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COLLECTION STATION LOCATION AND VEHICLE ROUTING OPTIMIZATION IN THE NATURAL RUBBER INDUSTRY

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A Dissertation Submitted in Partial Fulfillment of the Requirements
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งานวิจัยนี้ศึกษาสภาพปัญหาปัจจุบันของระบบการเก็บรวบรวมวัตถุดิบในอุตสาหกรรมยางพาราเพื่อเป้าหมายกำไรสูงสุดของระบบการเก็บรวบรวมวัตถุดิบ ในการจัดตั้งระบบการเก็บรวบรวมวัตถุดิบ นอกจากการตัดสินใจในด้านสถานที่ตั้งจุดรวบรวมวัตถุดิบ การจัดสรรจุดรวบรวมวัตถุดิบกับผู้ขาย และการจัดเส้นทางขนส่งแล้ว การคัดเลือกผู้ขายเป็นอีกปัจจัยหนึ่งที่ต้องพิจารณาเนื่องจากผลกระทบของระบบแรงจูงใจ โดยภายใต้เงื่อนไขของระบบแรงจูงใจที่ทางโรงงานกำหนดขึ้น ผู้เก็บรวบรวมวัตถุดิบต้องเก็บวัตถุดิบให้มากขึ้นเพื่อที่จะได้ราคารับซื้อวัตถุดิบที่โรงงานที่สูงขึ้น ดังนั้น จึงมีความจำเป็นที่จะต้องคัดเลือกผู้ขายเข้ามาในระบบ อีกทั้งต้องคำนึงถึงขนาดของรถและระยะเวลาในการเก็บรวบรวมวัตถุดิบด้วย วัตถุประสงค์หลักของงานวิจัยเพื่อหากลุ่มผู้ขายที่เหมาะสมที่ทำให้ระบบการเก็บรวบรวมวัตถุดิบมีกำไรสูงสุด งานวิจัยนี้จึงได้วิเคราะห์และสร้างโปรแกรมเชิงเส้นจำนวนเต็มแบบผสมและแบบทวิภาค สำหรับการแก้ปัญหาการจัดตั้งจุดรวบรวมวัตถุดิบและการจัดเส้นทางภายใต้เงื่อนไขระบบแรงจูงใจ ด้วยความซับซ้อนของปัญหาซึ่งมีความซับซ้อนเป็นอย่างมาก จึงได้พัฒนาฮิวริสติก ซึ่งประกอบด้วยขั้นตอน 3 ขั้นตอน ขั้นตอนแรก คือ การจัดตั้งและจัดสรรจุดรวบรวมวัตถุดิบกับผู้ขาย เป็นการสร้างคำตอบที่เป็นไปได้หนึ่งคำตอบ ขั้นตอนที่สอง คือ ขั้นตอนการปรับปรุงเส้นทาง เพื่อพัฒนาคุณภาพคำตอบในเชิงการลดต้นทุน ขั้นตอนที่สาม เป็นการคัดกรองผู้ขายเพื่อหากลุ่มผู้ขายที่มีศักยภาพที่จะให้คำตอบที่ดีกว่าคำตอบที่ได้จากขั้นตอนที่สอง งานวิจัยนี้ได้ทดสอบด้านการคำนวณเพื่อวิเคราะห์คุณภาพคำตอบและเวลาที่ใช้ในการหาคำตอบ เมื่อเปรียบเทียบผลคำตอบกับปัญหาต้นฉบับ พบว่า ฮิวริสติกให้ผลคำตอบที่เทียบเท่ากับปัญหาต้นฉบับ โดยมีความแตกต่างเฉลี่ยน้อยกว่าร้อยละ 15.7 ในขณะที่ใช้เวลาหาคำตอบที่รวดเร็วกว่าปัญหาต้นฉบับ โดยมีความแตกต่างเฉลี่ยมากกว่าร้อยละ 99.8

ภาควิชา..........วิศวกรรมอุตสาหการ..... ลายมือชื่อนิสิต...
สาขาวิชา..........วิศวกรรมอุตสาหการ..... ลายมือชื่ออ.ที่ปรึกษาวิทยานิพนธ์หลัก......................
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KEYWORD; LOCATION ALLOCATION/ VEHICLE ROUTING/ STEP-PRICE/ HEURISTICS/ NATURAL RUBBER.

KANYA AUCKARA-AREE : COLLECTION STATION LOCATION AND VEHICLE ROUTING OPTIMIZATION IN THE NATURAL RUBBER INDUSTRY. THESIS ADVISOR : ASST. PROF. REIN BOONDISKULCHOK, D.ENG., 114 pp.

This research addresses a real–life problem which aims to maximize profit of raw material collection system in the natural rubber industry. To establish the collection system, the system investigated in this research is concerned with not only location decision, allocation decision, and routing decision, but also with supplier selection decision with influence of step–price policy. Step–price policy sets by the factory give incentive to collector to collect as large quantity as possible of natural rubber from suppliers in order to receive a higher price for raw material. It is essential to find the set of suppliers included in the system. In addition, other conditions such as vehicle capacity and biological time duration are also considered. The main objective of this research is to find the optimal set of suppliers so that the profit of the collection system is maximized. The location allocation and vehicle routing with step–price policy is formulated as a Mixed Integer Programming model (MIP). With lots of complexities present in the problem, a heuristic method consisting of three stages is developed. The location allocation stage constructs one feasible solution while the routing improvement is then applied in order to reduce total system cost. The supplier screening stage is lastly added to find other potential sets of suppliers who can generate better profit. Computational test results are analyzed and discussed based on both performance and solving time. The comparison of the results shows that the solution of the heuristic solution method is slightly different from the mathematical model solution of which a less than 15.7% average difference is recorded. Meanwhile, computational time is saved more than 99.8% of average difference.

Department......Industrial Engineering
Field of study....Industrial Engineering
Academic year..........2009..........
Student's signature....กันยา อัครอารีย์.....
Advisor's signature..............................

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 General Background

Natural rubber is currently one of the most important economic crops in Thailand. Thailand produces and exports natural rubber which accounts for 34% of total world production, and for 47% of total world export (Rubber Research Institute of Thailand, 2008). In 2008, Thailand has earned 223,628.3 million Baht from exporting natural rubber (Office of Agricultural Economics, 2008). However, according to the total natural rubber production (3.166 million tons), 89% of exported natural rubber was in semi–final product such as smoked sheets (Rubber Research Institute of Thailand, 2008). Therefore, in order to be the leader of world natural rubber industry, the government concerns much to improve this profitable industry not only in production performance and marketing, but also in management practice including supply chain management.

Raw material collection system is one important part in a supply chain of the natural rubber industry where attention needs to be paid. When considering the raw material collection system in the natural rubber industry, the collection process appears to be the main activity in the system. The logistics cost is a huge portion in the costs of the collection system. Most of the logistics costs both fixed costs such as collection station fixed costs, and variable costs like transportation costs rely on the operation model of raw material collection system. In addition to these, the natural rubber industry has specific characteristics such as perishable product that affects collection time and incentive system which influences collected quantity, which is also needed to be considered when setting up a raw material collection system.

Generally, the important aspect in designing the collection system is the decision on locating facilities such as collection stations, plants or factories, allocating suppliers or customers to the selected facilities, and transporting products from supplier to the factory through the collector system. From collection station's perspective, the location and the number of collection stations are both major factors in designing the collection system because changing the number of collection stations affects the supply chain cost. Relating to the viewpoint of the collection station, suppliers should be assigned to a proper collection station. Another point concerned with raw material collection design problem is raw material transportation. In supply chain network, to implement routing shipment is more complex to operate than direct shipment. According to transportation condition, a vehicle needs to visit suppliers in the route and returns to the collection station under the capacity of the vehicle and within biological time constraints. Thus, number of suppliers selected in the route and number of vehicles used in the routing are key factors that should be investigated. In addition to the aforesaid factors, with step–price environment, different quantity levels give different raw material prices. Since different sets of suppliers yield the difference of revenue, and make a difference in the system cost, it is essential to find a set of suppliers included in the system. Therefore, to establish such a complicate raw material collection system, it is necessary to involve not only the location decisions but also the allocation decision, and routing decision which should be determined and the supplier selection decision should be examined as well.

The purpose of this research is to find a solution for the problem of setting up raw material collection system with step–price condition. With the holistic view model that considers step–price condition together with vehicle capacity and time duration restrictions, the optimal collection system needs to be found. The solution of the developed model is the strategy used for raw material collection system set up by determining the location and the number of collection stations that need to be opened, a set of suppliers included into the system and the allocation of selected suppliers to each collection station, and a set of preliminary routes referring to the number of vehicles. This research emphasizes on the maximization of profit from raw material collection which interrelates with revenue from collected supply and total system cost.

1.2 Raw Material Collection System in the Natural Rubber Industry

The overview of raw material collection system in the natural rubber industry and the process of raw material collection are given in this section. Furthermore, description of the incentive system used in raw material collection system is also explained.

1.2.1 Structure of the Natural Rubber Industry in Thailand

There are three major parties operating in raw material collection system in the natural rubber industry in Thailand. The first party is the rubber planters or supplier part. The second party is the factory part, and the last party is the collector part.

1.2.1.1 Supplier

Suppliers are responsible for two types of rubber products such as latex and rubber sheets which are basically produced. Growing areas are geographically dispersed in many regions, and the size of growing areas vary from a range of smallholdings to plantation estates (more than 40 ha each). In Thailand, the amount of smallholdings is 2,414,500 ha which accounts for 99% of total natural rubber growing area (2,433,900 ha) (Rubber Research Institute of Thailand, 2008). The productivity of natural rubber depends on many factors such as season, financial support, economic as well as social and political factors.

1.2.1.2 Manufacturer

The function of a factory is to transform raw material into semi–final products or final products. There are five types of semi–final products produced in Thailand that are (1) concentrated latex, (2) block rubbers, (3) smoked sheets, (4) air dried sheets, and (5) crepes. On the part of factory, the availability of raw materials conforming to the production plan is the major factor for producing products. To have steady production process, a factory needs predictable and regular raw materials for production supply. Furthermore, as most agricultural products are seasonal materials with short shelf life, the uncertainty of supply availability and shelf life of raw materials are important factors impacting on the production (Haan et al, 2003; Nambiar et al., 1989).

1.2.1.3 Collector

Due to the significant supply factor affecting the production process, the collector system is set up for raw material collection in order to make the flow of raw materials more certain. A collector or a dealer who acts as intermediary between farmers and manufacturers is the last party. Collectors have a duty to collect raw materials from such supply sources as smallholdings, and then transport the collected materials to factories.

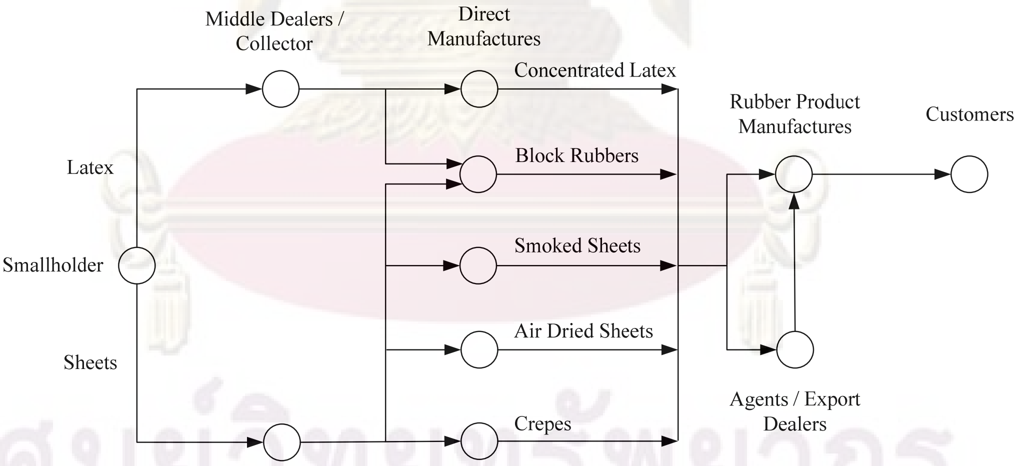


Figure 1.1 The material flow of natural rubber in the natural rubber industry

As illustrated in Figure 1, two types of rubber are brought from supply points to collection stations separately. At the collection stations, rubber is weighed, graded and bought. Next, rubber is transported to direct manufacturing in order to prepare for the production process of final products. After preprocessing, the rubber products are either directly delivered to rubber product manufacturing or agency dealers who act as intermediary between two manufacturing and normally work for large manufacturers. Next, the rubber products are produced and finally, distributed to the customers.

The traditional process in rubber production is to transform latex into un-smoked sheets and then to smoked sheets. However, in the framework of this study, we mainly concentrate on the chain of latex starting from rubber smallholder to concentrated latex factory. The reason for choosing latex is that rubber products produced from latex requires high latex’s quality. In addition, though latex is easier to be processed than rubber sheet, it is more difficult for time management due to hard biological time constraint. Latex has to be transferred to the collection station within biological time to ensure that latex does not pre–coagulate.

1.2.2 Raw Material Collection Process in Real World

We now give the review of latex collection operations in real world situation (Information from both surveying and interviewing three parties: suppliers, collectors, and manufacturers in Southern provinces of Thailand).

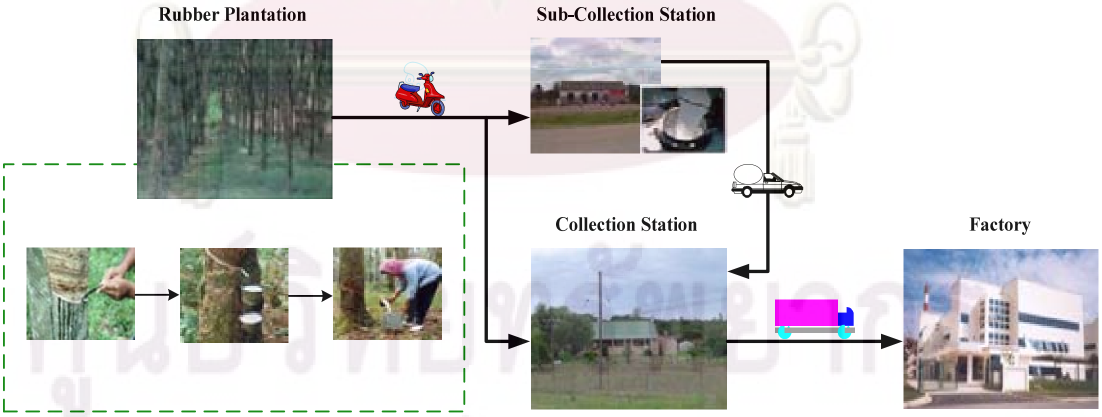


Figure 1.2 The raw material collection process in the natural rubber industry

1.2.2.1 Supplier Operation

The operations of latex collection start from tapping rubber trees. Rubber trees are normally tapped alternate–daily between 3 a.m. – 6 a.m. because it maximizes latex yield. A planter can tap (500 – 1000) trees daily depending on the extent of his plantation. After a short break, the planter returns to rubber trees and transfers the latex from the cup into a bucket. This operation can be completed in one to two hours time. The planter then transports his crop (50 – 110 liter) to a nearby sub–collection station on a motorcycle.

1.2.2.2 Collector Operation

At the sub–collection station, latex is sampled for its dry rubber content and weighed. Then, latex is poured into the collection tank (capacity 1500 – 2200 liter). One sub–collection station can serve between 20 – 30 planters. A collector pays the planters according to the weight of their latex, dry rubber content and current market rubber price. When the tank is full, a collector then transports latex from sub–collection station to other larger collection station. The delivery time is 1 – 2 hours based on distance between two collection stations, and the traffic.

The same operation occurs at all collection stations. The collected latex is also sampled for its dry rubber content and weighed. Latex from both planters and sub–collection stations are poured into a collection tank (capacity 25000 liter). An amount of preservative is added to ensure that the latex remains fluid at least up to the time of processing. This is an important process; otherwise the latex will coagulate and will be reclassified into a lower grade of rubber. However, too much amount of preservative also affects the quality of product. Raw material can be stocked in the collection tank 1 – 2 days based on the amount of added preservative. Next, the latex is transported to a factory by a truck with capacity of 18,500 – 29,000 liters. The delivery time is 1 – 2 hours based on distance between the collection station and a factory, and also the traffic.

1.2.2.3 Manufacturer Operation

The factory processes the collected latex into products depending on manufacturing types as mentioned previously. The rubber products are passed into storage and next transported by lorries to the customers.

1.2.3 Step–price System

In the natural rubber industry, the price of each grade of rubber depends mainly on the market price set in daily by the government. The collectors who buy raw material from the suppliers have the same trading system. They pay the suppliers according to weight and graded quality. Nevertheless, because many factories have comparatively larger capacity than supply of raw material, an incentive system such as loan support, quota and incentive price is created for the benefit of the collector so that raw material supply to the factory will be more reliable and predictable.

One of the incentive policies which are used in raw material collection system in the natural rubber industry is a step–price policy. The so called ‘step–price policy’ is that the price of raw material is increased for higher raw material quantity. For example, if the supply quantity is X kilograms, the price of raw material is A Baht (Baht–Thai monetary unit), but when the supply quantity is added to Y kilograms, where $Y > X$ the price will be B Baht, where $B > A$. This implies that when the more supply quantity is collected, the higher raw material price will be paid to the collector. This incentive price policy is set to help the factory to make sure that more raw materials will be supplied to.

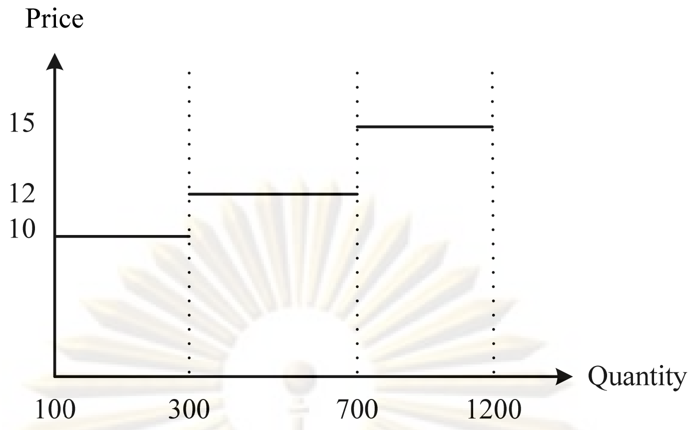


Figure 1.3 An example of step–price policy

1.3 Analysis of Raw Material Collection System

In this section, the raw material collection system operating in real world is analyzed in various perspectives such as problems that occur in real world operation, and aspects which impact on the set up of raw material collection system. The proper design of raw material collection system is also suggested.

