to solve with large problems. However, it is found that HGA2 yields the similar results to HGA1 and GGA when used to solve with small problems. This is the shortcoming of HGA2 and it is not recommended to solve small problems.

## 4.8 Computation Results of HGA in LRPER

This section will explain about the heuristic test application in the real problem, which has already been mentioned in some parts in section 1. Real problem used as the case study is the case of Regional Blood Bank V (RBC V). There are four 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 the blood service approximately 1,200 units per week.

The data gathered from the case study, and its detail are shown in appendix A, including:

- Locations of all 93 hospitals.
- Distance between hospitals (in km.).
- Operating costs of LBB, depending on hospital sizes (in bath).
- Capacity of LBB in each hospital (in unit).
- The average of blood requirements per week (in unit).
- The average number of emergency referrals 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 source code of the program could be seen in Appendix B.

The first step of this heuristic test method is to compare results similar to section 4.8. 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 the results include the following information.

### 4.8.1 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.

**Table 4.8** 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 | 43,618 | | | |
| Average | | | | 11.70 | 16.52 | 5.37 |

### 4.8.2 Results Description

From the results shown in section 4.8.1 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 (printout of this result is shown in Appendix C).See more explanation below:

4.8.2.1Hospitals chosen to be setup as LBBs

With the results of solving LRPER problem done by HGA2, it is found that there are 20 hospitals chosen to be setup as LBB. There are 5 LBBs in Nakhon Ratchasimaand 3 LBBs,one each in Chaiyaphum, Buriram and Surin. Further details can be seen in Table 4.9.

**Table 4.9**Hospitals chosen to be setup as Location Blood Banks

| **Province** | **Hospitals 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 |

4.8.2.2 Allocation of hospitals for each LBB

Results of hospital allocation for each LBB are arranged according to the province area as shown in Table 4.10. An example of the allocation result can be explained as follows. In Nakhon Ratchasima, LBB 2 is responsible to transport blood for hospitals 1, 3, 10, and 13.

4.8.2.3 Blood transportation route arrangement for 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 4.11. An example of the route arrangement result is as follows. In Nakhon Ratchasima, blood transportation route 1 starts from LBB 7, then out to deliver blood to hospitals 8, 17, 4, and 6, respectively. After the completion, the blood delivery vehicle returns to LBB 7.

**Table 4.10**Allocation of hospitals for each LBB

| Provinces | 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 |
| Chaiyaphum | 11 | 12, 15, 14, 17, 16, 10, 9, 8, 7 |
| | 2 | 3, 4, 6 |
| | 5 | 13 |
| Buriram | 3 | 2, 5, 6, 7, 12 |
| | 20 | 14, 1516, 17, 18, 21, 22, 23, 24 |
| | 9 | 1, 4, 8, 10, 11, 13, 19 |
| Surin | 9 | 1, 2, 3, 4, 5, 6, 8 |
| | 12 | 7, 13, 14, 15, 16 |
| | 11 | 10 |

**Table 4.11** The route for transportation.

| Provinces | Route No. | Route Arrangement |
|---|---|---|
| Nakorn 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 |

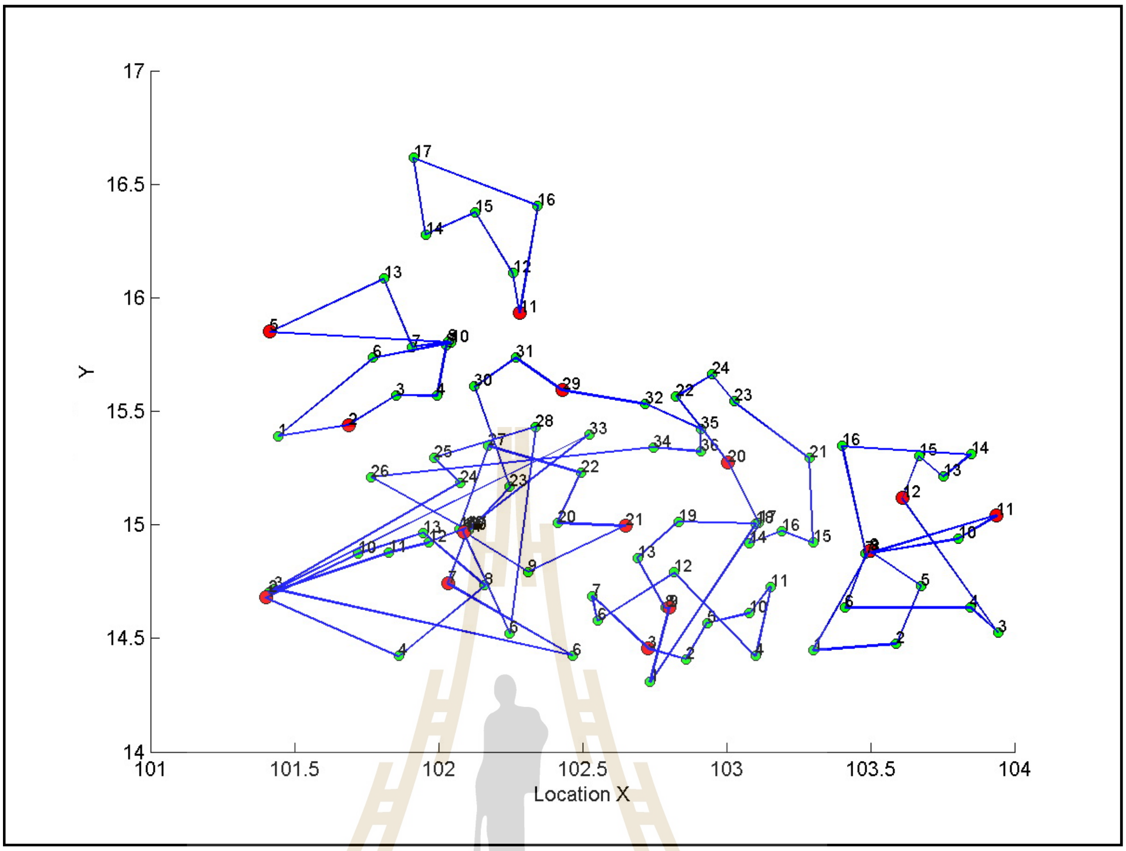


**Figure 4.3** Result of solving the LRPER by HGA2

### 4.8.3 Interpretation of Cost Structure in Setting up Local Blood Banks

In order to establish each local blood bank, available budget will be taken into consideration. This budget will usually be used to set up a number of blood banks that cover hospitals in responsible area of each RBC. Cost structure to each LBB compose of operating cost, transportation cost, and emergency referral cost. Operating cost of each LBB varies depending on the size of the facility and the number of employees. This operating cost is essential for decision maker to decide which locations are suitable to be established as LBBs. Therefore, this cost is important and must be incorporated into the objective function of LRPER problem. Other relevant costs are transportation costs and blood transportation costs in emergency cases. In this section, results from computation will be discussed to reflect the importance of each cost in the cost structure in setting up LBBs.