1.3.1 Problems in Real World

According to current raw material collection system operating in real world, many uncertainties happen at the collection station. The problems can be mentioned as follows:

- A collector does not know which suppliers will bring their crop to the collection station. This uncertainty bases on the supplier's decision and the relationship between the collector and suppliers.
- A collector does not know how much raw material that each supplier will transport to the collection station. This problem depends on season and tapping labor.

- A collector does not know when suppliers will come to the collection station. This problem depends on the distance between rubber plantation and the collection station; moreover, it can affect the quality of raw material since raw material is time–degradable.

Therefore, collector cannot manage both quantities of raw material and transportation time from the collection station to a factory. For instance, if the quantity of raw material is lower than expected quantity, raw material will be treated by using more chemical, and stocked for delivery to a factory on the next day. In addition, if the operation at the collection station finishes too late to transport to a factory, raw material will also be treated and stocked in the stock tank. Both problems can have a dire effect on quality of raw material which may result in a lower grade of raw material. The more chemical is used; the quality cost is increased with a consequent reduced income for the collector. Hence, the proper raw material collection system should be introduced to overcome problems of this nature and improve system efficiency.

1.3.2 Discussion on Proper Design Option of Raw Material Collection System

In view of today’s operation of raw material collection system, it seems that there has been a wide range of aspects impacting on the establishment of a collection system. In this study, three crucial aspects namely, the number of collection stations, the supplier–collector relationship, and the transportation movement have been analyzed for designing a proper raw material collection system.

1.3.2.1 Aspect of Collection Station

When considering the inbound collection network, the number of collection stations is the main aspect in designing the collection system. Changing the number of collection stations affects total supply chain cost (Daskin et al., 2003; Krarup and Pruzan, 1990; ReVelle and Eiselt, 2005). As revealed by Chopra (2003), as the number of facilities in a supply chain increases, the facility cost surly increases. Nevertheless, increasing the number of facilities decreases the transportation cost.

Here, we categorize the number of collection stations into two groups as one collection station and multiple collection stations. Only one collection station in operation gives certainly a lower collection station fixed cost than multiple collection stations. However, only one collection station may not be sufficient for collecting and transporting latex within biological time constraint. It can affect the collection and transportation time, and the quality of raw material since latex is time–degradable product. As a result, multiple collection station option is suggested even though the increasing of the number of collection stations brings about high collection station fixed cost, but makes raw material collection more convenient and efficient. Multiple collection stations moreover, shorten the distance between collection stations and both suppliers and the factory.

1.3.2.2 Aspect of Supplier–Collector

The relationship between supplier and collector is another essential aspect that needs to be considered thoroughly in the natural rubber industry. Availability of supply delivered to the factory is affected by the supplier–collector relation. The concept of partnership should be one element taking care in supply chain management (Maloni and Benton, 1997; O'Keeffe, 1998). In this study, the relationship between supplier and collector is classified as contracted and non–contracted suppliers. Contracted suppliers mean that all suppliers in the system have to transport their product to the collection stations. On the other hand, non–contracted suppliers do not need to send their supply to the collection stations. The supply from suppliers could be transported to other collectors.

Due to the presence of contracted suppliers, a collector certainly knows suppliers will bring their product to the collection station, and the collector will transfer all supply to the factory which will result in a decrease of collection cost.

When it comes to non–contracted suppliers, a collector is unaware of which supplier will bring their product to the collection station. This problem has an effect on the uncertainty production supply leading to high inventory cost and collection cost. Thus, contracted suppliers option is recommended because of the uncertainty of supply from non–contracted suppliers which can have a significant impact on raw material collection system than from contracted suppliers.

1.3.2.3 Aspect of Transportation Movement

Transportation movement is also an important aspect that should be investigated in the supply chain network. Chopra and Meindl (2001: 261–302) have stated that type of shipment influences transportation time and distance affecting transportation cost. Laporte (1988) has introduced two terminologies of shipment that are route of type R and route of type T. Route of type R (for replenishment) is that the route connects a pair of two nodes between different layers. For instance, a depot is connected to a customer. In one hand, route of type T means a tour connecting a node in a layer with more nodes belonging to other layers. For example, a depot is connected via a tour to a certain number of customers served by the same vehicle. In this study, two shipment patterns that are direct shipment and routing shipment are analyzed.

With direct shipment, the vehicle fixed cost is increased since every path requires one vehicle for transporting latex. The transportation cost and the overtime cost are also affected by direct shipment because the distance of one trip is long. When operating direct shipment, collector cannot manage transportation time between suppliers and collector resulting in high inventory cost. If operation at the collection station finishes too late to transport to the factory, latex will be treated by using more chemical and stocked in the stock tank. Adding more preservative increases chemical cost and quality cost with a consequent reduction of income. Therefore, changing from direct shipment to routing shipment makes the collection system more profitable since routing shipment consolidates shipments to multiple suppliers on a single vehicle. Not only the vehicle cost is low, but routing shipment also gives a decrease in transportation cost and inventory cost.

According to the analysis of problems in real world and the discussion on proper raw material collection system, as shown in Figure 1.4 is proposed in this research. The proposed design will help a collector to have better control both supply quantity and delivery time which may lead to use a lower amount of chemical. The expected total system cost should be decreased. In the proposed design, collector has a function of collecting and transporting raw material to a factory with the main objective of getting profit from buying and selling raw material. Sub–collector, in addition, can be either set as a supplier with large supply or can be changed to be a collector’s truck operators or third party for picking up the raw material.

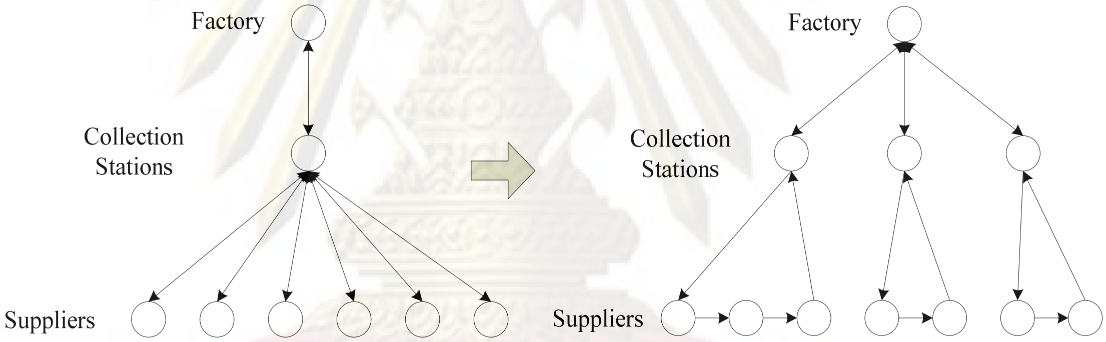


Figure 1.4 A proposed raw material collection system

1.3.3 Decisions of the Collector

There are two levels of collector decisions relating to the proposed raw material collection system. The first level is responsible for making set up decisions while the second level is the operation decisions. The decision maker considers the design of proper raw material collection system involving location decision, supplier selection decision, allocation decision, and transportation decision. Given the system mechanism, it seems that the operation decision is concerned on daily implementation of raw material collection system relating to transportation decision only.

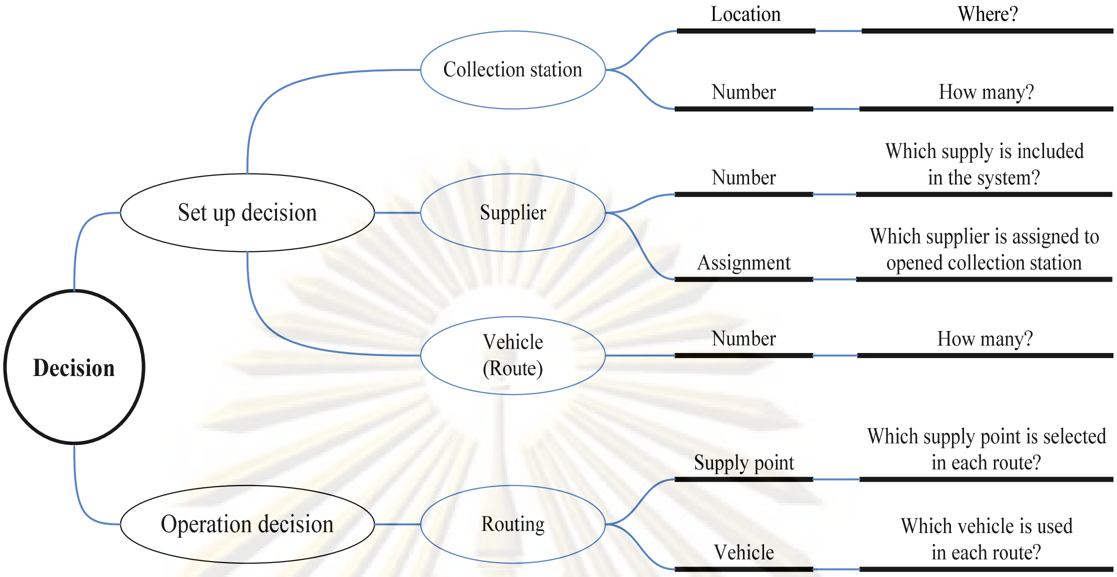


Figure 1.5 The decisions of the collector

1.3.3.1 Set up Decision

In order to set up a proper raw material collection system, it is important to examine both the number of collection stations and the location of each collection station. Since it is given that not all suppliers are required to be selected, the selection of suppliers based on location and supply of suppliers should be determined. The assignment of selected suppliers should be decided after supplier selection is organized. In transportation decision, number of suppliers selected in the route and number of vehicles used in the routing should be investigated. Moreover, the routes should be scheduled restricted to vehicle capacity and perishable time duration.

Given: (a) a set of potential collection station locations,

(b) a set of possible suppliers,

(c) a factory location,

(d) a set of vehicle.

Determine: (a) a set of selected suppliers which maximizes total revenue,

(b) the number and location of collection stations that need to be opened so that collection station set up cost and transportation cost from collection stations to a factory are minimized,

(c) a set of preliminary routes referring to the number of vehicles.

Constraint: (a) capacity of vehicle,

(b) biological time duration,

(c) step–price policy.

1.3.3.2 Operation Decision

For the implementation of the raw material collection system, the reassignment of open collection stations and selected supplier should be considered in line with the change of supply and price. The reassignment of routing to collect raw material from all selected suppliers under vehicle capacity and biological time constraints should be determined as well.

Given: (a) a set of open collection stations,

(b) a set of selected suppliers,

(c) a set of vehicles.

Determine: (a) a set of daily routes that raw material collection cost is minimized.

Constraint: (a) capacity of vehicle,

(b) biological time duration,

(c) step–price policy.

It is observed that the set up decision making is the static case while the operation decision is dynamic case. However, this problem studied is not long–term profit maximization since collection stations can be relocated. It means that if the parameters such as supplier supply, location, or price are dramatically changed, the location decision will be reconsidered.

1.4 Statement of the Problem

In order to set up a proper collection system, the designing of raw material collection system is studied in this research. The period for setting a design covers expected period life of the collection station. The collection system investigated consists of a number of suppliers, multiple collection stations with unlimited stocking area, and one factory to which collected raw material has to be sent. Suppliers in the system considered can either be planters themselves or sub–collectors who collect raw material from a group of planters. In the system considered, raw material is collected from suppliers and then transported to the factory through the collector system. Raw material transportation is divided into two levels. The first level is the transportation between the supply point and the collection station while the second one includes the transportation between the collection station and the factory.

For the first level, the identical vehicles with limited material handling capacity are dispatched from a collection station to visit a set of suppliers in order to collect raw material. When collection process is completed, the vehicle will return to its collection station. The collected raw material is then unloaded and prepared to delivery to the factory. For the second level, larger vehicle will transport collected raw material directly from each collection station to the factory. Figure 1.6 gives an illustration of raw material collection system investigated in this research.

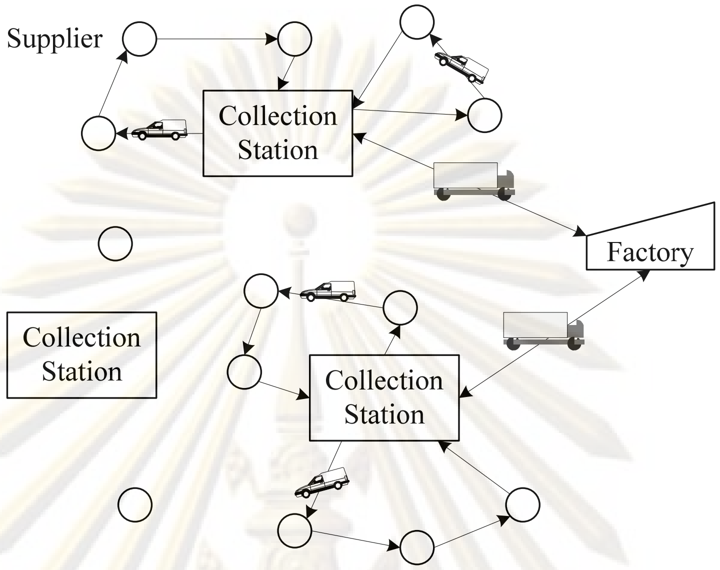


Figure 1.6 The raw material collection system considered in this study

Because of the relatively larger demand than supply, most factories have incentive policies for their collectors so as to facilitate more supply quantities to the factories. One of the incentive policies which are used in raw material collection system is the 'step–price policy'. Generally in the collection system, raw material price at each collection station is always based on the government price while raw material price at the factory varies according to step–price quantity levels. In this study, all collection stations pay suppliers with the same raw material price. The step–price quantity levels and step–prices offered to the collector are created by the factory. For example, if the raw material price at collection station is p_0 and q^* is collected quantity, if $q_1 < q^* \le q_2$ then raw material price at the factory is p_1, but if $q_2 < q^* \le q_3$ then the price of raw material at the factory is p_2 which is equal to p_1 plus incentive price. Therefore, from a collector's viewpoint, when the buying price (p_0) is fixed and the selling price per unit (step–price) is varied, a collector has to collect more raw material quantity in order to receive higher price for raw material at the factory.

In order to set up raw material collection system under step–price policy circumstance, a collector has to collect more raw material quantity by expanding collection area. The more suppliers visit, the more income receives; however, when a collector decides to visit more suppliers, traveling distance will be longer which will result in higher transportation cost. Because each set of suppliers yields different collected quantity resulting in different revenue; therefore, the set of suppliers included in the system is a vital point for designing raw material collection system. With step–price policy condition, it has to be a trade–off between revenue received from totally collected quantity and total cost both fixed cost and variable cost from expanding collection area if we want to get higher step–price level.

Moreover, the system considered here includes time duration and vehicle capacity constraints. Since raw material, an agricultural product is perishable; quality of raw material can decay quickly. The collection process should be kept within biological time duration relevant to the perishability of raw material. Not only biological time duration but also the vehicle capacity can limit the collection process. For example, if the capacity of vehicle is full, the vehicle has to return to the collection station.

Consequently, in order to maximize profit of the raw material collection system, a collector must decide where to collect raw material from and the number of suppliers, how many collection stations and where they should be located, how many vehicles in the system, and what the routes of each vehicle to take are. A collector has to trade the strategy off between revenue from collected supply and total system costs which include both fixed cost and variable cost for the setting up raw material collection system under vehicle capacity, time duration and step–price policy circumstances.

1.5 Research Objective

The objective of this research is to develop a mathematical model for an integrated location allocation and vehicle routing problem with step–price policy. The strategy for supplier selection, collection station location, and transportation planning in order to get maximum profit from raw material collection is determined. The developed model will be applied for setting up raw material collection system for the natural rubber industry and can be applied to other agricultural industries whose characteristics of the system are the same.

1.6 Research Scope

The integration of the location allocation and the routing problem for setting up the raw material collection system is studied in this research. The assumptions are defined in order to confine the scope of the study.

1.6.1 The Characteristics of the Raw Material Collection System

This study considers the case of setting up proper design of raw material collection system. The setting up of the collection system studied here is assumed to consider only one period such as one year set up. In raw material collection system, raw material is collected from suppliers and then sent to the factory through the collection stations. The locations of possible suppliers, potential collection stations, and a factory are given. Only one factory with unlimited demand is operated in the raw material collection system. The collection station is uncapacitated collection station. All collection stations have unlimited area for stocking raw material before transporting the collected raw material to the factory. This implies that each collection station can serve as many suppliers as the collector desires.

In this research, only a single raw material is considered in the collection system. This means that only one identical product is produced by suppliers and collected by the collector. Quality of raw material is assumed to be one grade of quality. Supply of suppliers investigated is deterministic supply and varies according to the season variation. Raw material price at each collection station is assumed to use the same price while raw material price at the factory varies according to step–price quantity levels. The step–price policy set by the factory is based on step–function in which step–prices and the quantity levels are known. The revenue from each supplier is linearly proportional to collected quantity.

In the situation of study, it is the practice not to hold the raw material over 1–2 days. Therefore, this research is assumed that the set up situation is for a single day operation. All unit costs and prices are given as static values. The collection process from all selected suppliers to the factory will be finished within one day. The collector will sell the collected raw material on the same day of purchase to assure that the loss from price variation will not occur. There is no inventory consideration in this research.

The system cost includes raw material buying cost, fixed cost of collection station, fixed cost of vehicle, transportation cost between collection station and supplier, and transportation cost between collection station and factory. All data used in this research is based on the historical data.

1.6.2 The Characteristics of Raw Material Collection

There are two levels of raw material transportation considered in this problem. The first level of raw material transportation is routing transportation between suppliers and the collection station. The transportation here is assumed to contract to the third party for picking up the raw material. The example is that trucks can be rented from car rental partner. The transportation cost here includes both the vehicle fixed cost and the routing cost.

At the first level of raw material transportation, there is one type of capacitated vehicle used in collection of raw material. The capacity of vehicle is assumed to be comparatively larger than accumulated collected raw material on each single supplier. Each collection station has its own vehicles for collecting from suppliers and transporting raw material to collection stations. The number of vehicles available at each collection station is unlimited. Irrespective of the number of vehicles needed for raw material collection, the collector can support them. Each route starts and ends at the same collection station. There is one truck per one route; therefore, the number of trucks is equal to the number of routes. Each truck is operated only once per day. In the raw material collection, the supplier is visited only once by one vehicle.

Collection process between the supplier and the collection station has to be finished within biological time duration. Traveling time is given to be proportional to traveling distance. The loading time at the supplier point is considered. It is assumed that the loading time is proportional to supply of supplier. This means that there is more supply, the more loading time is required at the supplier point. No shortage or delay occurs for the collection of raw material at any supplier’s point. It is assumed that every supplier has responsibility of getting raw material ready for picking up at any time.

For the second level of raw material transportation, collected raw material from each collection station is directly transported to the factory. The transportation between the collection station and the factory is assumed to subcontract to the transporter such as logistics partner. The transportation cost here is charged for total collected quantity delivering from each particular collection station to the factory.

1.7 Research Contributions

For the last two decades, many location allocation and vehicle routing models have been proposed. Each model is characterized by various viewpoints such as hierarchical structure (single layer or multiple layers), the number of facilities to locate (single facility or multiple facilities), the capacity constraints (facility capacity or vehicle capacity), other route constraints, and the form of the objective function (Min et al., 1998; Nagy and Salhi, 2007). The raw material collection system studied here is similar to that of Nambiar et al. (1981, 1989). They investigated the real–life problem of plant location and vehicle routing in the natural rubber industry. The problem was decomposed into two parts: a plant location part and a vehicle routing part**.** Constructive heuristic with clustering based methods have been applied for solving the problem considered. The model under consideration was restricted to vehicle capacity and biological time constraints. However, there is no step–price policy considered in the raw material collection system.

In this research, the developed model for setting up proper raw material collection system places emphasis on the consideration of location of collection station, selection of suppliers, and transportation of raw material collection under the influence of step–price policy and the limitation of vehicle capacity and collection time duration. The environments considered make the model more complex but more realistic. Although the location allocation problem and vehicle routing problem have been considered and studied for a long time; nonetheless, no existing research has explored all characteristics addressed in the model. The comparison of related research is depicted in Table 1.1.

Table 1.1 The comparison of the journals related to the research

Literature	Hierachical level		Facility		Facility capacity		Supply		Vehicle type		Vehicle capacity		Time duration		Price, Cost value		Objective		Method
	Single	Multiple	Single	Multiple	Limited	Unlimited	Deterministic	Stochastic	Homogeneous	Heterogeneous	Limited	Unlimited	No deadlines	deadlines	Constant	Vary	Max. Profit	Min. Cost	
Aksen and Aras (2005)	✓		✓			✓	✓		✓		✓			✓	✓		✓		Heuristic
Aras et al. (2008)	✓			✓		✓	✓		✓		✓		✓			✓	✓		Metaheuristic
Albareda-Sambola et al. (2005)	✓			✓	✓		✓		✓		✓		✓		✓			✓	Metaheuristic
Ambrosino and Scutellà (2005)		✓		✓	✓		✓		✓		✓		✓		✓			✓	Exact solution
Aykin (1995)	✓			✓		✓	✓		✓			✓	✓		✓			✓	Heuristic
Barreto et al. (2007)	✓			✓	✓		✓		✓		✓		✓		✓			✓	Heuristic
Boolbinder and Reece (1988)	✓			✓		✓	✓		✓		✓		✓		✓			✓	Exact solution
Chan et al. (2001)	✓			✓		✓		✓	✓		✓			✓	✓			✓	Heuristic
Hansen et al. (1994)	✓			✓	✓		✓		✓		✓		✓		✓			✓	Heuristic
Lin and Kwok (2006)		✓	✓			✓	✓		✓		✓			✓	✓			✓	Metaheuristic
Melechovský et al. (2005)	✓			✓	✓		✓		✓		✓		✓			✓		✓	Metaheuristic
Nambiar et al. (1981)	✓			✓	✓		✓		✓		✓			✓	✓			✓	Heuristic
Nagy and Salhi (1996)	✓			✓		✓	✓		✓		✓		✓		✓			✓	Heuristic
Nagy and Salhi (1998)		✓		✓		✓	✓		✓		✓			✓	✓			✓	Heuristic
Perl and Daskin (1985)	✓			✓		✓	✓		✓		✓		✓		✓			✓	Heuristic
Srivastava (1993)	✓			✓		✓	✓		✓			✓	✓		✓			✓	Heuristic
Tuzun and Burke (1999)	✓			✓		✓	✓		✓		✓		✓		✓			✓	Metaheuristic
Waszen and Zäpfel (2004)	✓			✓		✓	✓		✓		✓			✓		✓		✓	Heuristic
Wu et al. (2002)		✓		✓	✓		✓			✓	✓			✓	✓			✓	Metaheuristic
This research		✓		✓		✓	✓		✓		✓			✓		✓	✓		Heuristic

1.8 Research Methodology

This research is undertaken in term of the operation research approach as mentioned below: (1) defining the research problem, (2) formulating the mathematical model, and lastly (3) solving the model.

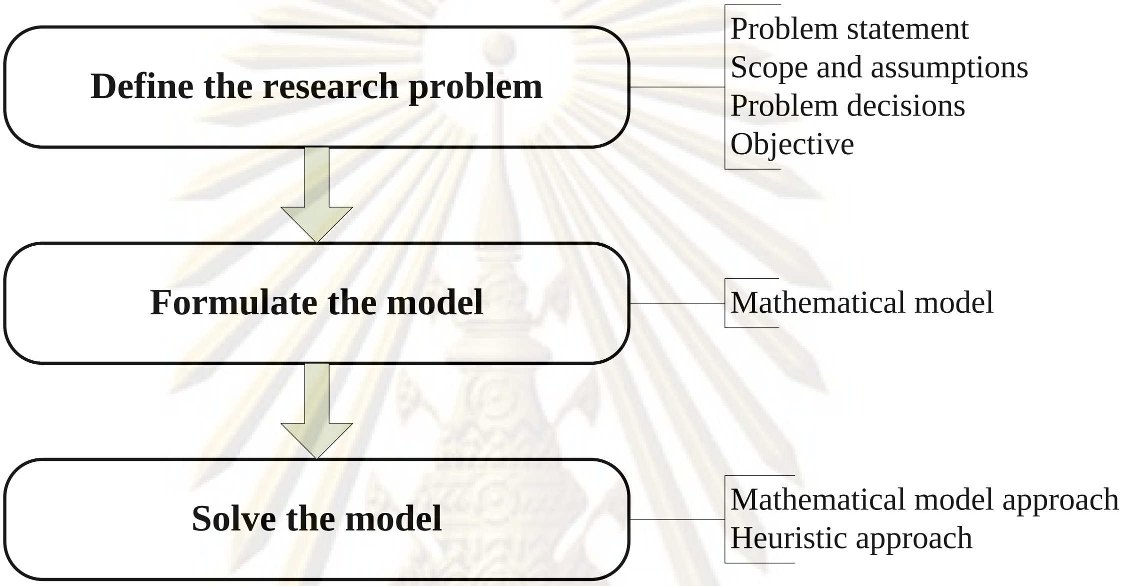


Figure 1.7 Methodology Flow of this research

1.8.1 Problem Definition Stage

Problem definition involves defining the statement and the scope of the problem under investigation. The research problem studied here is defined based on the real world situation. However, it would be impossible to convey the entire circumstances of natural rubber collection situations, because the behavior of problem situation is widely expanded in every area of raw material collection activities. Though numerous implications of the real world situation are interested and valuable to study, a model of this nature cannot fulfill all elements of a complete situation. It is always an abstraction of the real situation. As Taha (2003: 1–10) revealed that the majority of applications in operation research usually involve approximations. The assumed real world is abstracted from a real situation by concentrating on the dominant variables that control the behavior of the real world system.

In this research, the location allocation and vehicle routing with step–price policy problem has been investigated. The problem under consideration is discussed in the problem statement section and research scope section. Elements that are relevant to the problem considered are characterized. The statement of the problem, the description of the decisions, the objective of the study, and specification of the limitations under which the studied system operates are identified.

1. Decisions of the problem considered are the location and the number of open collection stations, a set of selected suppliers and the allocation of selected suppliers to collection stations, as well as a set of preliminary routes referring to the number of vehicles operated in the system.

2. The objective of the problem considered is to maximize the profit of the raw material collection system.

3. Constraints or limitations related to the conditions of the raw material collection system are step–price policy, vehicle capacity, and collection time duration.

1.8.2 Model Formulation Stage

At this stage, the problem definition from previous stage will be translated into a mathematical model. Model formulation entails translating the problem definition into mathematical relationships. The mathematical model, a representative of the problem, performs in an amenable manner the mathematical functions representing the relation of variables and behaviors of the system studied. In this research, an integrated model of location allocation and vehicle routing problem with step–price policy is formulated. The model formulation should be performed relying on a computer–based analysis even though the problem statement is confined to more than the real world situation because the formulation can affect the solution of the problem considered.

In the development of location allocation and vehicle routing models, flow formulations have appeared to be the most widely used (Albareda-Sámbola et al., 2005; Ambrosino and Scutellà, 2005; Aykin, 1995; Bookbinder and Reece, 1988; Hansen et al., 1994; Laporte, 1988; Nambiar et al., 1981; Or and Pierskalla, 1979; Perl and Daskin, 1985). In this research, the mathematical model is developed by the use of location and routing models, some formulations are based on flow formulations; furthermore, step function formulations expressed in Tsai (2007) are added. Although flow formulations are very flexible, they are complicated to be solved to optimality due to their size and structure. Approximated algorithms are therefore preferable in finding solution.

1.8.3 Model Solution Stage

After formulating the model, an effective tool or method is selected for solving the problem. Since the location allocation and vehicle routing problem is in general NP–hard problem, it is not surprising that most algorithms are approximated algorithms which are either exact methods or heuristic methods. Exact methods provide significant insights into the problems, but exact procedures can only tackle relatively small instances and in very special classes of problems (Ambrosino and Scutellà, 2005; Bookbinder and Reece, 1988; Even et al., 2004; Labbé et al., 2004; Laporte, 1988). The useful methods mostly proposed recently are heuristics (Aykin, 1995; Barreto et al., 2007; Muyldermans et al., 2002; Nambiar et al., 1981, 1989; Srivastava, 1993; Wasner and Zäpfel, 2003). The metaheuristics such as simulated annealing algorithm and genetic algorithm that are mostly applied for solving vehicle routing problem are also suggested to solve the integrated location and routing problem (Aras et al., 2008; Lin and Kwok, 2006; Prins et al., 2006; Tuzun and Burke, 1999; Wu et al., 2002).

Based on the literature, heuristic solution methods for location allocation and vehicle routing problem are performed in two types of sequential methods that are location allocation routing (LAR) and allocation routing location (ARL). In the location allocation routing (LAR) methods, facilities are located, suppliers or customers are then allocated to facilities and routes are finally defined (Lin and Kwok, 2006; Nagy and Salhi, 1996; Nambiar et al., 1981, 1989; Srivastava, 1993; Wu et al., 2002). In the opposite way, the allocation routing location (ARL) methods are the methods that construct a set of routes first assuming all facilities open, locations are then selected (Barreto et al., 2007; Hansen et al., 1994; Tuzun and Burke, 1999).

In this research, a heuristic solution approach is hence proposed for solving the problem. The heuristic solution method is developed based on the location allocation routing approach together with supplier selection approach. The heuristic solution approach is divided into three stages which can be termed as location allocation stage, routing improvement stage, and supplier screening stage. The first stage that deals with construction of the initial solution relaxes the problem considered from location allocation and vehicle routing problem to uncapacitated facility location problem. Given the initial solution from location allocation stage, the routing improvement stage is the improvement of initial solution in term of total system cost minimization. The last stage is supplier screening stage which screens both potential sets of selected suppliers and non potential sets of selected suppliers. The set of selected supplier giving highest value of maximum possible profit will be carried on solving in the stages of location allocation and routing improvement in order to find a new best solution. The computational analysis will also be proposed and discussed in this dissertation.

1.9 Thesis Structure

The outline of this dissertation is as follows. The relevant literature is reviewed in Chapter 2. In Chapter 3, the integrated location allocation and vehicle routing model with step–price policy is formulated. Based on the complexity of the problem, the heuristic solution approach consisting of three stages which are location allocation stage, routing improvement stage, and supplier screening stage is developed and analyzed in Chapter 4. Finally, Chapter 5 provides with the summary and future research directions.

CHAPTER II

LITERATURE REVIEW

The problem that is investigated in this research relates to three well–known problems in operation research area which are the location problem, the vehicle routing problem, and the location routing problem. Firstly, the problem involving in the location of facility is briefly reviewed. Secondly, the vehicle routing problem is concisely presented. The problem integrating facility location problem and vehicle routing problem which happens to be the main problem under consideration is lastly presented. Since there is a board range of perspectives which has been presented in the literature, the literature review is emphasized on problems associated with profit maximization viewpoint. The definition of the problems, the development of the problems as well as the solution approach are reviewed in this chapter.

2.1 The Location Problem

The problem of locating facilities is not new to the operations research community. The location problem may be defined as: given a set of potential locations, select as facilities those which will satisfy the given constraints, while meet the required objectives. Four major components characterized location problems are (1) customers, who are presumed to be already located at points or on routes, (2) facilities that will be located, (3) a space in which customers and facilities are located, and (4) a metric that indicates distances or times between customers and facilities. For issues of problem formulations see Krarup and Pruzan (1990: 37–48).

Many researchers have extensively studied the location problem covering models which range in complexity from simple linear, single–stage, single–product, uncapacitated, deterministic models to non–linear probabilistic models. ReVelle and Eiselt (2005) have reviewed a number of important problems concerned with the facility location both from a problem statement/formulation standpoint and from an algorithmic point of view. Lucas and Chhajed (2004) have presented a survey of application of operation research–based techniques to location problem especially in agriculture. Model formulations such as network location models, continuous location models and mixed integer programming models have been summarized in Klose and Drexl (2005).

A common objective in designing such a supply network is to determine the least system cost so that the requirements of all suppliers or customers are satisfied. However, one of the interesting characteristics now arising from the location problem is the investigation of profit receiving from operating supply chain system. Few studies have addressed this kind of situation. The survey of profit maximization location model is provided by Hansen, Peeters, and Thisse (1995).

For a given set of demand points, a profit maximizing supply chain design model in which a company can choose whether to satisfy a customer’s demand has been studied by Meyerson (2001) and Shen (2006). In Meyerson (2001), decision maker needs to open some facilities so that every demand could be satisfied from the local facility, and total profit was maximized, and an approximation algorithm has been developed to solve this problem. The problem considered by Shen (2006) has addressed that the company could set different sale prices for different regions. The problem was formulated as a set–covering model, and was solved by using branch–and–price algorithm. Another profit maximizing location model is proposed by Adler and Smilowitz (2007), where profit maximizing objectives were combined to cost–based network formulations within a given theoretic method.

The decisions for locating single facility in which customers were served, and the price of its product in order to maximize total profit were presented in Zhang (2001). A new facility location–allocation model to find the optimal locations of a predetermined number of collection centers as well as the optimal incentives offered by the company to product holders depending on the condition of their used items has been proposed by Aras et al. (2008). They have addressed the problem of locating collection center that aims to collect used products from product holders. The remaining value of the used products that can be captured by recovery operations is the company’s motivation for the collection operation. Each product holder has an inherent willingness to return, and makes the decision on the basis of the financial incentive offered by the company. The incentive depends on the condition of the returned item referred to as return type. Tabu search method was set to solve medium and large–size instances. They only modeled the collection operation of the company so the decisions about the shipment of collected used products from collection centers to disassembly centers or to remanufacturing facilities are out of the scope of their study.

2.2 The Vehicle Routing Problem

The vehicle routing problem (VRP), first introduced by Dantzig and Ramser (1959), is one of the most widely studied combinatorial optimization problems. The general routing problem may be defined as: finding the sequence of pick up or delivery points which may be visited by a vehicle, starting and ending at some depots. Nowadays, the vehicle routing problem has been explored in problem structure and discovered in solution approach in a wide variety both theoretical and practical applications. Many variants in vehicle routing category have been investigated. For example, capacitated vehicle routing problem is concerned the situation that every vehicle has a limited capacity. The vehicle routing problem with time windows, in one hand, is the problem considering every client has to be served within a certain time window. The problem that some values such as demand and number of customer are random is classified as stochastic vehicle routing problem (Assad, 1988; Toth and Vigo, 2002).

The VRP is a well known integer programming problem that falls into the group of NP hard problems, which means that the computational effort required to solve this problem increases exponentially with the problem size. The solution methods applied for solving vehicle routing problem and its variants is raised rapidly and performed good performance both quality and computational time's point of view. Abundance and variety heuristic solution methods both constructive heuristic approach and metaheuristic approach have been proposed in literature. Some classical and modern heuristic methods for the vehicle routing problem have been revealed in Laporte et al. (2000). Here, three variants relating to research problem, which are capacitated vehicle routing problem, vehicle routing problem with time windows, and vehicle routing problem with profits are further reviewed.

The capacitated vehicle routing problem is like the vehicle routing problem with the additional constraint that every vehicle has uniform capacity of a single commodity. Toth and Vigo (2002) have reviewed the exact algorithms based on the branch and bound approach for the solution of the vehicle routing problem where only the capacity constraint is considered. Achuthan et al. (2003) have studied the capacitated vehicle routing problem with common vehicle capacity, fixed or variable number of vehicles, and an objective to minimize the total distance traveled by all the vehicles. They developed the branch and cut algorithm and several new cutting planes for solving the problem. Metaheuristic such as genetic algorithm, simulated annealing, and tabu search are applied to solve the capacitated vehicle routing problem, for example, work of Berger and Barkaoui (2003) have proposed a competitive hybrid genetic algorithm to the classical capacitated vehicle routing problem. Tarantilis (2005) has developed an adaptive memory programming method for solving the capacitated vehicle routing problem.

The vehicle routing problem with time windows is the problem that routing is restricted with time windows. Time window is associated with each customer wherein customer has to be supplied. The objective is to minimize the vehicle fleet and the sum of travel time and waiting time needed to supply all customers in their required hours. As the same as the capacitated vehicle routing problem, many exact method and heuristics method are applied to the vehicle routing problem with time windows. Liu and Shen (1999) developed a two–stage metaheuristic based on a new neighborhood structure to solve the vehicle routing problem with time windows. They constructed routes in a nested parallel manner to obtain higher solution quality. Tan et al. (2001) have investigated various heuristic methods (genetic algorithm, simulated annealing, and tabu search) to solve the vehicle routing problem with time windows. Bard et al. (2002) studied the problem of finding the minimum number of vehicles required to visit a set of nodes subject to time windows and capacity constraints. Each node required the same type of service. An exact method based on branch and cut was introduced. Lau et al. (2003) have studied a variant of the vehicle routing problem with time windows where a limited number of vehicles was given. To solve the problem, they proposed tabu search approach. They also allowed time windows to be relaxed by introducing the penalty for lateness.

The vehicle routing with profits is the problem which is closer to the problem studied. The vehicle routing problem with profits is a variant of the vehicle routing problem that it is not necessary to visit all suppliers or customers. A usual characteristic of the vehicle routing problem is that every customer has to be serviced and that, normally, no value is associated with the service. However, this problem proposes to select vertices depending on a profit value that is gained when the visit occurs. Feillet et al. (2005) have elaborated on traveling salesman problem with profits and vehicle routing problem with profits. The vehicle routing problem with profits may be seen as bi–criteria vehicle routing problem with two opposite objectives, one pushing a deliver to travel to collect profit and the other inciting a deliver to minimize travel costs with the right to drop vertices. This problem has appeared under several names such as the profitable tour problem and the orienteering problem.