Tables 4.12 and 4.13 shown the results of real problem computed using the HGA2 heuristic, which yields the best solution. According to these tables, it is clear that the operating cost is the most important one among all the costs in managing LBBs. Moreover, it is our objective to set up LBBs in such a way that human lives are the most important factor to consider and transportations due to the fact that referral cases are limited to some certain travel distance.

**Table 4.12** Results and percentages of each cost in setting up LBBs in each province.

| **Provinces** | **No. LBBs** | **$OC_{LBB}$** | | **PDC** | | **EDC** | | **Total** | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Baht** | **%** | **Baht** | **%** | **Baht** | **%** | **Baht** | **%** |
| Nakhon Ratchasima | 5 | 10,961 | 38.26 | 3,981 | 42.60 | 2,590 | 46.08 | 17,532 | 40.19 |
| Chaiyaphum | 3 | 5,961 | 20.80 | 1,087 | 11.63 | 756 | 13.45 | 7,804 | 17.89 |
| Buriram | 3 | 5,769 | 20.13 | 3,145 | 33.65 | 1,436 | 25.55 | 10,350 | 23.73 |
| Surin | 3 | 5,961 | 20.80 | 1,132 | 12.11 | 839 | 14.93 | 7,932 | 18.19 |
| Total | 14 | 28,652 | 100.0 | 9,345 | 100.00 | 5,621 | 100.0 | 43,618 | 100.00 |

**Table 4.13**The result of operating costs

| | NakhonRatchasima | | Chaiyaphum | | Buriram | | Surin | | |
|---|---|---|---|---|---|---|---|---|---|
| | **LBB no.** | **OC** | **LBB no.** | **OC** | **LBB no.** | **OC** | **LBB no.** | **OC** | |
| | 2 | 1,923 | 11 | 1,923 | 3 | 1,923 | 9 | 1,923 | |
| | 14 | 2,885 | 2 | 2,115 | 20 | 1,923 | 12 | 1,923 | |
| | 7 | 2,115 | 5 | 1,923 | 9 | 1,923 | 11 | 2,115 | |
| | 21 | 1,923 | | | | | | | |
| | 29 | 2,115 | | | | | | | |
| Sum. Of | 10,961 | | 5,961 | | 5,769 | | 5,961 | | 28,652 |
| Total costs | 17,532 | | 7,804 | | 10,350 | | 7,932 | | 43,618 |
| % operating costs | 62.52 | | 76.38 | | 55.74 | | 75.15 | | 65.69 |

# CHAPTER V

# CONCLUSIONS

## 5.1 Conclusion

Blood logistics is an approach to distribute blood effectively and efficiently. Determining locations of blood banks and distribution planning of blood product are crucial for a strategic decision making in the blood logistics. Locations of facilities and vehicle routing planning are critical in any application areas. 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 for determining 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 operating costs of LBBs, periodic delivery costs, and emergency referral delivery costs. We propose a Hybrid Genetic Algorithm (HGA) to solve the LRPER. HGA is able to solve the locations of blood banks and vehicle routing for blood distribution decisions simultaneously. GA is proposed based on chromosomes representing both the number of LBBs and the routing of the vehicles. Our proposed HGA composes of HGA1andHGA2. HGA1 is developed based on GGA procedure with added greedy and nearest heuristics into location chromosomes and routing chromosomes, respectively. HGA2 is developed based onHGA1 procedure and additional solution improvement procedure using neighbourhood search method (insertion move and two-opt move). This research also compares the results of HGA1 and HGA2to GGA using known problem instances and our test problems. Results indicate that the HGA2 is a stability heuristic that shows better solutions on the average.

## 5.2 Limitation of the Study

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.



## 5.3 Applications of the Work

The primary objective of this research has been the development of a location-routing framework which can be used to improve distribution planning system. The complexity of this problem has resulted in a lack of solution techniques to the problem. Almost all of the previous research in this area has concentrated on solving either the location problem or the vehicle scheduling problem. There is a 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.

## 5.4 Recommendation for Future Work

As a consequence of this study, 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 modified 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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# APPENDIX A

# Data set for LRPER

**Table A.1** Parameter of data set for LRPER

| Province | Hospital | Operating costs (Bath) | Capacity (Unit) | Demand (Unit) | No.Emergency Referral |
|---|---|---|---|---|---|
| NakhonRatchasima | 1 | 2,115 | 70 | 53 | 5 |
| | 2 | 1,923 | 50 | 5 | 7 |
| | 3 | 2,115 | 70 | 6 | 2 |
| | 4 | 1,923 | 50 | 10 | 4 |
| | 5 | 2,115 | 70 | 17 | 2 |
| | 6 | 1,923 | 50 | 14 | 6 |
| | 7 | 2,115 | 70 | 40 | 7 |
| | 8 | 2,115 | 70 | 30 | 1 |
| | 9 | 1,923 | 50 | 14 | 4 |
| | 10 | 2,115 | 70 | 42 | 3 |
| | 11 | 2,115 | 70 | 21 | 6 |
| | 12 | 2,115 | 70 | 10 | 0 |
| | 13 | 1,923 | 50 | 5 | 0 |
| | 14 | 2,885 | 100 | 43 | 8 |
| | 15 | 2,885 | 100 | 8 | 1 |
| | 16 | 2,885 | 100 | 9 | 7 |
| | 17 | 2,885 | 100 | 89 | 1 |
| | 18 | 2,115 | 70 | 7 | 2 |
| | 19 | 2,115 | 70 | 6 | 2 |
| | 20 | 2,115 | 70 | 26 | 1 |