Many exact solution procedures and heuristics procedures are proposed for solving vehicle routing problem with profits. For example, work of Aksen and Aras (2005), Butt and Cavalier (1994), Butt and Ryan (1999), Fischetti and Toth (1988). Butt and Cavalier (1994) have concerned the problem of recruiting athletes. A recruiter had to recruit football players from high schools of the area in a given number of days. Each day, he had a limited amount of time to visit some chosen high schools and come back home. A reward was assigned to each high school based on its recruiting potential. The objective was to visit a set of high schools maximizing the recruiting potential. They proposed a greedy algorithm for solving this problem. Butt and Ryan (1999) have faced the same problem, but they proposed the classical set partitioning formulation used in column generation procedure. Chao et al. (1996) developed a new heuristic for solving the orienteering problem without time windows. Their heuristic consisted of two steps: initialization and improvement. Firstly, a greedy method was used in the initialization step in order to insert the point with the cheapest insertion cost onto the path. Then, two point exchanges algorithm was used to improve the solution. One interesting work under capacitated vehicle routing problem with profits was presented by Aksen and Aras (2005). In their work, a single depot capacitated vehicle routing problem with a flexible size fleet of homogenous vehicles was studied. They adapted the marginal profit analysis for customer selection. The customer whose marginal profit was non–positive was discarded from the route.

2.3 The Location Routing Problem

In today’s logistics environment, supply chain models involve making trade–offs between more than one business function within the supply chain as it is reflective of real world dimensions (Min and Zhou, 2002). An integrated model between a location problem and a routing problem dealing with multi–functional problems has been widely studied in supply chain management. Though some researchers indicated that the location is a strategic problem, while the routing is a tactical problem (routes can be redrawn frequently; locations are normally for a much longer period), Nagy and Salhi (2007) have discussed that the use of location–routing could decrease costs over a long planning horizon within which routes are allowed to change.

Many studies (Ambrosino and Scutellà, 2005; Laporte, 1988; Min et al., 1998; Srivastava, 1993; Tuzun and Burke, 1999; Wu et al., 2002) have pointed out that the location routing problem (LRP) is defined as vehicle routing problem in which the optimal number and locations of the depot are to be determined simultaneously with the vehicle schedules and the distribution routes so as to minimize the total costs. Nagy and Salhi (2007) have defined the location routing problem from a hierarchical viewpoint that it is a problem which aims to solve a facility location problem (the master problem), but in order to achieve this, it is simultaneously needed to solve a vehicle routing problem. Consequently, the location routing problem may be stated as: given a feasible set of potential depot sites and customer sites, find the location of the depots and the routes to customers from the depots so that the overall cost of depot location and good distribution is minimized.

The location routing problem is conceptually more difficult than the classical location problem in which once the facility is located, the location routing problem requires a visitation of suppliers / customers through tours, whereas the classical location problem assumes the straight line from the facility to customer / supplier. Therefore, the difference is that the classical location problem ignores tour when locating facilities and subsequently may lead to increased distribution cost. It can be concluded that facility location, customer allocation to facilities and vehicle routing are interrelated decisions in location routing problem.

In reviewing the location routing problem, we concentrated on the structure of the problem referring to characteristic of the model; furthermore, the solution approach is discussed together. According to Min et al., 1998, the simple problem in a location routing problem is the problem addressed on the single layer with only single uncapacitated facility and single uncapacitated vehicle.

Multiple facilities and / or multiple vehicles are another extension of single layer model. A number of studies have been conducted on this kind of location routing problem. Nambiar et al. (1981, 1989) the specific problem of locating central rubber processing factories to process smallholder’s rubber collected daily from a number of collection stations in natural rubber industry in Malaysia. Both vehicle capacity and biological time windows were included in the model. They decomposed their problem into plant location problem and vehicle routing problem. Heuristic solution methods for single depot case and multiple depots case were proposed.

Customers were clustered according to the capacity and the maximum distance constraints of the vehicle. Then for each potential depot and each cluster, a traveling salesman problem was solved. Perl and Daskin (1985) studied three layers distribution system consisting of supply sources, distribution centers and customers in the location routing problem. They first introduced the concept of iterating between location phase and routing phase. The location phase was formulated as an integer linear problem and solved to optimality using implicit enumeration. The routing phase used a saving heuristic method. Bookbinder and Reece (1988) considered a multi–product problem for two stages of distribution (factories–warehouses–customers). In their problem, after solving the master problem that was the warehouse problem, the vehicle routing problem for each open distribution center was solved. Each sub problem was solved to optimality in an iterative framework.

The distribution system design problem composed of multiple facilities and multiple vehicles with limited capacity was considered by Srivastava and Benton (1990). Time windows constraint was added in their problem considered. They presented heuristic based on the moves drop and add in the location phase. The routing phase was solved using a saving algorithm. The very similar algorithms were proposed in Srivastava (1993). Tuzun and Burke (1999) have considered the same problem as Srivastava (1993) did but they employed two–phase tabu search for the solution of the location routing problem. Hansen, Hegedahl, Hjortkjær, and Obel (1994) have modified mathematical formulation of Perl and Daskin (1985) in order to provide an improved formulation based on flow variables and flow constraints. A sequential heuristic method with decomposing the problem into three sub problems was proposed. Aykin (1995) considered the hub location and routing problem in which the hub locations and the service types for the routes between demand points are determined together. A mathematical formulation of the problem and an algorithm solving the hub location and the routing sub problems separately in an iterative manner were presented.

Wu et al. (2002) have considered the location routing problem with multiple depots, multiple fleet types (heterogeneous vehicles), and limited number of vehicles for each different vehicle type. They present a decomposition based method for solving the multi–depot location routing problem. Each sub problem is solved in a sequential and iterative manner by the simulated annealing algorithm but with a simpler neighborhood structure. Barreto et al. (2007) have investigated the capacitated facility location problem wherein capacity of both facility and vehicle were limited. A sequential heuristic with cluster–based method was proposed. The heuristic started by clustering customers according to vehicle capacity. For each cluster, a traveling salesman problem was solved. Finally, depot locations were found by treating each tour as a single customer.

Such a more complicated system: multiple layers, multiple capacitated facilities, multiple capacitated vehicles, and time windows consideration have been investigated. Min (1996) considered the problem of location consolidation terminals. In the problem, products from several supply sources were aggregated at terminals before sending them to customers. The problem was more complicated than the basic location routing problem in which both customers and suppliers were needed to allocate to terminals. Both exact algorithm and heuristic with clustering were proposed. Albareda-Sambola et al. (2005) studied a combined location routing problem which considered capacitated primary facilities and one single vehicle associated with each open facility. Their work was focused on a deterministic and static (one single period) problem. The initial solution was solved by applying a rounding procedure to the model, and tabu search was then applied to select new subsets of open facilities and to operate current routing sub problem. Ambrosino and Scutellà (2005) have studied complex distribution network design problems, which involve facility location, warehousing, transportation and inventory decisions. Their distribution network system is made up of four layers which are supply points, central depots, regional depots, and demand points. Both direct replenishment and delivery tour are concerned. However, they assume to know the location and the demand of each client, whose demands are specified in units of a single representative commodity. Also, the location and the capacity of each potential facility are known. Furthermore, they assume to know the maximum number of vehicles available for the whole distribution network and the capacity of non–homogeneous vehicle. Two kinds of mathematical programming formulations are proposed for all the problems introduced.

More aspects such as stochastic problem and dynamic problem have been investigated in the location routing problem. A majority of location routing problem literature has heavily considered the development of deterministic models. In practice, however, demand and location of customers as well as travelling time may not be known a priori then the uncertainty should be taken into account in the model. Simchi-Levi (1991) studied the traveling salesman location problem and extended to capacitated salesman. A polynomial time heuristic has been presented for the case of network and modified for the planar location. Chan et al. (2001) formulated a multiple depots, multiple vehicles, location routing problem with stochastically processed demand. Two steps which were allocation and location routing were proposed to solve the problem. The priori tours were solved by taking the expected value of the random demand, and posterior tours were applied by selecting a minimum length tour for each demand realization. Liu and Lee (2003) have considered a stochastic customer demand and include inventory costs in the location routing problem. An initial solution was found by clustering the customers. For each cluster, the depot was located nearest to the centre and the traveling salesman problem was solved. A hierarchical improvement method was then used based on the moves drop and shift for the location phase. Both routing and inventory costs were evaluated for possible move.

Dynamic problem divides the planning horizon into multiple periods. Due to the uncertainty of some parameters like demand, the model may deal with decisions of relocating existing facilities and re–routing vehicles. Nambiar et al. (1981) proposed the solution which provided a sequence of location to be opened at different times. They allowed a factory to be closed down when another was opened and to be re–opened later. Laporte and Dejax (1989) considered multiple planning periods, whereby in each period both locations and routes may be changed. The network optimization problem was solved to optimality. The problem studied by Ambrosino and Scutellà (2005) found that the problem was extended to analyze the four layers distribution system during the time horizon.

CHAPTER III

THE LOCATION ALLOCATION AND VEHICLE ROUTING WITH STEP-PRICE POLICY PROBLEM

This chapter proposes the mathematical formulation for the location allocation and vehicle routing with step–price policy problem. Not only location decision, allocation decision, and routing decision, the model also states supplier selection decision due to the effect of step–price parameter. The basic trade–off of the model is between revenue and total system cost for the purpose of profit maximization. The numerical example is provided for clarifying the model.

The chapter is organized as follows: Introduction explaining the important decisions in raw material collection system is identified in Section 3.1. Problem description is described in Section 3.2. Assumption and notation are given in Section 3.3 and 3.4, respectively. The model formulation will be proposed in Section 3.5. The numerical example is provided in Section 3.6. Finally, the conclusions of this work are presented in Section 3.7.

3.1 Introduction

Similar to the distribution system, the important factors in designing raw material collection system are locating facilities such as collection stations and factories, allocating suppliers or customers to each service area, and transport plans covering all members in the system. The natural rubber industry has specific characters which need to be considered when establishing the collection system such as perishable product affecting collection time and incentive system influencing collected quantity. The analysis of factors needed for setting up of a proper raw material collection system is determined as in Figure 3.1.

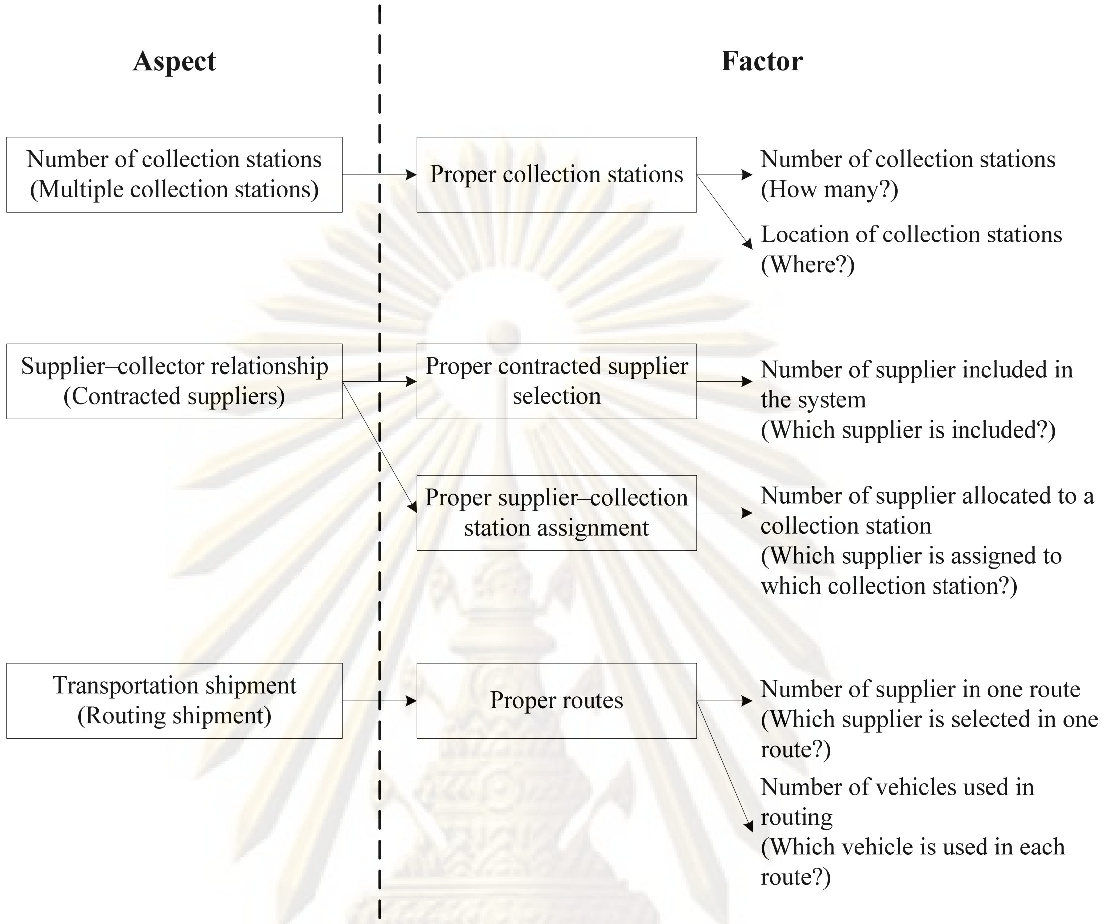


Figure 3.1 The factors in designing raw material collection system

In regard to collection station factors, it seems that the appropriate number of collection stations has to be examined since the fixed cost of collection stations is likely to impact on the number of collection stations. Not only the number of open collection stations, but also the location of open collection stations should be analyzed as well. The location decision has to be compromised the distance between collection stations and both suppliers and the factory. For supplier factors, the number of suppliers included in the collection system should be determined. The more suppliers are added to the system, the more collected supply leads to the more income despite the higher transportation cost. Apart from this, we should decide which supplier is assigned to open collection stations. Selected suppliers should be allocated to proper collection station so that the system costs paid for raw material collection is minimized. For routing factor, in order to implement routing shipment which is more complex to operate than direct shipment, it needs to be determined what the routes of vehicles are. Both suppliers selected in the route and number of vehicles used in routing shipment have to be analyzed. Therefore, the optimum raw material collection system is a challenging work that needs to be examined by the collector.

For the last two decades, many location allocation and vehicle routing models have been proposed. Each model is characterized by the number of facilities to locate (single facility or multiple facilities), by the capacity constraints (facility capacity or vehicle capacity), by other route constraints, and by the form of the objective function (Min et al., 1998; Nagy and Salhi, 2007). Given set of suppliers or customers, most studies have extensively developed models so as to minimize total system costs in the range of various complicated environments such as multiple hierarchical structure (Ambrosino and Scutellà, 2005), multiple vehicle types (Wu et al., 2002), demand in stochastic situation (Chan et al., 2001; Liu and Lee, 2003), and planning in dynamic case (Ambrosino and Scutellà, 2005, Nambiar et al., 1981). Rarely does research address the profit maximizing problem. This research model hence undertakes other viewpoints by introducing the step–price policy environment in the model. In the step–price circumstance, different quantity levels give different raw material prices. It can be said that step–price policy is price–quantity dependent condition. Since each set of suppliers has differing total collected quantity leading to the difference of raw material prices, it is essential to find the set of suppliers included in the system.

In the development of location allocation and vehicle routing models, flow formulations have appeared to be the most widely used (Albareda-Sámbola et al., 2005; Ambrosino and Scutellà, 2005; Aykin, 1995; Bookbinder and Reece, 1988; Hansen, Hegedahl, Hjortkjær, and Obel, 1994; Laporte, 1988; Nambiar et al., 1981; Or and Pierskalla, 1979; Perl and Daskin, 1985). Laporte (1988) has pointed out some mathematical models distinguishing between three–index and two–index location and routing flow formulations. Hansen, Hegedahl, Hjortkjær, and Obel (1994) have modified the integer linear programming formulation of Perl and Daskin (1985) in order to provide an improved formulation, based on flow variables and flow constraints.

Consequently, the model investigated is extended from the basic model of location allocation and vehicle routing problem by considering the selection of supplier. The aim of the model is to optimize raw material collection system in which the profit throughout the system is expected to maximize. The mathematical model is developed by location and routing models mentioned in Ambrosino and Scutellà, 2005; Nambiar et al., 1981, and Wu et al., 2002. Some formulations are based on flow formulations provided by Laporte, 1988; furthermore, step function formulations expressed in Tsai (2007) are also added.

3.2 Problem Description

The aim of this research is to set up a proper raw material collection system. In the collection system considered here, raw material is collected from suppliers and then transported to the factory through the collector system. The system is composed of a number of suppliers, multiple uncapacitated collection stations, and one factory where collected raw material has to be delivered to. There are two levels of raw material transportation. The first level deals with the transportation between the supplier and the collection station while the second level is accountable for transportation between the collection station and the factory. An example of the system can be seen in Figure 3.2. For the first level, one type of capacitated vehicles is dispatched from a collection station to visit a set of suppliers in order to collect raw material. When the collection process is completed, the vehicle will return to its collection station. The collected raw material is then unloaded and prepared to deliver to the factory. It is assumed that each collection station has its own vehicles in which the number of vehicles availability is unlimited. This implies that no matter how many vehicles are needed in the system, it can be supported by the collection stations. The collection process is affected by the limitation of vehicle capacity and biological time duration. For example, if either the capacity of vehicle is full or the collection time is met the biological time, the vehicle has to return to the collection station. For the second level, larger vehicle will transport collected raw material directly from each collection station to the factory.