**Table A.1** Parameter of data set for LRPER(Continued)

| Province | Hospital | Operating costs (Bath) | Capacity (Unit) | Demand (Unit) | No.Emergency Referral |
|---|---|---|---|---|---|
| | 21 | 1,923 | 50 | 16 | 6 |
| NakhonRatchasima | 22 | 2,115 | 70 | 44 | 0 |
| | 23 | 2,115 | 70 | 29 | 0 |
| | 24 | 1,923 | 50 | 21 | 3 |
| | 25 | 1,923 | 50 | 8 | 0 |
| | 26 | 2,115 | 70 | 39 | 0 |
| | 27 | 2,115 | 70 | 10 | 0 |
| | 28 | 2,115 | 70 | 21 | 5 |
| | 29 | 2,115 | 70 | 24 | 4 |
| | 30 | 1,923 | 50 | 8 | 4 |
| | 31 | 1,923 | 50 | 6 | 3 |
| | 32 | 2,115 | 70 | 20 | 3 |
| | 33 | 1,923 | 50 | 4 | 0 |
| | 34 | 2,115 | 70 | 18 | 2 |
| | 35 | 1,923 | 50 | 5 | 1 |
| | 36 | 1,923 | 50 | 5 | 0 |
| Chaiyaphum | 1 | 1,923 | 50 | 5 | 1 |
| | 2 | 2,115 | 70 | 4 | 9 |
| | 3 | 2,115 | 70 | 6 | 1 |
| | 4 | 1,923 | 50 | 2 | 4 |

**Table A.1** Parameter of data set for LRPER(Continued)

| Province | Hospital | Operating costs (Bath) | Capacity (Unit) | Demand (Unit) | No.Emergency Referral |
|---|---|---|---|---|---|
| Chaiyaphum | 5 | 1,923 | 50 | 2 | 6 |
| | 6 | 1,923 | 50 | 3 | 2 |
| | 7 | 1,923 | 50 | 1 | 1 |
| | 8 | 1,923 | 50 | 2 | 1 |
| | 9 | 2,885 | 100 | 10 | 0 |
| | 10 | 1,923 | 50 | 3 | 0 |
| | 11 | 1,923 | 50 | 4 | 6 |
| | 12 | 1,923 | 50 | 8 | 4 |
| | 13 | 2,115 | 70 | 8 | 0 |
| | 14 | 1,923 | 50 | 9 | 0 |
| | 15 | 2,115 | 70 | 10 | 0 |
| | 16 | 1,923 | 50 | 4 | 0 |
| | 17 | 1,923 | 50 | 5 | 1 |
| Buriram | 1 | 1,923 | 50 | 3 | 4 |
| | 2 | 2,115 | 70 | 6 | 5 |
| | 3 | 1,923 | 50 | 5 | 7 |
| | 4 | 1,923 | 50 | 8 | 1 |
| | 5 | 1,923 | 50 | 3 | 3 |
| | 6 | 1,923 | 50 | 3 | 0 |
| | 7 | 1,923 | 50 | 7 | 0 |

**Table A.1** Parameter of data set for LRPER(Continued)

| Province | Hospital | Operating costs (Bath) | Capacity (Unit) | Demand (Unit) | No.Emergency Referral |
|---|---|---|---|---|---|
| Buriram | 8 | 2,115 | 70 | 11 | 4 |
| | 9 | 1,923 | 50 | 3 | 8 |
| | 10 | 2,115 | 70 | 15 | 0 |
| | 11 | 1,923 | 50 | 5 | 0 |
| | 12 | 1,923 | 50 | 4 | 0 |
| | 13 | 1,923 | 50 | 5 | 3 |
| | 14 | 2,885 | 100 | 16 | 4 |
| | 15 | 1,923 | 50 | 12 | 3 |
| | 16 | 1,923 | 50 | 4 | 3 |
| | 17 | 1,923 | 50 | 4 | 2 |
| | 18 | 2,885 | 100 | 22 | 3 |
| | 19 | 2,115 | 70 | 14 | 6 |
| | 20 | 1,923 | 50 | 7 | 5 |
| | 21 | 2,115 | 100 | 12 | 1 |
| | 22 | 1,923 | 50 | 3 | 1 |
| | 23 | 2,115 | 70 | 5 | 4 |
| | 24 | 1,923 | 50 | 4 | 3 |
| Surin | 1 | 2,115 | 70 | 4 | 4 |
| | 2 | 1,923 | 50 | 7 | 1 |
| | 3 | 1,923 | 50 | 4 | 1 |

**Table A.1** Parameter of data set for LRPER(Continued)

| Province | Hospital | Operating costs (Bath) | Capacity (Unit) | Demand (Unit) | No.Emergency Referral |
|---|---|---|---|---|---|
| Surin | 3 | 1,923 | 50 | 4 | 1 |
| | 4 | 2,115 | 70 | 14 | 0 |
| | 5 | 1,923 | 50 | 3 | 2 |
| | 6 | 1,923 | 50 | 17 | 1 |
| | 7 | 2,885 | 100 | 15 | 1 |
| | 8 | 2,885 | 100 | 28 | 0 |
| | 9 | 1,923 | 50 | 10 | 4 |
| | 10 | 2,115 | 70 | 15 | 2 |
| | 11 | 2,115 | 70 | 6 | 4 |
| | 12 | 1,923 | 50 | 7 | 3 |
| | 13 | 2,115 | 70 | 5 | 2 |
| | 14 | 2,115 | 70 | 10 | 1 |
| | 15 | 2,115 | 70 | 11 | 3 |
| | 16 | 1,923 | 50 | 8 | 0 |