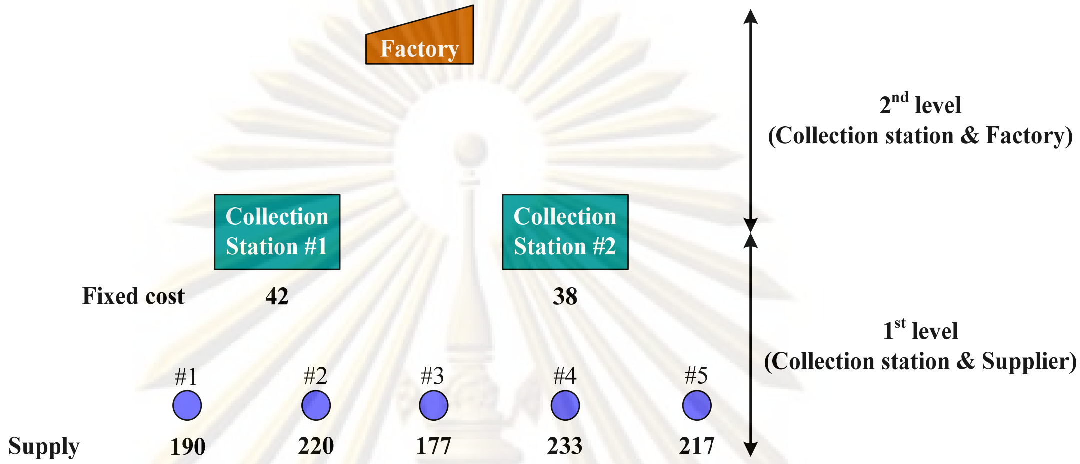
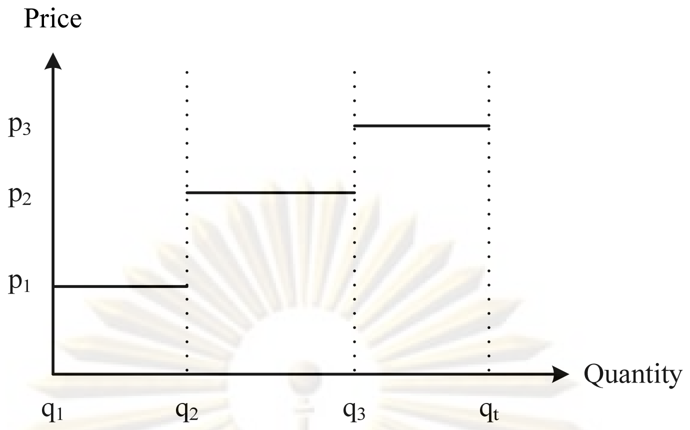


Figure 3.2 An example of raw material collection system

In the system investigated, the step–price policy is set by the factory. The factory has incentive policies for the collectors so as to facilitate more supply quantity to the factory. Raw material price at each collection station is assumed to be the same price while the raw material price at the factory can vary according to step–price quantity levels. As Tsai (2007) has classified cases of quantity discount function, the step–price structure can be expressed as follows in Figure 3.3, where $q_1, q_2 ... q_t$ represent step–price quantity levels set by the factory, and $p_1, p_2 ... p_t$ stand for the step–prices offered by the factory, respectively.



$$p(Q) = \begin{cases} p_1 & \text{for } q_1 < Q \le q_2 \\ p_2 & \text{for } q_2 < Q \le q_3 \\ \vdots & \\ p_t & \text{for } q_t < Q \end{cases}$$

Figure 3.3 An example of step–price structure

Due to step–price policy, a collector has to collect a large quantity of raw material in order to receive a higher price for raw material at the factory. Nevertheless, when a collector decides to visit more suppliers, the collection cost will normally increase. Because each supplier has discrete supply, hence each set of selected suppliers yields different collected quantity resulting in different revenue. On the other hand, each set of selected suppliers has differing results on the system cost (collection station fixed cost, vehicle fixed cost, and transportation cost). From the example presented in Table 3.1, it can be observed that step–price policy and a set of selected suppliers affect the decision of the model. For instance, the number of selected suppliers in set {1, 2, 4, 5} is as the same as in set {2, 3, 4, 5}; however, both sets of selected suppliers show differing profit. In addition to that, the profit from set {1, 2, 5} differs from set {3, 4, 5} even though the total collected supply is the same. When adding more suppliers, the profit may not increase because marginal cost may be higher than marginal profit as shown in set {1, 2, 3, 4, 5}. Therefore, it can be concluded that by adding one supplier to the system, total collected quantity certainly increases; however, the profit value may increase or decrease depending on step–

prices and a set of selected suppliers. In step–price policy condition, it has to be a trade–off between revenue receiving from total collected quantity and total cost both fixed cost and variable cost if we want to get higher step–price level.

Table 3.1 The results from each set of selected suppliers

Selected suppliers	Total collected supply	Revenue	Total system cost	Profit	Open collection stations	Allocated suppliers
1 2 5	627	1410.75	1403.16	7.59	1	1 2
					2	5
3 4 5	627	1410.75	1400.22	10.53	2	3 4 5
2 3 4 5	**847**	**2032.8**	**1944.37**	**88.43**	**2**	**2 3 4 5**
1 2 4 5	860	2064	1996.12	67.88	1	1 2
					2	4 5
1 2 3 4 5	1037	2488.8	2458.83	29.97	1	1 2
					2	3 4 5

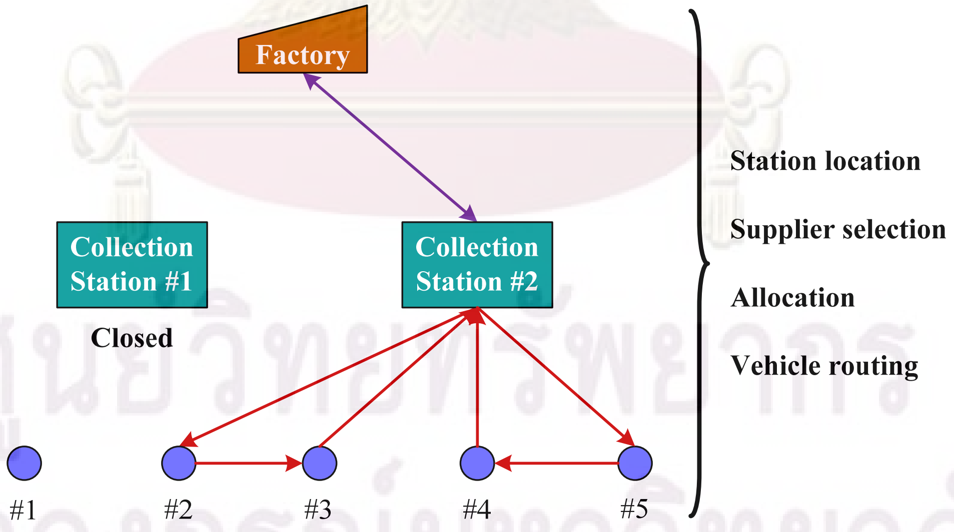


Figure 3.4 An example depicting the best result of the system

By given a set of possible suppliers, a set of potential collection station locations, and a factory, the decision of the model is to determine the location and the number of collection stations that need to be open, a set of suppliers included in the system and the allocation of selected suppliers to each collection station, and a set of preliminary routes referring to the number of vehicles. The objective of the model is to maximize the profit of the system which is the revenue from collected raw material minus the total system costs for the setting up of raw material collection system under step–price policy circumstance.

3.3 Assumption

The assumption is the same as mentioned in research scope. Only the case of setting up of raw material collection system is investigated in this research. In the system considered here, raw material is collected from suppliers and then sent to the factory through the collection stations. Only one factory with unlimited demand is operated in the system considered. Collection stations have unlimited capacity for keeping collected raw material before transporting to the factory. The collection process from all selected suppliers to the factory is assumed to be finished within the same day. There is one type of capacitated vehicle used in raw material collection. The capacity of vehicle is assumed to be larger than accumulated collected quantity from each single supplier. Each collection station has its own vehicles in which the number of vehicles availability is unlimited. Each route starts and ends at the same collection station. There is one vehicle per one route. Each vehicle is operated only once a day. The selected supplier is visited only once by one vehicle. Collection process between supplier and collection station has to be finished within biological time duration. It is assumed that the loading time is proportional to the supply of the supplier. No shortage or delay should occur at any supplier points. It is assumed that every supplier has a responsibility of getting the raw material ready for picking up at any time. It is set that only one raw material is considered in the collection system. Quality of raw material is assumed to be one grade of quality. Supply of suppliers is deterministic supply. Raw material price at each collection station is assumed to be the same price. The step–price policy is set by the factory. The step–price policy considered here is based on step–function. The revenue is linearly proportional to collected quantity. Inventory condition and traffic condition are not considered in the system.

This study focuses on the location allocation and vehicle routing problem with step–price condition in the static environment.

1. The locations of possible suppliers, potential collection stations, and a factory are given.
2. Given a set of suppliers, not all suppliers are required to be included in the system. This means that each supplier in a given set will be selected for setting up the collection system.
3. All unit costs considered in the system are assumed to be known.
4. The transportation between the collection station and the supplier is assumed to contract to a third party for picking up the raw material. This means that trucks can be rented out from a car rental partner. The transportation cost here includes both the vehicle's fixed cost and the routing cost. The routing cost is dependent on the total distance between the collection stations and the selected suppliers.
5. The transportation between the collection station and the factory is assumed to subcontract to the transporter such as logistics partner. The transportation cost is mainly charged from total collected quantity delivering from each collection station to the factory.
6. The system cost that this research has considered includes raw material buying cost, fixed cost of collection station, fixed cost of vehicle, transportation cost between the collection station and the supplier, and transportation cost between the collection station and the factory.

7. The setting up of raw material collection system studied here is assumed to consider one period only.

8. One type of capacitated vehicle is considered, and the vehicle capacity is assumed to be known.

9. Each collection station has its own set of vehicles. Each vehicle is assumed to belong to one collection station only.

10. Traveling time, loading time and biological time are assumed to be known. Traveling time is proportional to traveling distance while loading time is proportional to collected quantity.

11. Supply of suppliers is deterministic supply, and is assumed to be known.

12. Each collection station is assumed to use the same price for raw material.

13. All step–prices and step–price quantity levels at the factory are known in advance.

14. The first level of step–price is assumed not equal to zero because raw material price at the collection station begins at level 0. This means that there is no profit at level 0 since raw material purchase price at collection station equals to raw material selling price at a factory. Therefore, the step–price level always starts from level 1.

15. It is typically assumed that the relationships of step–prices are $price_1 < price_2 < ... < price_t$.

16. Data used in this research is based on the historical data.

3.4 Notation

The sets, indices, parameters and decision variables used in the model are defined in this section.

Sets:

I	represents the set of possible suppliers
J	represents the set of potential collection stations
V	represents the set of vehicles
T	represents the set of step–prices
N	represents the set of nodes, whereby $N = I \cup J$

Indices:

i	represents the supplier index, whereby $i \in I$
j	represents the collection station index, whereby $j \in J$
k	represents the vehicle index, whereby $k \in V$
s	represents the step–price index, whereby $s \in T$
g,h	represents the node index, whereby $g,h \in N$

Costs:

c_j	represents the fixed cost of collection station j, $j \in J$
β	represents the fixed cost of vehicle used between collection station and supplier
h_j	represents the transportation cost per unit quantity between collection station j and factory, $j \in J$
r_{gh}	represents the transportation cost between node g and node h, $g,h \in N$

Prices:

p_0	represents the raw material price per unit quantity at collection station
p_s	represents the raw material price per unit quantity at factory at step–price s, $s \in T$

Parameters:

s_i	represents the supply of supplier i, $i \in I$
q_s	represents the minimum quantity level at step–price s, $s \in T$
e_{kj}	represents the vehicle k set by collection station j, $k \in V$, $j \in J$ $e_{kj} = 1$ if vehicle k is set by collection station j; otherwise $e_{kj} = 0$
L	represents the capacity of vehicle used between collection station and supplier
o_{gh}	represents the traveling time between node g and node h, $g,h \in N$
a_i	represents the loading time at supplier i, $i \in I$
B	represents the biological time duration related to the perishability of raw material

Decision variables:

y_s	represents quantity sold at step–price s, $s \in T$
f_{ghk}	represents quantity transported from node g to node h with the vehicle k, $g,h \in N$, $k \in V$
w_j	represents 1 if collection station j is opened, $j \in J$; 0 otherwise
z_i	represents 1 if supplier i is included in the system, $i \in I$; 0 otherwise
u_s	represents 1 if step–price s is chosen, $s \in T$; 0 otherwise
x_{ghk}	represents 1 if an arc from node g to node h is on the route of vehicle k, $g,h \in N$, $k \in V$; 0 otherwise

3.5 Mathematical Model

The model of location allocation and vehicle routing with step–price policy problem can be formulated as follows:

$$Max \sum_{s \in T} p_s y_s - \Big(p_0 \sum_{h \in N} \sum_{j \in J} \sum_{k \in V} f_{hjk} + \sum_{j \in J} c_j w_j + \beta \sum_{j \in J} \sum_{h \in N} \sum_{k \in V} x_{jhk} + \sum_{g \in N} \sum_{h \in N} \sum_{k \in V} r_{gh} x_{ghk} + \sum_{h \in N} \sum_{j \in J} \sum_{k \in V} h_j f_{hjk} \Big) \qquad (3.1)$$

Subject to

$$\sum_{s\in T} y_s = \sum_{i\in I} s_i z_i \tag{3.2}$$

$$q_s u_s \le y_s \le q_{s+1} u_s \qquad \forall s \in T \tag{3.3}$$

$$\sum_{s\in T} u_s = 1 \tag{3.4}$$

$$\sum_{h\in N} \sum_{k\in V} x_{hik} = z_i \qquad \forall i \in I \tag{3.5}$$

$$\sum_{g\in N} \sum_{k\in V} x_{igk} = z_i \qquad \forall i \in I \tag{3.6}$$

$$\sum_{g\in N, g\neq h} x_{ghk} - \sum_{g\in N, g\neq h} X_{hgk} = 0 \qquad \forall h \in N\,,\ \forall k \in V \tag{3.7}$$

$$\sum_{h\in N, h\neq j} x_{jhk} \le e_{kj} w_j \qquad \forall j \in J\,,\ \forall k \in V \tag{3.8}$$

$$\sum_{i\in I} x_{jik} \le e_{kj} \qquad \forall j \in J\,,\ \forall k \in V \tag{3.9}$$

$$\sum_{i\in I} x_{ijk} \le e_{kj} \qquad \forall j \in J\,,\ \forall k \in V \tag{3.10}$$

$$\sum_{g\in N, g\neq i} f_{gik} + \sum_{g\in N, g\neq i} s_i x_{gik} = \sum_{h\in N, h\neq i} f_{ihk} \qquad \forall i \in I\,,\ \forall k \in V \tag{3.11}$$

$$\sum_{g\in N, g\neq i} f_{gik} \le \sum_{h\in N, h\neq i} f_{ihk} \qquad \forall i \in I\,,\ \forall k \in V \tag{3.12}$$

$$f_{ghk} \le L x_{ghk} \qquad g, h \in N\,,\ k \in V \tag{3.13}$$

$$\sum_{g\in N} \sum_{h\in N, h\neq g} o_{gh} x_{ghk} + \sum_{i\in I} \sum_{g\in N, g\neq i} a_i x_{gik} \le B \qquad \forall k \in V \tag{3.14}$$

$$y_s \ge 0 \qquad \forall s \in T \tag{3.15}$$

$$f_{ghk} \ge 0 \qquad g, h \in N\,,\ k \in V \tag{3.16}$$

$$w_j \in \{0,1\} \qquad \forall j \in J \tag{3.17}$$

$$z_i \in \{0,1\} \qquad \forall i \in I \tag{3.18}$$

$$u_s \in \{0,1\} \qquad \forall s \in T \tag{3.19}$$

$$x_{ghk} \in \{0,1\} \qquad g, h \in N\,,\ k \in V \tag{3.20}$$

The objective function (3.1) aims at maximizing the profit of raw material collection system which is the revenue from raw material collection minus the sum of raw material buying cost, collection station fixed cost, vehicle fixed cost, transportation cost between collection station and supplier, and transportation cost between collection station and factory. In constraints (3.2), total quantity sold at step–price s is equal to total collected quantity from selected suppliers. The constraints (3.3) enforce quantity sold at step–price s must be in its step–price quantity level. The constraints (3.4) assure that only one step–price is selected. This implies that only one quantity level is chosen. To ensure only selected suppliers will be visited only once by one vehicle, the constraints (3.5) and (3.6) are added. Flow conservation constraint is expressed in constraints (3.7). This indicates that if a vehicle arrives at the node, it will leave that node. The constraints (3.8) guarantee that vehicle k departs only from open collection stations. In constraints (3.9) and (3.10), a vehicle will leave and return to its own collection station. Moreover, these constraints ensure that each vehicle will leave from its own collection station mostly once. The constraints (3.11) state that the amount of quantity transported from the supplier is equal to the amount of quantity received by that supplier plus its own supply. The constraints (3.12) represent the subtour elimination constraint. This specifies that the quantity flows out from the supplier's point must not be lower than the quantity flows at the supplier's point. In capacity constraints (3.13), the collected quantity must not be larger than the capacity of vehicle. The constraints (3.14) make sure that travelling time in the route of vehicle k and loading time of all suppliers allocated in that route must not exceed the biological time. The constraints (3.15) and (3.16) restrict variables y_s and f_{ghk} to non–negativity. Finally, the constraints (3.17) to (3.20) force variables w_j, z_i, u_s and x_{ghk} to binary, respectively.

3.6 Numerical Examples

In this section, we solve numerical examples of the problem considered using the mathematical model as proposed in Section 3.5. Since this research is concerned with the real–life situation of natural rubber collection, some parameters used in this research such as supply of suppliers and step–prices are based on the historical data. In general, for one factory, there will be 30 – 40 collectors delivering raw material to the factory. However, for one collector, the number of suppliers varies according to operation area. Both supply from sub–collectors who can be defined as suppliers with large supply quantity and suppliers or planters who will send to the collector. According to the survey area, one sub–collector has 30 – 40 planters, and one collector has 30 – 100 suppliers including both sub–collectors and suppliers. Locations of suppliers, collection stations, and the factory are generated in uniformly distribution in the range of $[0, 200]^2$. Raw material price (p_0) at collection station is set according to market price. Vehicle capacity (L) is no greater than 5000. Biological time (B) is set no greater than 10000. Traveling time per distance (o_{gh}) is set as 1, and loading time per quantity (a_i) is set as 0.025 and 0.05. Data generation is shown in Table 3.2.

Table 3.2 The parameters generated in this research

Parameter	Data generation
Collection station fixed cost (c_j)	Uniform distribution [20, 50], related to historical data
Vehicle fixed cost (β)	Uniform distribution [25, 35], related to historical data
Transportation cost per distance between collection station and supplier	0.25, 0.5 and 1, related to historical data
Transportation cost per quantity between collection station and factory	$0.001 \times$ distance between collection station and factory, related to historical data
Supplier supply (s_i)	Uniform distribution [100, 300] and [300, 500], related to historical data
Raw material step–price (p_s)	p_0 + Uniform [0.1, 1.5]
Minimum step–price quantity level (q_s)	30%, 50%, and 80% of sum of supply

(1) Example case #1: 2 collection stations, 2 suppliers, and 2 step–prices

Two potential collection stations, two possible suppliers and two step–prices are provided for verifying mathematical model. To verify the mathematical model, the example case #1 is solved with the use of mathematical model by the AMPL/CPLEX 8.0.0 solver and extended to do total enumerations. The results from mathematical model solution report the same solution with maximum profit as received from total enumerations.