**Table A.2** Example of Distance between hospitals

| **Hospital** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 3 | 6 | 89 | 128 | 156 | 83 | 95 | 120 | 45 | 62 | 73 | 77 | 92 | 88 | 91 | 92 | 89 | 92 | 144 |
| **2** | 3 | 0 | 3 | 93 | 123 | 153 | 82 | 93 | 117 | 44 | 57 | 74 | 75 | 87 | 85 | 88 | 89 | 86 | 88 | 143 |
| **3** | 6 | 3 | 0 | 119 | 122 | 151 | 81 | 94 | 114 | 41 | 53 | 68 | 72 | 83 | 83 | 85 | 86 | 83 | 86 | 140 |
| **4** | 89 | 93 | 119 | 0 | 61 | 91 | 42 | 61 | 82 | 83 | 74 | 69 | 78 | 71 | 73 | 76 | 77 | 74 | 77 | 113 |
| **5** | 128 | 123 | 122 | 61 | 0 | 30 | 45 | 29 | 47 | 85 | 75 | 66 | 75 | 60 | 66 | 61 | 60 | 61 | 58 | 83 |
| **6** | 156 | 153 | 151 | 91 | 30 | 0 | 73 | 58 | 48 | 111 | 104 | 95 | 104 | 132 | 133 | 141 | 131 | 133 | 130 | 94 |
| **7** | 83 | 82 | 81 | 42 | 45 | 73 | 0 | 17 | 39 | 41 | 32 | 28 | 35 | 30 | 29 | 32 | 33 | 30 | 33 | 72 |
| **8** | 95 | 93 | 94 | 61 | 29 | 58 | 17 | 0 | 24 | 56 | 46 | 39 | 48 | 33 | 39 | 35 | 33 | 34 | 32 | 56 |
| **9** | 120 | 117 | 114 | 82 | 47 | 48 | 39 | 24 | 0 | 79 | 69 | 60 | 68 | 54 | 60 | 56 | 54 | 55 | 52 | 40 |
| **10** | 45 | 44 | 41 | 83 | 85 | 111 | 41 | 56 | 79 | 0 | 13 | 28 | 32 | 43 | 42 | 44 | 46 | 43 | 45 | 100 |
| **11** | 62 | 57 | 53 | 74 | 75 | 104 | 32 | 46 | 69 | 13 | 0 | 20 | 25 | 32 | 30 | 33 | 34 | 31 | 34 | 76 |
| **12** | 73 | 74 | 68 | 69 | 66 | 95 | 28 | 39 | 60 | 28 | 20 | 0 | 5 | 16 | 14 | 17 | 18 | 15 | 17 | 72 |
| **13** | 77 | 75 | 72 | 78 | 75 | 104 | 35 | 48 | 68 | 32 | 25 | 5 | 0 | 22 | 20 | 22 | 24 | 21 | 23 | 77 |
| **14** | 92 | 87 | 83 | 71 | 60 | 132 | 30 | 33 | 54 | 43 | 32 | 16 | 22 | 0 | 3 | 4 | 4 | 2 | 3 | 44 |
| **15** | 88 | 85 | 83 | 73 | 66 | 133 | 29 | 39 | 60 | 42 | 30 | 14 | 20 | 3 | 0 | 3 | 4 | 2 | 4 | 46 |
| **16** | 91 | 88 | 85 | 76 | 61 | 141 | 32 | 35 | 56 | 44 | 33 | 17 | 22 | 4 | 3 | 0 | 3 | 2 | 4 | 55 |
| **17** | 92 | 89 | 86 | 77 | 60 | 131 | 33 | 33 | 54 | 46 | 34 | 18 | 24 | 4 | 4 | 3 | 0 | 1 | 3 | 42 |
| **18** | 89 | 86 | 83 | 74 | 61 | 133 | 30 | 34 | 55 | 43 | 31 | 15 | 21 | 2 | 2 | 2 | 1 | 0 | 3 | 45 |
| **19** | 92 | 88 | 86 | 77 | 58 | 130 | 33 | 32 | 52 | 45 | 34 | 17 | 23 | 3 | 4 | 4 | 3 | 3 | 0 | 42 |
| **20** | 144 | 143 | 140 | 113 | 83 | 94 | 72 | 56 | 40 | 100 | 76 | 72 | 77 | 44 | 46 | 55 | 42 | 45 | 42 | 0 |

# APPENDIX B

## The source code of programing MATLAB

```
clear all
close all
clc

tic

%  Setting Part
 NOW = datestr(now,30);
part_Result = sprintf('Result\\%s\\',NOW);
mkdir(part_Result);        % Folder
part_graph = sprintf('%sGraph\',part_Result);
 A = sprintf('%s\\Command.txt',part_Result);

diary(A)
diary on

load('Data.mat')

Location_ALL = Location;

%============================
L_A = Location(1:36,:);
L_B = Location(37:53,:);
L_C = Location(54:77,:);
L_D = Location(78:93,:);

F_A = fixed_cost(1:36,:);
F_B = fixed_cost(37:53,:);
F_C = fixed_cost(54:77,:);
F_D = fixed_cost(78:93,:);

R_A = ri(1:36,:);
R_B = ri(37:53,:);
R_C = ri(54:77,:);
R_D = ri(78:93,:);

D_A = distance(1:36,1:36);
D_B = distance(37:53,37:53);
D_C = distance(54:77,54:77);
D_D = distance(78:93,78:93);


Group_Node_A = 5;
Group_Node_B = 3;
Group_Node_C = 3;
Group_Node_D = 3;


for loop=1:4

clear Location distance fixed_costri Route
clearTotal_Costtotal_Distance

disp('======= Setting Parameter ========')
```

```
switch loop

case 1
disp('NakhonRatchasima')
disp('Location A')

        Location = L_A;
distance = D_A;
fixed_cost = F_A;
ri = R_A;

        Node = 36             % Node fix
Group_Node = Group_Node_A       % Group_Node
Value_Distance_Over = 80
part_graph = sprintf('%sGraph_%d\',part_Result,loop);

case 2
disp('Chaiyaphum')
disp('Location B')

        Location = L_B;
distance = D_B;
fixed_cost = F_B;
ri = R_B;

        Node = 17             % Node fix
Group_Node = Group_Node_B       % Group_Node
Value_Distance_Over = 50
part_graph = sprintf('%sGraph_%d\',part_Result,loop);

case 3
disp('Buri Ram')
disp('Location C')

        Location = L_C;
distance = D_C;
fixed_cost = F_C;
ri = R_C;

        Node = 24             % Node fix
Group_Node = Group_Node_C       % Group_Node
Value_Distance_Over = 50
part_graph = sprintf('%sGraph_%d\',part_Result,loop);

case 4
disp('Surin')
disp('Location D')

        Location = L_D;
distance = D_D;
fixed_cost = F_D;
ri = R_D;

        Node = 16             % Node fix
Group_Node = Group_Node_D       % Group_Node
Value_Distance_Over = 50
```

```
part_graph = sprintf('%sGraph_%d\',part_Result,loop);

otherwise

end
        %=================================

        Chromosome = 500       % Chromosome
Cost_Distance = 1      % Cost_Distance
Round_OPE = 2000        % Round Operation


% Call function Function_HGA_ER,Function_HGA_FIX_COST,Function_GA
%
Function_HGA_ER_Exchange,Function_HGA_FIX_COST_Exchange,Function_GA_E
xchange

    [Total_Cost Route total_Distance] =
Function_HGA_ER_Exchange(Location,distance,fixed_cost,ri,Chromosome,N
ode,Group_Node,Cost_Distance,Round_OPE,Value_Distance_Over,Location_A
LL,part_graph);

Route_ALL{loop} = Route;
Total_Cost_Final{loop} = Total_Cost;
total_Distance_Final{loop} = total_Distance;

disp(' ')
disp('=====================================================')
disp('===                Successful                      ===')
disp('=====================================================')
disp(' ')
end

    % ================================================
    % =============== Plot Graph Route ===============
    % ================================================

figure('Color','w','Position',[100 100 700 600])
set(gca,'FontSize',10,'YGrid','off')
hold on;

plot(Location_ALL(:,1),Location_ALL(:,2),'ko','MarkerSize',5,'MarkerF
aceColor','g'); % plot location all
hold on;

for loop=1:4

clearRoute_Master Location
Route_Master = Route_ALL{loop};


switch loop
case 1
                Location = L_A;
Group_Node = Group_Node_A;       % Group_Node
case 2
```

```
                Location = L_B;
Group_Node = Group_Node_B;       % Group_Node
case 3
                Location = L_C;
Group_Node = Group_Node_C;       % Group_Node
case 4
                Location = L_D;
Group_Node = Group_Node_D;       % Group_Node
end

   % Find New Route
forRoute_Group_Node=1:Group_Node
clearBuff_fix_cost_HGABuffer_RouteEnd_Route
                % Get  Route from OPE Chromosome
End_Route = max(find(Route_Master(Route_Group_Node,:) > 0));

Buffer_Route = Route_Master(Route_Group_Node,1:End_Route);

cleartext_nameLocation_Route_OPE

for j=1:End_Route                  % Sort Route
Location_Route_OPE(j) = Buffer_Route(1,j);  % Read Location
text_name(j) = Buffer_Route(1,j);

    %                  end
end

clear Route

                    % Frist Node
                    X1 = Location(Location_Route_OPE(1),1);
                    Y1 = Location(Location_Route_OPE(1),2);
plot(X1,Y1,'ko','MarkerSize',7,'MarkerFaceColor','r'); % plot
location all
hold on;

                    % plot route
for i=1:End_Route-1

                        X1 = Location(Location_Route_OPE(i),1);     %
XX , 1
                        X2 = Location(Location_Route_OPE(i+1),1);
                        Y1 = Location(Location_Route_OPE(i),2);     %
YY , 2
                        Y2 = Location(Location_Route_OPE(i+1),2);

                        vertice1=[X1,X2];
                        vertice2=[Y1,Y2];

plot(vertice1,vertice2,'LineWidth',1);
hold on;

                        % Node name
                        s = int2str(text_name(i));
text(X1,Y1,s,'FontSize',8,'VerticalAlignment','Baseline');
hold on;
```

```
end

                    % End Node name
                    s = int2str(text_name(i+1));
text(X2,Y2,s,'FontSize',8,'VerticalAlignment','Baseline');
hold on;

                    X1 = Location(Location_Route_OPE(i+1),1);     %
XX , 1
                    X2 = Location(Location_Route_OPE(1),1);
                    Y1 = Location(Location_Route_OPE(i+1),2);     %
YY , 2
                    Y2 = Location(Location_Route_OPE(1),2);

                    vertice1=[X1,X2];
                    vertice2=[Y1,Y2];
plot(vertice1,vertice2,'LineWidth',1);
hold on;

xlabel('Location X')
ylabel('Location Y')
                   A = sprintf( 'Route  ALL Location Exchange');
title(A);

                   % Save jpeg
end

part_graph = sprintf('%sGraph\',part_Result);
           A = sprintf('%sRoute ALL Location Exchange',part_Result);
print( '-dtiff', A);

end

disp('=====================================')
Runing_Timer_Mintune = toc/60

diary off
    % save_data = [Total_Cost];
    %
    % dlmwrite('Result.xls',save_data,'-
append','delimiter','\t','newline','pc');
    %

    % close all
```

# APPENDIX C

# Printout results of GGA, HGA1 and HGA2 for LRPER

```
======= Setting Parameter ========
NakhonRatchasima (Location A)
Node = 36
No.LBB = 5
Limit Distance = 50
Initial population = 500
Transportation Cost = 1
no. iteration =  2000
==========================================
============  Function_HGA_ER ============
==========================================
 ============  Random Chromosome ============
 ============  Random Hybrid Chromosome ER  ============
 ======= Calculate Cost All Chromosome ========
 ======= Operation GA Start ========
Random_Number = 0.0678
Select_Chromosome_Master = 56
Cost_Min_Random = 23049
Cost_Min_Operate = 2.0695e+04
Index_Round_MIN_Cost = 1199
======= save Graph ========
===================================================================
========             "Exchange Operate"             ========
===================================================================
===================================================================
=====       New Route Exchange Operate minimize distance      ====
```

```
=====           and Calculate Cost            ====
==================================================================
========    Show Parameter "Exchange Operate"     ========
Location_Over =

  33    3

  27    0

  19   26

   8    4

   2    0

Route_Master =

   7   17   33    3    6    0    0    0    0    0

  21   20   22   27   15    9    0    0    0    0

  29   31   30   23   19   26   34   36   35   32

   1   10   13    8    4    0    0    0    0    0

  14   18   16   12   11    2   24   25   28    5

Route_Exchange =

 Columns 1 through 15

   7   17    0    0    6    0    0    0    0    0    0    0    0    0    0

  21   20   22    0   15    9    0    0    0    0    0    0    0    0    0

  29   31   30   23    0    0   34   36   35   32   33    0    0    0    0

   1   10   13    0    0    0    0    0    0    0    0    3    0    0    0

  14   18   16   12   11    0   24   25   28    5    0    0   27   19   26

 Columns 16 through 18

   8    4    0

   0    0    0

   0    0    0
```

```
  0   0   2

  0   0   0

Final_Route_Exchange =

  7   8  17   4   6   0   0   0   0   0   0   0

 21  20  22  15   9   0   0   0   0   0   0   0

 29  31  30  23  33  32  34  36  35   0   0   0

  2   1   3  10  13   0   0   0   0   0   0   0

 14  18  16  19  12  11  24  25  26  27  28   5

======================================================================

========          Compare Cost Parameter          ========

======================================================================

GGA Min. Cost= 23049

HGA1 Min. Cost = 2.0695e+04

HGA2 Min. Cost= 1.7532e+04

=========================================================

===          Successful          ===

=========================================================

 ======= Setting Parameter ========

Chaiyaphum (Location B)

Node = 17

No.LBB = 3

Limit Distance = 50

Initial population =  500

Transportation Cost = 1

no. iteration =  2000

============================================
```