Table 3.3 The data used in the example case #1

<table>
<tr><td colspan="2">Supplier</td><td colspan="2">Coordinate X</td><td colspan="2">Coordinate Y</td><td>Supply</td></tr>
<tr><td colspan="2">1</td><td colspan="2">1</td><td colspan="2">72</td><td>164</td></tr>
<tr><td colspan="2">2</td><td colspan="2">89</td><td colspan="2">158</td><td>251</td></tr>
<tr><td>Station</td><td>Coordinate X</td><td colspan="2">Coordinate Y</td><td colspan="2">Fixed cost</td><td>Transportation cost (Station &Factory)</td></tr>
<tr><td>1</td><td>58</td><td colspan="2">89</td><td colspan="2">42</td><td>0.112712</td></tr>
<tr><td>2</td><td>29</td><td colspan="2">30</td><td colspan="2">38</td><td>0.111463</td></tr>
<tr><td colspan="2">Factory</td><td colspan="3">Coordinate X</td><td colspan="2">Coordinate Y</td></tr>
<tr><td colspan="2">1</td><td colspan="3">84</td><td colspan="2">39</td></tr>
<tr><td colspan="2">Step</td><td colspan="3">Price</td><td colspan="2">Quantity</td></tr>
<tr><td colspan="2">1</td><td colspan="3">2</td><td colspan="2">124.5 < Q ≤ 207.5</td></tr>
<tr><td colspan="2">2</td><td colspan="3">2.25</td><td colspan="2">207.5 < Q</td></tr>
<tr><td colspan="3">Raw material cost</td><td colspan="4">1.75</td></tr>
<tr><td colspan="3">Transportation cost (Station &Supplier)</td><td colspan="4">0.25</td></tr>
<tr><td colspan="3">Fixed cost of vehicle</td><td colspan="4">32</td></tr>
<tr><td colspan="3">Capacity of vehicle</td><td colspan="4">500</td></tr>
<tr><td colspan="3">Loading time per quantity</td><td colspan="4">0.025</td></tr>
<tr><td colspan="3">Traveling time per distance</td><td colspan="4">1</td></tr>
<tr><td colspan="3">Biological time</td><td colspan="4">1000</td></tr>
</table>

Table 3.4 The result of the example case #1 solved by mathematical model solution method

Profit = 22.183, solve time = 0.04 sec.

Collection station	Route	Total distance	Total load	Total time
1	S1-1-2-S1	258.1697	415	268.5447

Table 3.5 The result of the example case #1 solved by total enumerations method

No	Collection station	Supplier	Route	Profit
1	1	1	S1-1-S1	-81.225
2	1	2	S1-2-S1	-14.612
3	1	1 2	S1-1-S1 S1-2-S1	19.163
4	**1**	**1 2**	**S1-1-2-S1**	**22.183**
5	2	1	S2-1-S2	-72.518
6	2	2	S2-2-S2	-43.159
7	2	1 2	S2-1-S2 S2-2-S2	-4.677
8	2	1 2	S2-1-2-S2	12.522
9	1 2	1 2	S1-1-S1 S2-2-S2	-51.384
10	1 2	1 2	S1-2-S1 S2-1-S2	-14.022

(2) Example case #2: 2 collection stations, 10 suppliers, and 3 step–prices with selection of all suppliers

Two potential collection stations, ten possible suppliers and three step–prices are provided as another illustrative figure of the example. All data relating to the model is shown in Table 3.6. Solving the Mixed Integer Programming (MIP) problem by the AMPL/CPLEX 8.0.0 solver, result of the numerical example is reported in Table 3.7.

Table 3.6 The data used in the example case #2

Supplier	Coordinate X	Coordinate Y	Supply
1	41	191	190
2	67	4	220
3	134	102	177
4	100	153	233
5	169	92	217
6	124	182	164
7	78	21	242
8	158	116	158
9	64	59	215
10	105	47	202

Station	Coordinate X	Coordinate Y	Fixed cost	Transportation cost (Station &Factory)
1	58	89	42	0.112712
2	29	30	38	0.111463

Factory	Coordinate X	Coordinate Y
1	84	39

Step	Price	Quantity
1	2	$605.4 < Q \leq 1009$
2	2.25	$1009 < Q \leq 1614.4$
3	2.3	$1614.4 < Q$

Raw material cost	1.75
Transportation cost (Station &Supplier)	0.25
Fixed cost of vehicle	32
Capacity of vehicle	800
Loading time per quantity	0.025
Traveling time per distance	1
Biological time	1800

Table 3.7 The result of the example case #2

Profit = 556.838, solve time = 17058.9 sec.

Collection station	Route	Total distance	Total load	Total time
1	S1-9-2-7-S1	170.8054	677	193.7259
	S1-3-8-5-10-S1	272.5580	754	291.4080
	S1-1-6-4-S1	301.0872	587	315.7622

arc

k = 1

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	1	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	1	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
S1	0	0	0	0	0	0	0	0	1	0	0	0
S2	0	0	0	0	0	0	0	0	0	0	0	0

k = 2

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	1	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	1	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	1	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	1	0
S1	0	0	1	0	0	0	0	0	0	0	0	0
S2	0	0	0	0	0	0	0	0	0	0	0	0

k = 3

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	1	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	1	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	1	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
S1	1	0	0	0	0	0	0	0	0	0	0	0
S2	0	0	0	0	0	0	0	0	0	0	0	0

quantity

k = 1

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	435	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	677	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	215	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

k = 2

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	177	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	552	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	335	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	754	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

k = 3

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	190	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	587	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	354	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

(3) Example case #3: 2 collection stations, 10 suppliers, and 3 step–prices with no selection of all suppliers

To present the case with no selection of all suppliers, the data of the example case #2 is adjusted as presented in Table 3.8 (transportation cost between collection stations is changed from 0.25 to 1). Solving the Mixed Integer Programming (MIP) problem by the AMPL/CPLEX 8.0.0 solver, result of the example case #3 is shown in Table 3.9.

The result shows that suppliers no 1 and 6 do not include in the system. In case of a supplier whose supply is too little with a higher distance cost will not be included in the collection system, whereas a supplier with a high supply despite the fact that he is located far from collection stations may be included in the system if overall revenue is higher than overall system cost.

Table 3.8 The data used in the example case #3

Supplier	Coordinate X	Coordinate Y	Supply
1	41	191	190
2	67	4	220
3	134	102	177
4	100	153	233
5	169	92	217
6	124	182	164
7	78	21	242
8	158	116	158
9	64	59	215
10	105	47	202

Station	Coordinate X	Coordinate Y	Fixed cost	Transportation cost (Station &Factory)
1	58	89	42	0.112712
2	29	30	38	0.111463

Factory	Coordinate X	Coordinate Y
1	84	39

Step	Price	Quantity
1	2	$605.4 < Q \leq 1009$
2	2.25	$1009 < Q \leq 1614.4$
3	2.4	$1614.4 < Q$

Raw material cost	1.75
Transportation cost (Station &Supplier)	1
Fixed cost of vehicle	32
Capacity of vehicle	800
Loading time per quantity	0.025
Traveling time per distance	1
Biological time	1800

Table 3.9 The result of the example case #3

Profit = 203.371, solve time = 29259.8 sec.

Collection station	Route	Total distance	Total load	Total time
1	S1-3-5-8-4-S1	285.2526	785	304.8776
	S1-9-S1	61.1882	215	66.5632
	S1-2-7-10-S1	206.2387	664	222.8387

arc

k = 1

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	1	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	1	0
5	0	0	0	0	0	0	0	1	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	1	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
S1	0	0	1	0	0	0	0	0	0	0	0	0
S2	0	0	0	0	0	0	0	0	0	0	0	0

k = 2

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	1	0
10	0	0	0	0	0	0	0	0	0	0	0	0
S1	0	0	0	0	0	0	0	0	1	0	0	0
S2	0	0	0	0	0	0	0	0	0	0	0	0

k = 3

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	1	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	1	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	1	0
S1	0	1	0	0	0	0	0	0	0	0	0	0
S2	0	0	0	0	0	0	0	0	0	0	0	0

quantity

k = 1

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	177	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	785	0
5	0	0	0	0	0	0	0	394	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	552	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

k = 2

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	215	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

k = 3

node	1	2	3	4	5	6	7	8	9	10	S1	S2
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	220	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	462	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	664	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

3.7 Conclusion

This research develops a mathematical model for an integrated location allocation and vehicle routing problem with step–price policy that is faced with the real–life situation in raw material collection and also more useful for the operation research community. The location and the number of collection stations, a set of selected suppliers and the allocation of selected suppliers to collection stations, as well as a set of preliminary routes referring to the number of vehicles so as to maximize the profit of the system considered are investigated in this study. The determination of optimum raw material collection system is conducted under the consideration of price–quantity dependence, capacity of vehicle, and collection time duration.

The mathematical model is beneficial for the use of determining the optimal raw material collection system with profit maximized criterion under the extension of step–price policy environment. It can be used for both single and multiple step–prices. For single step–price, the problem will turn to minimize system cost instead of profit maximization. The collector can apply the results for setting up of a raw material collection system.

Generally the integrated location allocation and vehicle routing MIP models are very large so that solvers like CPLEX are incapable of obtaining optimal solution in an acceptable computational time. The model developed then might solve to optimality but consume much time. As Laporte (1988) has indicated that three–index formulations are more versatile, but more costly in regard to solving time. Therefore, further research is needed to extend the application of heuristic approaches which can effectively solve larger or more real–life problems to near optimality within the reasonable computational time.

CHAPTER IV

LOCATION–ROUTING–SCREENING HEURISTIC

In this chapter, the heuristic solution approach for finding the best solution for the problem considered is proposed. The solution method investigates location allocation routing approach together with supplier selection approach. The heuristic procedure is divided into three stages that are location allocation stage, routing improvement stage, and supplier screening stage. Computational results are also presented and discussed in term of performance and the time taken to solve.

The chapter is organized as follows: Introduction which deals with heuristic methods for location allocation problem and vehicle routing problem is presented in Section 4.1. Heuristic description is explained in Section 4.2. All stages of heuristic procedure are given in Section 4.3. Computational results are provided in Section 4.4. Finally, the conclusions of this work are summarized in Section 4.5.

4.1 Introduction

According to the problem considered in this research, the mathematical model integrating the location allocation decision, supplier selection decision, and vehicle routing decision are developed. Undoubtedly, the structure of this integrated model is complex with a majority of integer variables and constraints. The developed model might solve it to optimality, but consumes a lot of time even for small scale instances. Numerous heuristic solutions are therefore, preferable in finding solution for the problem considered.

Location allocation problem and vehicle routing problem are termed as well known problem, the NP–hard problem. It is not surprising that most solution methods are approximated algorithms which are either exact methods or heuristic methods.

Exact methods provide significant insights concerning the problems; however, exact methods can be very successful for solving special cases of the problems such as the round–trip location problem (Ambrosino and Scutellà, 2005; Bookbinder and Reece, 1988; Even et al., 2004; Labbé et al., 2004; Laporte, 1988). The useful methods mostly proposed in recent are heuristic methods (Aykin, 1995; Barreto et al., 2007; Lin and Kwok, 2006; Muyldermans et al., 2002; Nambiar et al., 1981, 1989; Prins et al., 2006; Srivastava, 1993; Tuzun and Burke, 1999; Wasner and Zäpfel, 2003; Wu et al., 2002).

Based on the literature, it is apparent that heuristic solution methods for location allocation and vehicle routing problem are performed in two types of sequential methods that can be mentioned as location allocation routing (LAR) and allocation routing location (ARL). In the location allocation routing (LAR) methods, facilities are first located, suppliers or customers are then allocated to facilities and routes are finally defined (Lin and Kwok, 2006; Nagy and Salhi, 1996; Nambiar et al., 1981, 1989; Srivastava, 1993; Wu et al., 2002). In contrary to the above, the allocation routing location (ARL) methods are kind of methods that construct set of routes first, assuming all facilities are open, locations are then selected (Barreto et al., 2007; Hansen et al., 1994; Tuzun and Burke, 1999).

As has been described above, the exact methods can only tackle relatively small instances; this research hence proposes a heuristic solution method that can solve large–scale problems to near–optimality with a reasonable computational time. The heuristic solution method is developed based on the location allocation routing (LAR) approach (the location of collection stations and the assignment of suppliers to open collection stations are first examined; the routing improvement is then determined) together with supplier selection approach. The proposed heuristic method can be defined as Location–Routing–Screening heuristic (LRS). The sequential heuristic method which decomposes the problem considered into a location allocation problem and a vehicle routing problem is firstly applied to find one best solution. All possible combination sets of suppliers are secondly screened in order to find a better solution.

4.2 Heuristic Description

Owing to step–price policy which is one of the environment factors concerning this problem, the heuristic method is motivated by observing that different set of suppliers definitely gives the difference of revenue and system cost so that it can be implied that profit from each set of selected suppliers is different. Though there is only one group of supplies in an observed area, there are plenty of possible sets of selected suppliers. For example; if the total number of suppliers is 5, there will be 31 combination sets of selected suppliers. Each set of selected suppliers gives one profit with the result that there will be 31 solutions as illustrated in Figure 4.1. The best result is the solution from set of suppliers with highest profit. Thus, to find a set of suppliers giving maximum profit appears to be a challenge faced by this heuristic method.

Figure 4.1 An example of profit from each set of suppliers

If we consider each set of selected suppliers as one set of suppliers included in the collection system, it is simple to solve the problem. With a given set of selected suppliers, totally collected quantity is known and then revenue can be calculated by checking the total collected quantity with step–price policy, meanwhile, the system cost can be computed by solving location allocation problem and vehicle routing problem. Finally, the profit of each set of selected suppliers can be found.

Even this approach is so straightforward for solving the problem; nonetheless, the abundant sets of selected suppliers lead to the huge possible solutions of this problem. In addition, solving each set of suppliers is a time–consuming process. To limit a space of possible sets of suppliers, the supplier screening approach is therefore, introduced in this research. The screening criteria will reduce the space of solutions by discarding non potential sets of selected suppliers for fixed collection station location. As a result, the size of the problem is reduced significantly because there is no need to evaluate all possible sets of selected suppliers. Moreover, it tends to reduce the computation time.

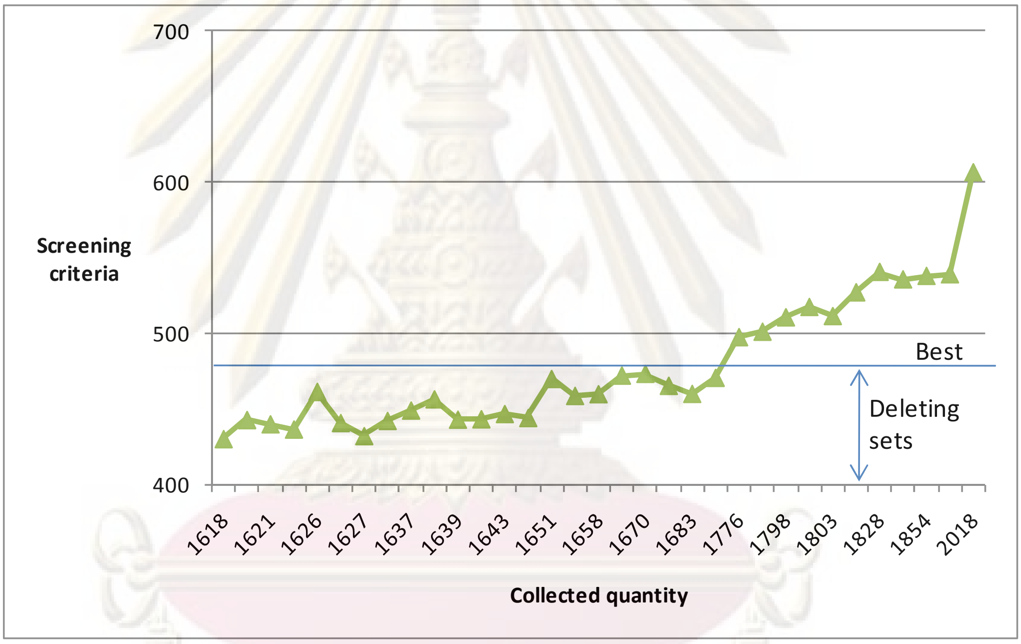


Figure 4.2 An example of the supplier screening approach

Due to ample chances for possible solutions, the LRS heuristic method started for finding one potential set of selected suppliers, and set a solution at this stage as the initial solution. Then, given the initial solution, the heuristic method improved the initial solution, and set a solution from the second stage as the best solution. Lastly, in the third stage, non potential sets of suppliers are screened by screening criteria. After screening process, the rest of sets of selected suppliers will be returned to the first and second stages to find a solution with a highest profit.

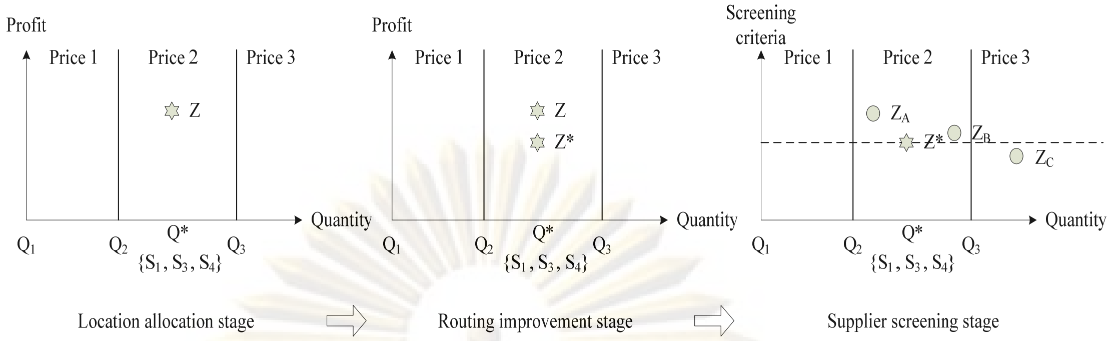


Figure 4.3 The demonstration of solution relation

4.3 Heuristic Procedure

The heuristic solution approach which is presented in Figure 4.4 consists of three stages: (1) location allocation stage, (2) routing improvement stage, and (3) supplier screening stage.