============ Function_HGA_ER ============

==========================================

============ Random Chromosome ============

============ Random Hybrid Chromosome ER ============

======= Calculate Cost All Chromosome ========

======= Operation GA Start ========

Random_Number = 0.6199

Select_Chromosome_Master= 572

Cost_Min_Random= 9.0245e+03

Cost_Min_Operate= 7.8635e+03

Index_Round_MIN_Cost = 368

======= save Graph ========

==================================================================

======== "Exchange Operate" ========

==================================================================

==================================================================

===== New Route Exchange Operate minnimun distance ====

===== and Calculate Cost ====

==================================================================

======== Show Parameter "Exchange Operate" ========

Location_Over =

15 14 17 16

8 10 6 0

13 7 9 0

Route_Master =

11 12 15 14 17 16 0

```
   2    3    4    8   10    6    1

   5   13    7    9    0    0    0

Route_Exchange =

 Columns 1 through 15

  11   12    0    0    0    0    0   15   14   17   16    8   10    0    0

   2    3    4    0    0    0    1    0    0    0    0    0    0    6    0

   5    0    0    0    0    0    0    0    0    0    0    0    0    0   13

 Columns 16 through 17

   7    9

   0    0

   0    0

Final_Route_Exchange =

  11   12   15   14   17   16   10    9    8    7

   2    3    4    6    1    0    0    0    0    0

   5   13    0    0    0    0    0    0    0    0

================================================================

========          Compare Cost Parameter          ========

================================================================

GGA Min. Cost= 9.0245e+03

HGA1 Min. Cost = 7.8635e+03

HGA2 Min. Cost= 7.8035e+03

====================================================

===           Successful           ===

====================================================

 ======= Setting Parameter ========

Buri Ram (Location C)
```

```
Hospital = 24

No. LBB = 3

Limit Distance = 50

Initial population = 500

Transportation Cost = 1

no. iteration =  2000

==========================================

============  Function_HGA_ER ============

==========================================

============  Random Chromosome ============

============  Random Hybrid Chromosome ER  ============

======= Calculate Cost All Chromosome =======

======= Operation GA Start =======

Random_Number = 0.3628

Select_Chromosome_Master=  313

Cost_Min_Random=  1.3207e+04

Cost_Min_Operate=  1.0564e+04

Index_Round_MIN_Cost=  1696

======= save Graph =======

===================================================================

========             "Exchange Operate"             ========

===================================================================

===================================================================

=====      New Route Exchange Operate minnimun distance      ====

=====              and Calculate Cost                  ====

===================================================================
```

```
========     Show Parameter "Exchange Operate"       ========

Location_Over =

  10   11    4

  15   22    0

  18    0    0

Route_Master =

   3    2    5   10   11    4   12    6    7

  20   17   14   16   15   21   23   24   22

   9    8   13   19   18    1    0    0    0

Route_Exchange =

   3    2    5    0    0    0   12    6    7    0    0    0    0    0    0

  20   17   14   16    0   21   23   24    0    0    0    0   15   22   18

   9    8   13   19    0    1    0    0    0   10   11    4    0    0    0

Final_Route_Exchange =

   3    2    5   12    6    7    0    0    0    0

  20   18   17   14   16   15   21   23   24   22

   9    8   10   11    4    1   13   19    0    0

=====================================================================

========          Compare Cost Parameter        ========

=====================================================================

GGA Min. Cost= 1.3207e+04

HGA1 Min. Cost = 1.0564e+04

HGA2 Min. Cost = 1.0350e+04

=========================================================

===          Successful          ===

=========================================================
```

```
======= Setting Parameter ========

Surin (Location D)

Hospital = 16

No.LBB  =  3

 Limit Distance = 50

Initial population = 500

Transportation Cost = 1

no. iteration =  2000

==========================================

============  Function_HGA_ER ============

==========================================

 ============  Random Chromosome ============

 ============  Random Hybrid Chromosome ER  ============

 ======= Calculate Cost All Chromosome ========

 ======= Operation GA Start ========

Random_Number=  0.5633

Select_Chromosome_Master =   512

Cost_Min_Random=  8.5285e+03

Cost_Min_Operate = 8.2125e+03

Index_Round_MIN_Cost =   174

======= save Graph ========

==================================================================

========             "Exchange Operate"             ========

==================================================================

==================================================================

=====      New Route Exchange Operate minnimun distance      ====
```

```
=====              and Calculate Cost               ====
================================================================
========     Show Parameter "Exchange Operate"       ========
Location_Over =
   2    1    0    0
  16    6    4    3
   8    0    0    0
Route_Master =
   9    5    2    1    0    0    0    0    0
  12   15   13   14   16    7    6    4    3
  11   10    8    0    0    0    0    0    0
Route_Exchange =
 Columns 1 through 15
   9    5    0    0    0    0    0    0    0    2    1    0    6    4    3
  12   15   13   14    0    7    0    0    0    0    0   16    0    0    0
  11   10    0    0    0    0    0    0    0    0    0    0    0    0    0
 Column 16
   8
   0
   0
Final_Route_Exchange =
   9    8    5    4    3    2    6    1
  12   15   13   14   16    7    0    0
  11   10    0    0    0    0    0    0
================================================================
========           Compare Cost Parameter          ========
```