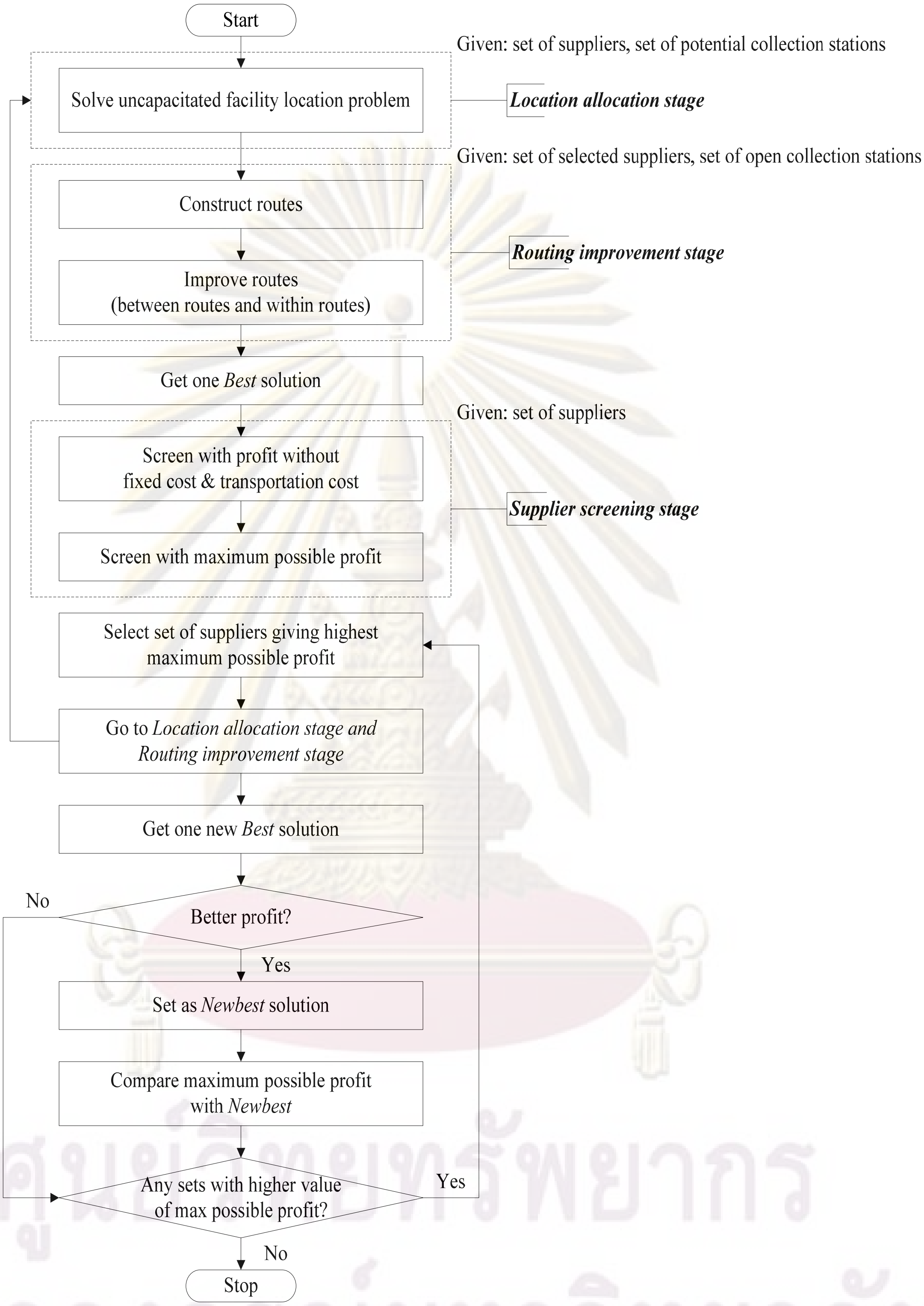


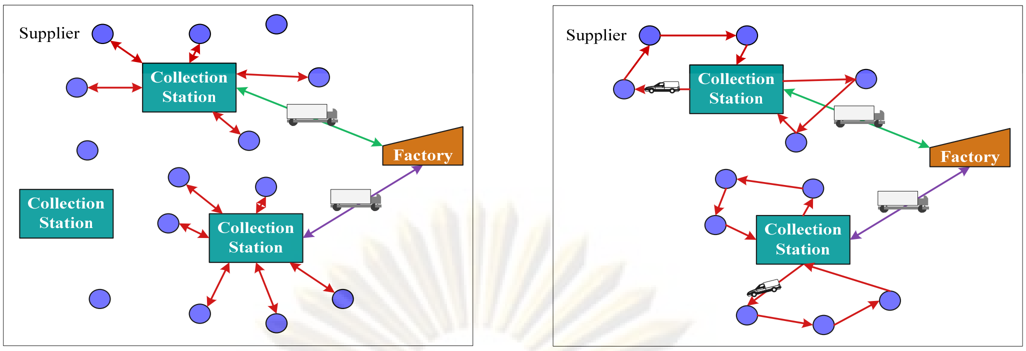
Figure 4.4 The flow of location–routing–screening heuristic method

Given set of suppliers, potential collection stations, and a factory, the sequential heuristic procedure starts from location allocation stage, and then it goes to routing improvement stage, and finally does supplier screening stage. The first stage in the construction of the initial solution relaxes the problem considered from location allocation and vehicle routing problem to uncapacitated facility location problem. A supplier will be allocated to a collection station if the profit from sending supply to that collection station is maximum. This means that a supplier does not need to be assigned to a nearest collection station. If the profit value from assigning to farther collection station is higher than the nearest collection station, the supplier will be allocated to that farther collection station. Moreover, if the profit values from transporting supply to all collection stations are negative, the supplier will be assigned to one artificial collection station where the profit value is zero. Suppliers whose supply is sent to this artificial collection station will not be included in the system.

Given the initial solution from location allocation stage, the routing improvement stage is the improvement of initial solution in term of total system cost minimization. Both route construction and route improvement are conducted at this stage. Not only is transportation cost decreased, but fixed cost of collection station may be reduced if suppliers belonging to that collection station are all relocated to other open collection stations.

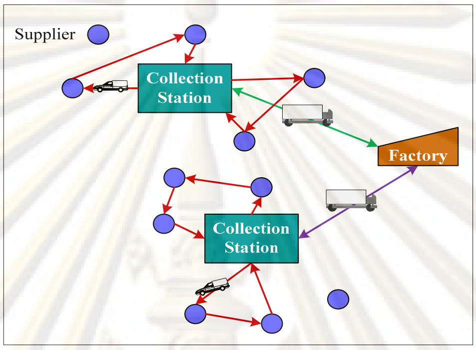
The last stage is the supplier screening stage which separates potential sets of selected suppliers and non potential sets of selected suppliers. This underlies two criteria: (1) profit without fixed cost and transportation cost and (2) maximum possible profit are proposed at this stage as screening criteria. The set of selected suppliers with highest maximum possible profit is selected. Then this set (as in input data) will return to a location allocation stage and a routing improvement stage in order to find a new best solution.

The procedure will stop when there is no improvement for a best solution or there are no sets of suppliers having maximum possible profit than a best solution.



Location allocation stage

Routing improvement stage



Final result

Figure 4.5 An example of results from each stage of the heuristic method

4.3.1 Location Allocation Stage

In location allocation stage, the research problem is relaxed from location and routing problem to location allocation problem. This means that the vehicle routing is not determined in this process. The aim of this stage is to find one potential set of selected suppliers who are to give maximized profit and construct a solution at this stage as the initial solution. The results from this part are the set of open collection stations, the set of selected suppliers, and the allocation of selected suppliers to open collection stations.

4.3.1.1 The Uncapacitated Facility Location Problem with Artificial Collection Station

Given single step–price, the location allocation problem is solved together with the selection of suppliers. The problem description at this stage is similar to the problem statement in Chapter 1; however, instead of routing transportation, raw material transportation is changed to direct transportation. A vehicle is dispatched from collection station to supplier point and then it will directly return to the collection station. This implies that there is one vehicle per one supplier. A supplier will be allocated to a collection station which gains a maximum profit from the collection of raw material. For this problem, one collection station is set as an artificial collection station. Suppliers whose supply is sent to this artificial collection station will be not included in the system. It is set that each supplier is assigned to exactly one collection station. Figure 4.6 presents the illustration of the location allocation stage with artificial collection station. In this study, we further assume that fixed costs of both collection station and vehicle are zero. The reason is that if there is no restriction of fixed cost of collection station, suppliers are freely assigned to any collection stations. The collection station that does not operate at this stage will be not considered in the later step. This implies that even though there is no fixed cost of collection station, the closed collection station has non potential for operating in the system.

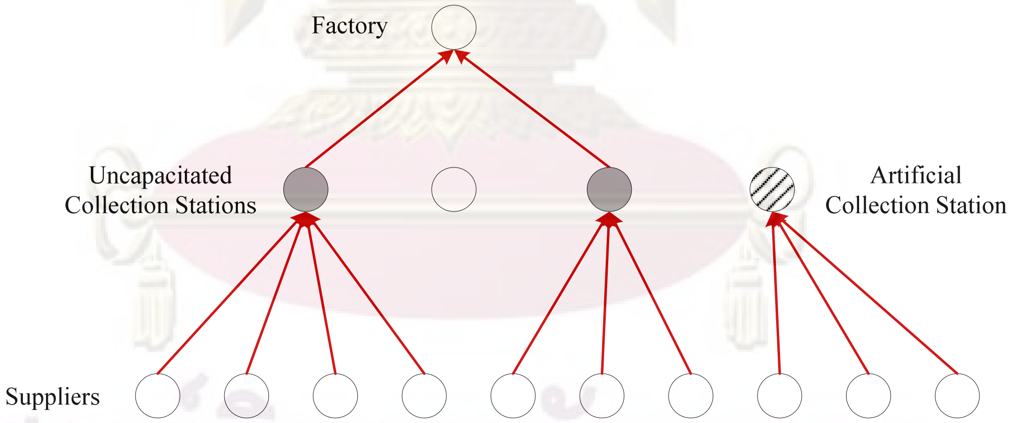


Figure 4.6 The uncapacitated facility location problem with artificial collection station

The raw material collecting system is composed of n possible suppliers, m potential collection stations, and one artificial collection station indexed by $m+1$. The sets, indices, parameters and decision variables are defined as follows:

Sets:

I	represents the set of possible suppliers
J	represents the set of potential collection stations
T	represents the set of step–prices

Indices:

i	represents the supplier index, whereby $i \in I$
j	represents the collection station index, whereby $j \in J$
$j = m+1$	represents an artificial collection station index
s	represents the step–price index, whereby $s \in T$

Costs:

c_j	represents the fixed cost of collection station j, $j \in J \cup m+1$
β	represents the fixed cost of vehicle using between collection station and supplier
h_j	represents the transportation cost per unit quantity between collection station j and factory, $j \in J \cup m+1$
r_{ij}	represents the transportation cost between supplier i and collection station j, $i \in I$, $j \in J \cup m+1$

Prices:

p_0	represents the raw material price per unit quantity at collection station
p_s	represents the raw material price per unit quantity at factory at step–price s, $s \in T$

Parameters:

s_i	represents the supply of supplier i, $i \in I$
q_s	represents the minimum quantity level at step–price s, $s \in T$

Decision variables:

w_j	represents 1 if collection station j is opened, $j \in J$; 0 otherwise
z_{ij}	represents 1 if supplier i is picked up by the collection station j, $i \in I$, $j \in J$; 0 otherwise

Given one step–price, the uncapacitated facility location problem with artificial collection station can be formulated as the following integer programming:

$$Max\sum_{i\in I}\sum_{j\in J} p_s s_i z_{ij} - \Big(\sum_{i\in I}\sum_{j\in J} p_0 s_i z_{ij} + \sum_{i\in I}\sum_{j\in J} h_j s_i z_{ij} + \sum_{i\in I}\sum_{j\in J} r_{ij} z_{ij} + \sum_{i\in I}\sum_{j\in J} \beta z_{ij} + \sum_{j\in J} c_j w_j\Big) \qquad (s)$$

We can rewrite the objective function as:

$$= \text{ maximize } \sum_{i\in I}\sum_{j\in J} s_i z_{ij}\ (p_s - p_0 - h_j) \quad - \quad \sum_{i\in I}\sum_{j\in J} r_{ij} z_{ij} \ - \ 0 \ - \sum_{j\in J} c_j w_j$$

$$= \text{maximize } \sum_{i\in I}\sum_{j\in J} p_{ij} z_{ij} \ - \ \sum_{j\in J} c_j w_j$$

where p_{ij} is the profit of supply of supplier i picking up by collection station j at step–price p_s, $i \in I$, $j \in J$

$$p_{ij} = s_i (p_s - p_0 - h_j) - r_{ij}$$

Replacing (*s*); therefore the problem is formulated as follows:

$$Max\sum_{i\in I}\sum_{j\in J} p_{ij} z_{ij} - \sum_{j\in J} c_j w_j \qquad (4.1)$$

Subject to

$$\sum_{j\in J\cup m+1} z_{ij} = 1 \qquad \forall i \in I \qquad (4.2)$$

$$\sum_{i\in I}\sum_{j\in J} s_i z_{ij} \geq q_s \qquad (4.3)$$

$$w_j - z_{ij} \geq 0 \qquad \forall i \in I \,,\ \forall j \in J \cup m+1 \qquad (4.4)$$

$$w_j \in \{0,1\} \qquad \forall j \in J \cup m+1 \qquad (4.5)$$

$$z_{ij} \in \{0,1\} \qquad \forall i \in I \,,\ \forall j \in J \cup m+1 \qquad (4.6)$$

The objective function, Equation (4.1), maximizes the profit of the system. Constraint (4.2) ensures that all suppliers are assigned to only one collection station. Minimum requirement of quantity level of each step–price is presented in Constraint (4.3). Constraint (4.4) guarantees that supply of suppliers is sent to only opened collection station. Constraint (4.5) and (4.6) are binary requirement on the decision variables.

4.3.1.2 Procedure

The procedure of location allocation stage is presented in Figure 4.7. Given set of possible suppliers, set of potential collection station, and one step–price, the process starts by solving the uncapacitated facility location problem with the objective of profit maximization. Repeat solving the uncapacitated facility location problem by replacing with other step–prices. The solution giving maximized profit will be selected and set as the initial solution then go to routing improvement stage.

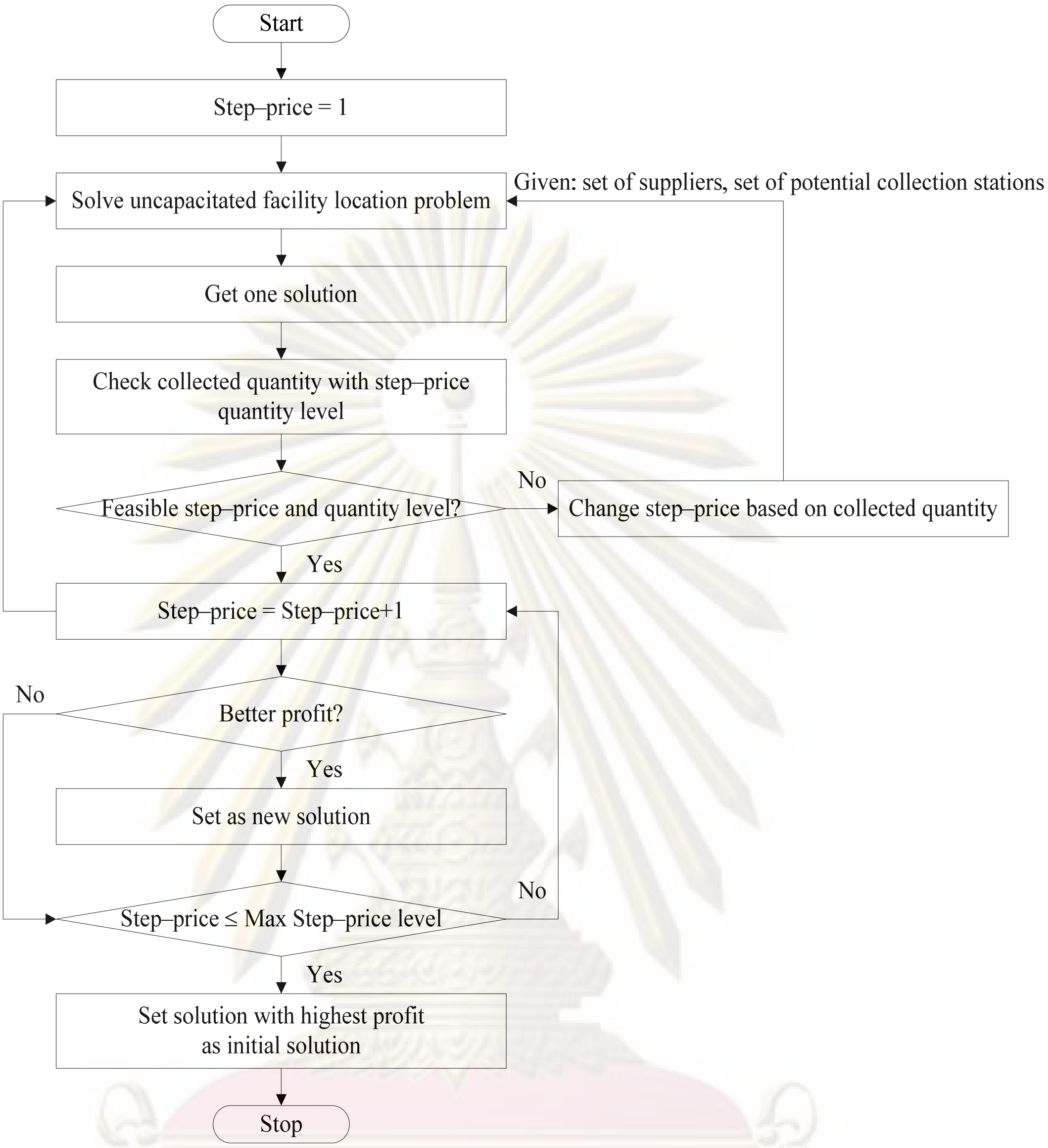


Figure 4.7 The flow chart of location allocation stage

4.3.2 Routing Improvement Stage

Given initial solution from location allocation stage, the vehicle routing problem is performed in routing improvement stage. At this stage, first, routes are constructed; second, the constructed routes are improved. The objective of this stage is to improve the solution by minimizing total system cost. The results at this stage which is regarded as the best solution for the problem are the set of open collection stations, the set of selected suppliers, the allocation of selected suppliers to open collection stations and the set of routes presenting the assignment of selected suppliers to each route.

4.3.2.1 Route Construction

In route construction section, given set of open collection stations, set of selected suppliers and the assignment of the selected suppliers to open collection stations, the capacitated vehicle routing problem with time duration is solved. In this research, the cheapest insertion method is applied to find feasible routs of suppliers. Each route is constructed on the basis not only of vehicle capacity limit, but by time duration too. It is set that the assignment of suppliers to collection stations is not changed. In this step, a supplier cannot move to other collection stations. Figure 4.8 illustrates a feasible solution from route construction process.