========================================================================

GGA Min. Cost = 8.5285e+03

HGA1 Min. Cost =8.2125e+03

HGA2 Min. Cost = 7.9315e+03

===========================================================

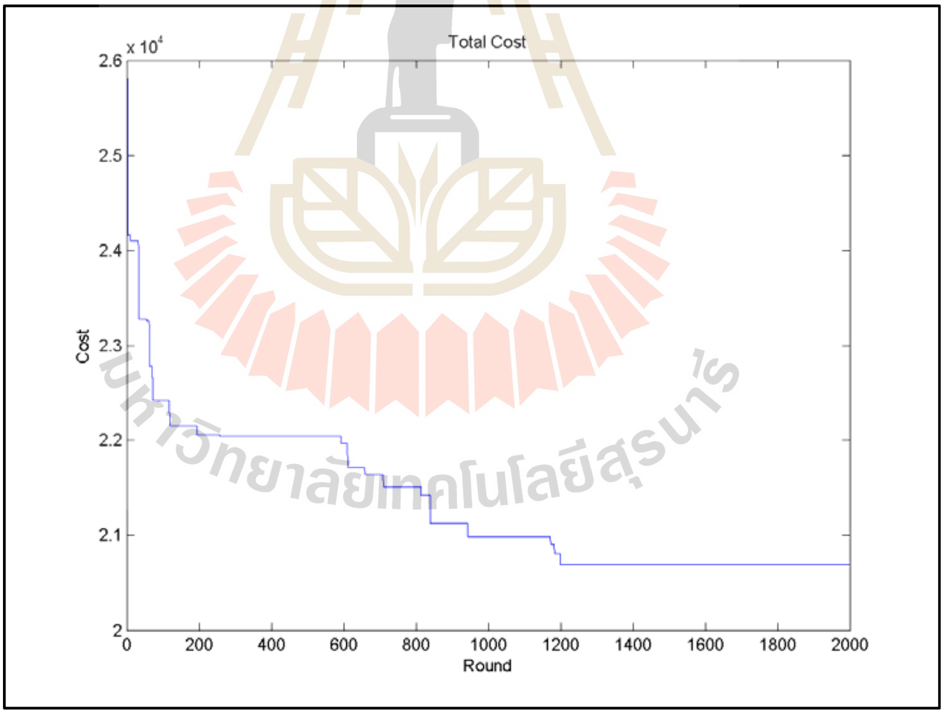
===                Successful                    ===

===========================================================

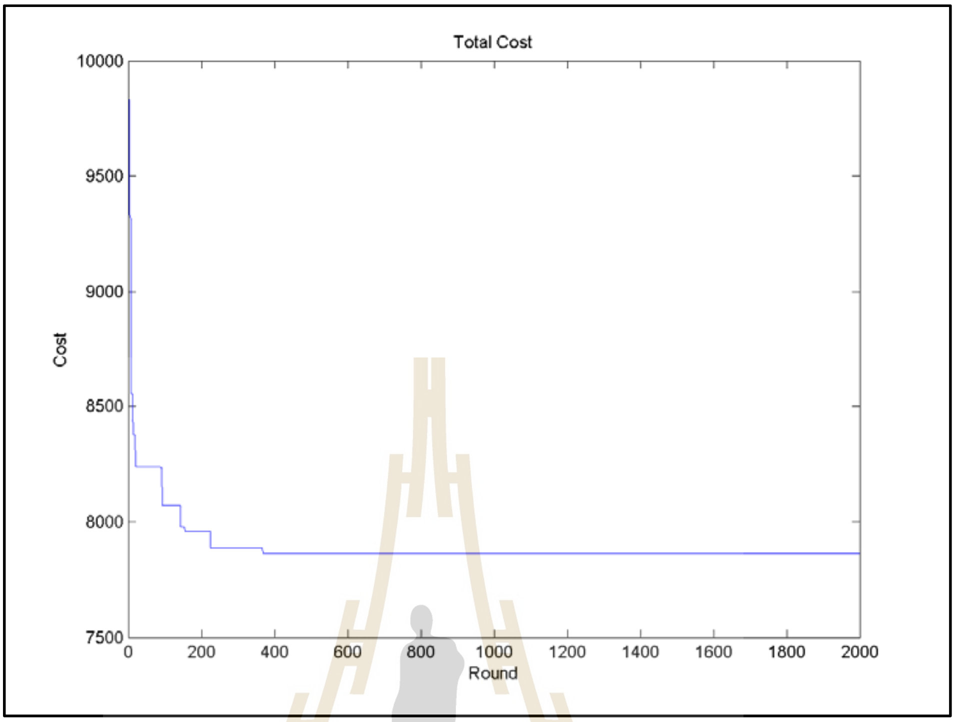
=======================================

Runing_Timer_Mintune =    0.6935

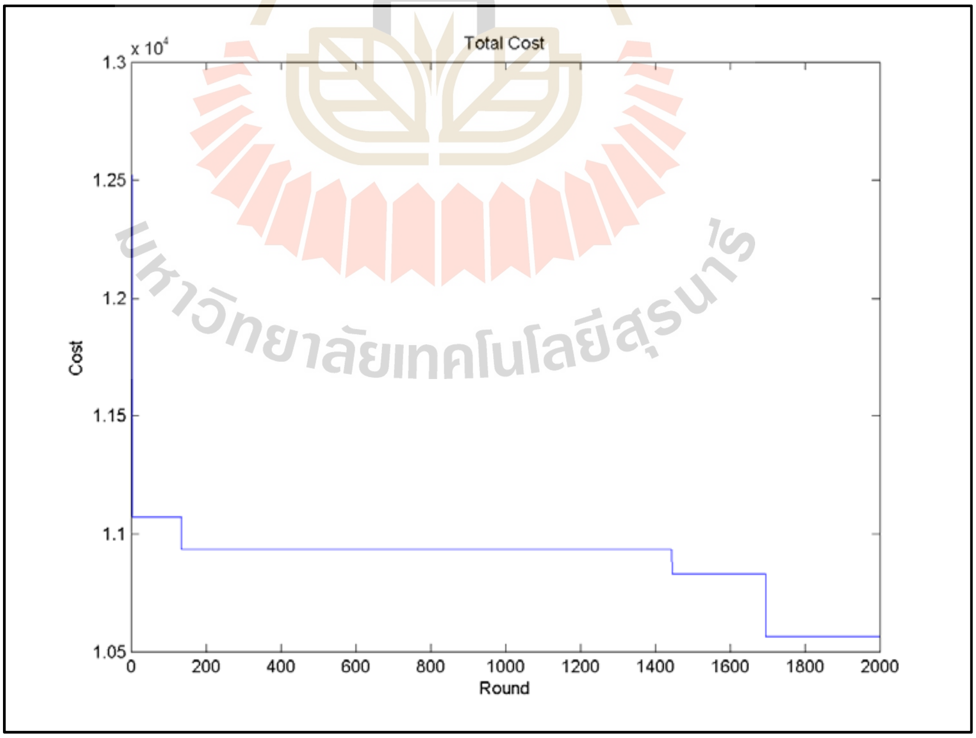
Total cost of HGA2 for NakhonRatchasima



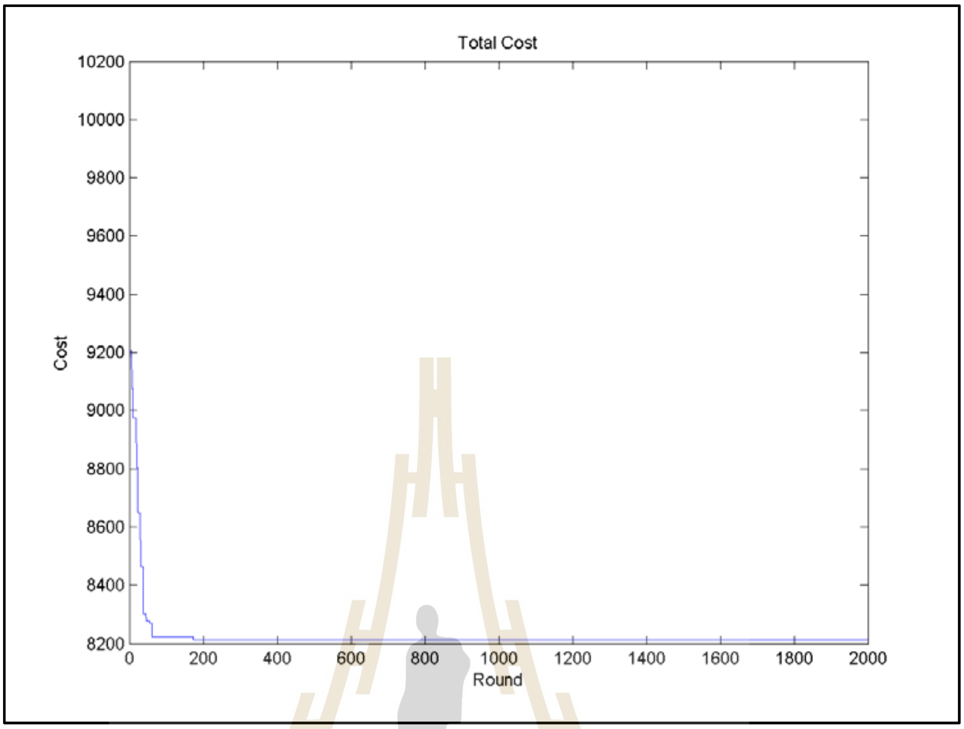
Total cost of HGA2 for Chaiyaphum



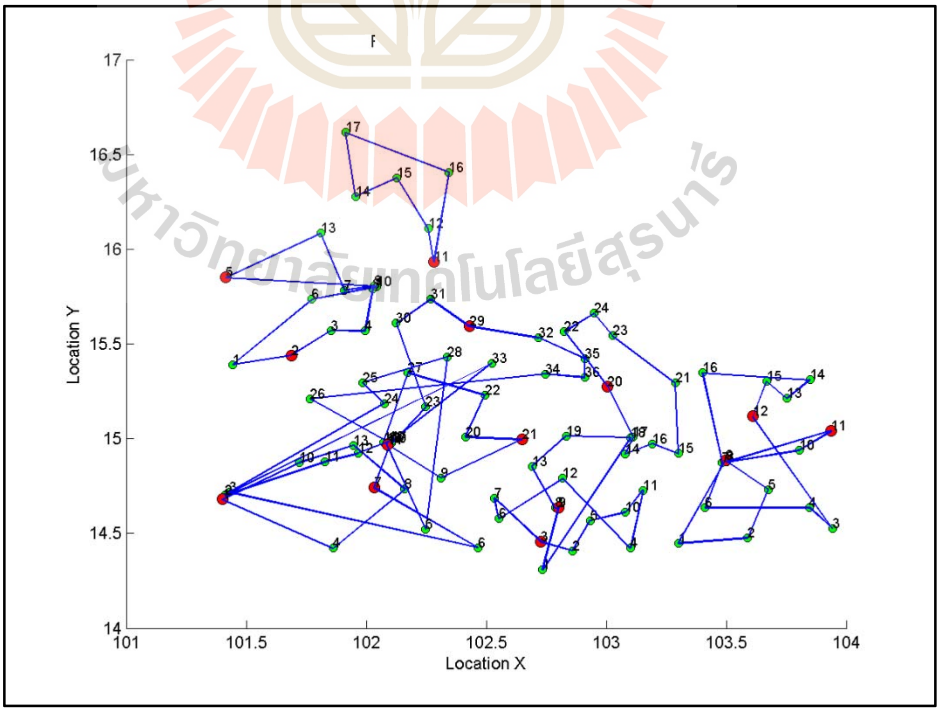

Total cost of HGA2 for Buriram



Total cost of HGA2 for Surin




Graph Result of HGA2 for LRPER



# BIOGRAPHY

Mr. Jarupong Banthao was born on October 1, 1978 in Ubon Ratchathani, Thailand. He received a B.Eng. in Industrial Engineering from Suranaree University of Technology in 1997. He received M.Eng. in Engineering Management from Vongchavalitkul University in 2004. After graduation, he served in position of lecturer at Faculty of Engineering and Architecture, Rajamangala University of Technology Isan. From 2009 to 2015 he was a Ph.D student in the school of Industrial Engineering at Suranaree University of Technology. His research interests lie in health care logistics and supply chain optimization.