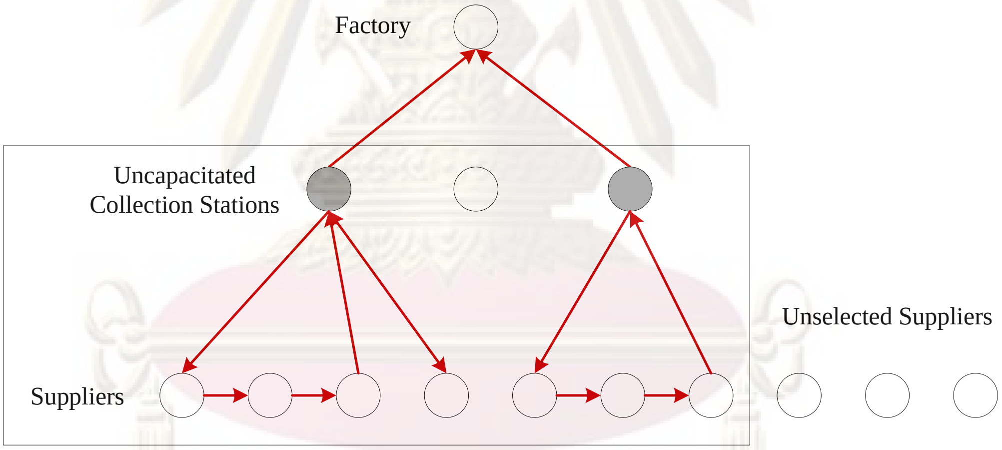


Figure 4.8 The route construction

Cheapest insertion algorithm:

Step 1: Given one opened collection station and list of un–routed suppliers, find starting route $R = \{i, station, i\}$ by selecting the supplier which is farthest away from the collection station.

Step 2: Update vehicle capacity and time duration then go to Step 3.

Step 3: For each of un–routed supplier g, find the best position of insertion by computing cost of inserting the supplier g between all edges $\{h, l\}$ in the current route *R*.

A measure of insertion cost is given by $C(h, g, l) = c_{hg} + c_{gl} - c_{hl}$.

Step 4: Select the supplier g^* which has the lowest insertion cost. If the insertion is feasible in term of vehicle capacity and route length, insert supplier g* in the least cost position between supplier h^* and supplier l^* in the current route *R*. Update vehicle capacity and route length.

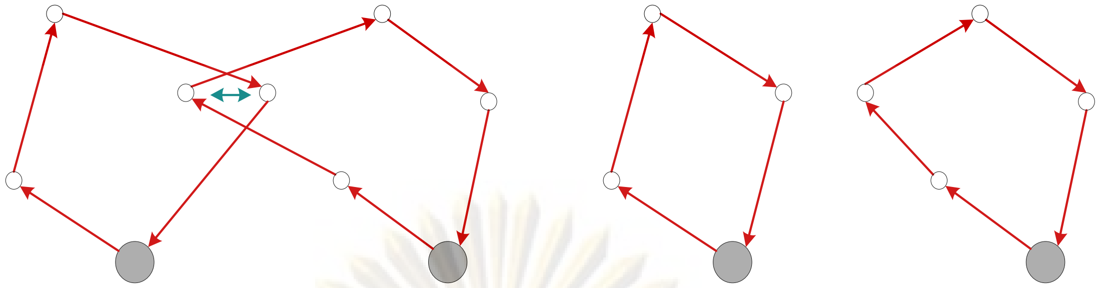
Step 5: Repeat Step 3 until vehicle capacity and route length are exceeded. A new route is then started and repeated Step 1. If all suppliers have been assigned to the route, go to Step 6.

Step 6: For the rest of opened collection station, begin a new route by repeating Step 1 until all opened collection stations are processed and all selected suppliers are routed.

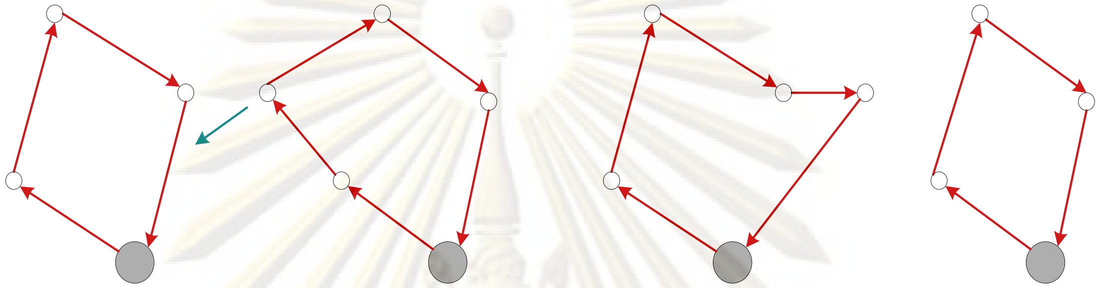
4.3.2.2 Route Improvement

In route improvement section, both within route and between routes improvements are applied. A between–route improvement method exchanges or relocates the position of nodes between two routes. The basic *k*–exchange neighborhoods for the vehicle routing problem are defined by Kindervater and Savelsbergh (1997: 339-344). A within–route improvement method seeks a move to improve the objective function by altering the sequence within a route. Such method as 2–OPT and 3–OPT are in this class of neighborhood moves.

For between routes improvement, supplier exchange method (1–1 exchange) and supplier insertion method (1–0 move) are applied. The supplier exchange tries to exchange the position of suppliers belonging to two different routes without changing the sequence of each route. This procedure repeats until no feasible exchange can improve the current solution found. On the other hand, the supplier insertion method attempts to insert a supplier from one route into another route. This move is performed until without improvement over the best solution found.



(1) Supplier exchange method



(2) Supplier insertion method

Figure 4.9 The illustrations of (1) supplier exchange method and (2) supplier insertion method

For within route improvement, 2–OPT method is used. The 2–OPT method starts with a feasible tour, and breaks it at two places. This move deletes two edges, thus breaking the tour into two paths, then reconnects those paths in the other possible way. The length of each reconnection is evaluated, and the smallest tour is defined a new tour. Figure 4.10 presents a feasible solution from route improvement process.

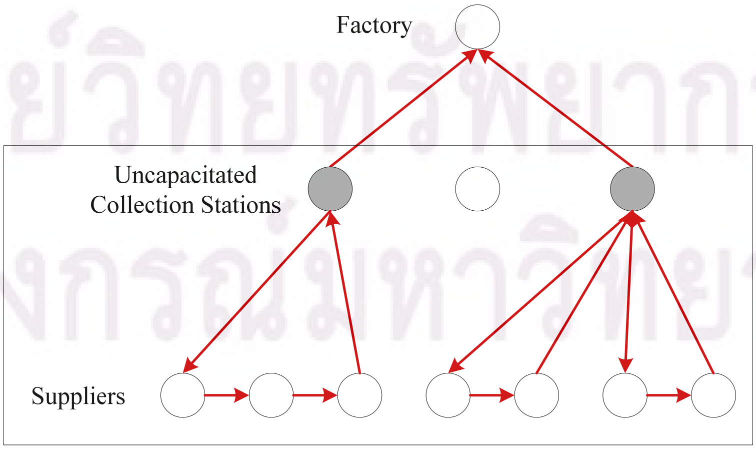


Figure 4.10 The route improvement

4.3.2.3 Procedure

The procedure of route improvement stage is shown in Figure 4.11. Given the solution from location allocation stage, routes are constructed by applying cheapest insertion method. A set of feasible routes is then entered the route improvement phase including between the routes and within the routes. The solution from the improvement is then set as a best solution of the research problem.

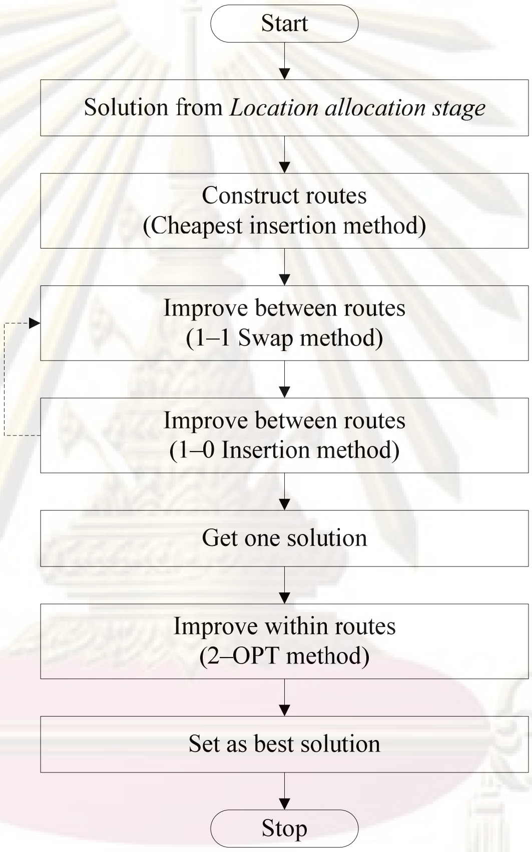


Figure 4.11 The flow chart of routing improvement stage

4.3.3 Supplier Screening Stage

Owing to step–price policy as mentioned above in the review, different set of suppliers provide the difference of profit. In general, to examine set of suppliers giving maximum, all possible sets of suppliers need to solve the problem of location allocation and vehicle routing. Determining each set of suppliers is time–consuming process. Therefore, it is better to investigate only sets of selected suppliers having good potential for better profit. The difficulty is how to confine all possible sets of selected suppliers. At this stage, two screening criteria i.e. (1) profit without fixed cost and transportation cost and (2) maximum possible profit are proposed to discard non potential sets of suppliers. The screening with profit without fixed cost and transportation cost is firstly performed. The screening with maximum possible profit is secondly determined. The purpose of supplier screening stage is to find potential sets of suppliers with higher profit by comparison with best solution from routing improvement stage. The results from this part are the set of selected suppliers which have the potential of giving better profit.

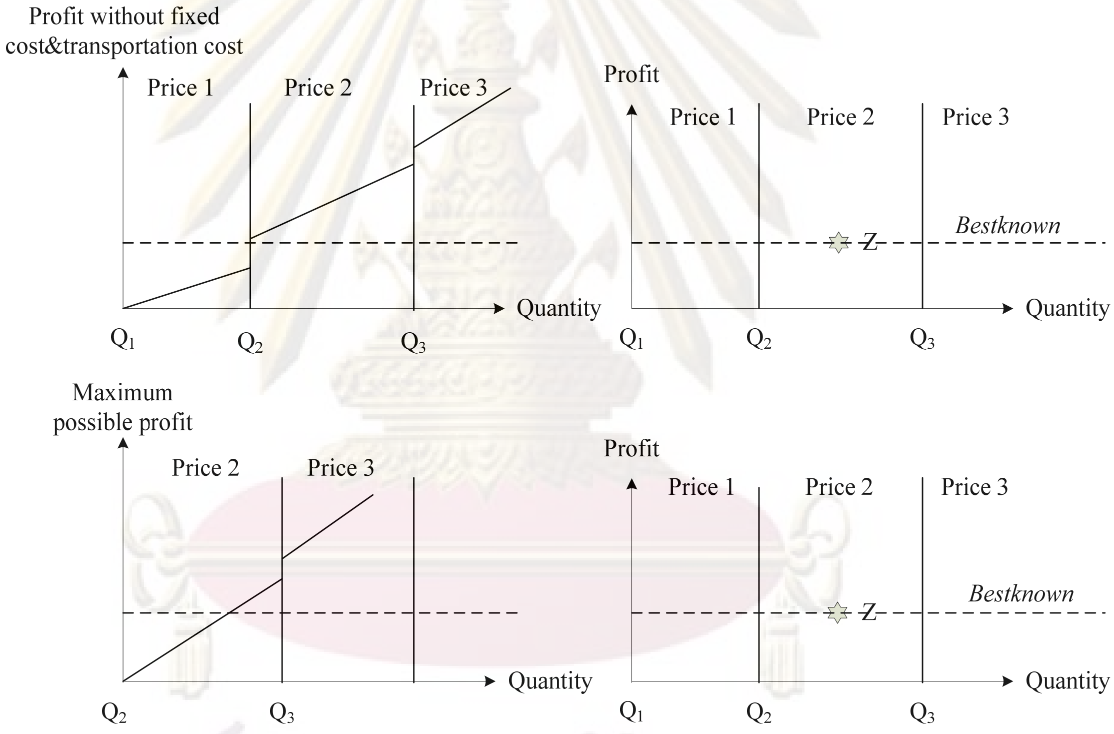


Figure 4.12 The concept of screening criteria: (1) profit without fixed cost and transportation cost, and (2) maximum possible profit

4.3.3.1 Profit without Fixed Cost and Transportation Cost

At this stage, each combination set of selected suppliers is computed profit without fixed cost and transportation cost (*Profit*) as follows:

$$Profit = Revenue - RMcost \tag{4.7}$$

(1) Revenue (*Revenue*)

Given set of selected suppliers, total collected quantity (Q) is known. Then select p_s by checking Q with step–price quantity levels ($q_s < Q \leq q_{s+1}$).

$$Revenue = p_s \times Q \tag{4.8}$$

(2) Raw material cost (*RMcost*)

$$RMcost = p_0 \times Q \tag{4.9}$$

The *Profit* criterion is calculated easily and taken less time in both calculation and screening. On the contrary, the screening quality is poor since this criterion does not represent other costs influencing to the raw material collection system such as collection station fixed cost. Total potential sets of suppliers after screening with this criterion is still large. As a result, maximum possible profit is introduced in the second process.

4.3.3.2 Maximum Possible Profit

At this stage, each set of suppliers is calculated for maximum possible profit (*maxProfit*) as follows:

$$maxProfit = Revenue - minCost \tag{4.10}$$

(1) Revenue (*Revenue*)

Given set of selected suppliers, revenue is calculated as described in Section 4.3.3.1: Profit without fixed cost and transportation cost.

(2) Minimum possible cost (*minCost*)

Minimum possible cost represents the minimum system cost both fixed cost and variable cost required in raw material collection system. In this study, the *minCost* is the sum of (2.1) raw material cost, (2.2) collection station fixed cost, (2.3) vehicle fixed cost, (2.4) transportation cost between a collection station and a factory, and (2.5) transportation cost between a collection station and a supplier.

(2.1) Raw material cost (*RMcost*)

Raw material cost is computed as presented in (4.9).

(2.2) Collection station fixed cost (*Fixedcost_C*)

Collection station fixed cost is determined from the sum of fixed costs of open collection stations for a best solution. The collection stations considered here are only open collection stations for a best solution. The collection stations which are closed from location allocation stage and routing improvement stage will not be included in this estimated cost. In location allocation stage, there is no fixed cost of collection station considered in the solution process, the collection station which is closed at this stage means that it has no potential to operate in the collection system.

$$Fixedcost\_C = \sum_{j \in J'} c_j \tag{4.11}$$

J' represents the set of open collection station from best solution

(2.3) Vehicle fixed cost (*Fixedcost_V*)

Vehicle fixed cost is estimated from the cost of vehicle using in raw material collection system where the number of vehicle, the total collected quantity is divided by vehicle capacity. This estimated cost refers to the minimum number of vehicle using for raw material transportation in the collecting system.

$$Fixedcost\_V = \beta \frac{Q}{L} \tag{4.12}$$

β represents the fixed cost of vehicle using between a collection station and a supplier

L represents the capacity of vehicle using between a collection station and a supplier

(2.4) Transportation cost between a collection station and a factory (*Tcost_SF*)

Transportation cost between a collection station and a factory is evaluated from minimum transportation cost between a collection station and a factory. The minimum transportation cost is selected from minimum value of transportation cost between an open collection station and a factory.

$$Tcost\_SF = Q \times \min(h_j) \tag{4.13}$$

$\min(h_j)$ represents minimum transportation cost per unit quantity between a collection station j and a factory, $j \in J'$

(2.5) Transportation cost between a collection station and a supplier (*Tcost_SS*)

The illustration of this transportation cost can explain as Figure 4.13. This cost is composed of two directions that are collection station to supplier, and supplier to node. For transportation cost between a collection station and a supplier, it is chosen from the least cost (distance) between a supplier and one node plus from the least cost between a collection station and one node (supplier) which is not a collection station itself. We do not concern whether the route is formed or not, but consider that each node has one leg leaving from the node.

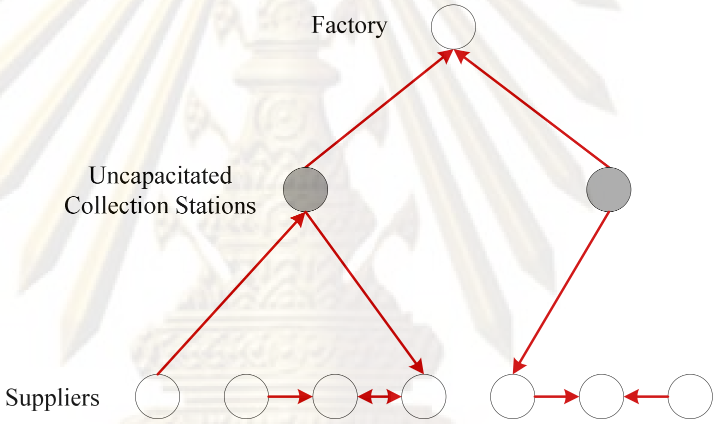


Figure 4.13 The illustration of minimum transportation between a collection station and a supplier

$$Tcost\_SS = \sum_{i \in I'} (\min r_{ih}) + \sum_{j \in J'} (\min r_{ji}) \tag{4.14}$$

I' represents the set of selected suppliers

r_{ih} represents transportation cost between a supplier i and node h, $i \in I'$, $h \in I' \cup J'$

r_{ji} represents transportation cost between a collection station j and a supplier i, $j \in J'$, $i \in I'$

$\min\ r_{ih}$ represents minimum transportation cost between a supplier i and node h, $i \in I'$, $h \in I' \cup J'$

$\min\ r_{ji}$ represents minimum transportation cost between a collection station j and a supplier i, $j \in J'$, $i \in I'$

If $|I'|$ = 1, it is set that $\sum_{i \in I'} (\min r_{ih}) = \sum_{j \in J'} (\min r_{ji})$, owing to only one supplier in the system so the transportation cost from a supplier to one node is equal to the transportation cost from a collection station to a supplier.

The screening quality of the *maxProfit* criterion performs good results. Total potential sets of suppliers after screening is much lower than screening by the *Profit* criterion. This screening criterion is able to discard a lot of non potential sets of suppliers because it represents more realistic system cost of the raw material collection system. However, calculation of maximum possible profit is more complex than the *Profit* criterion so that it consumes more time than the *Profit* criterion.

4.3.3.3 Procedure

The procedure of supplier screening stage is presented in Figure 4.14. Given set of possible suppliers, the process starts by calculating profit without fixed cost and transportation cost (*Profit*). The set of supplier whose *Profit* is lower than best known (*Best*) from routing improvement stage will be deleted from the system. The rest of sets of supplier are further calculated for maximum possible profit (*maxProfit*). A set of suppliers whose *maxProfit* is lower than *Best* will also be discarded from the system. The set of selected suppliers with highest maximum possible profit is selected. Then this set (as in input data) will return to a location allocation stage and a routing improvement stage in order to find a new best solution.

The procedure will stop when there is no improvement for a best solution or there are no sets of suppliers having *maxProfit* higher than *Best*.

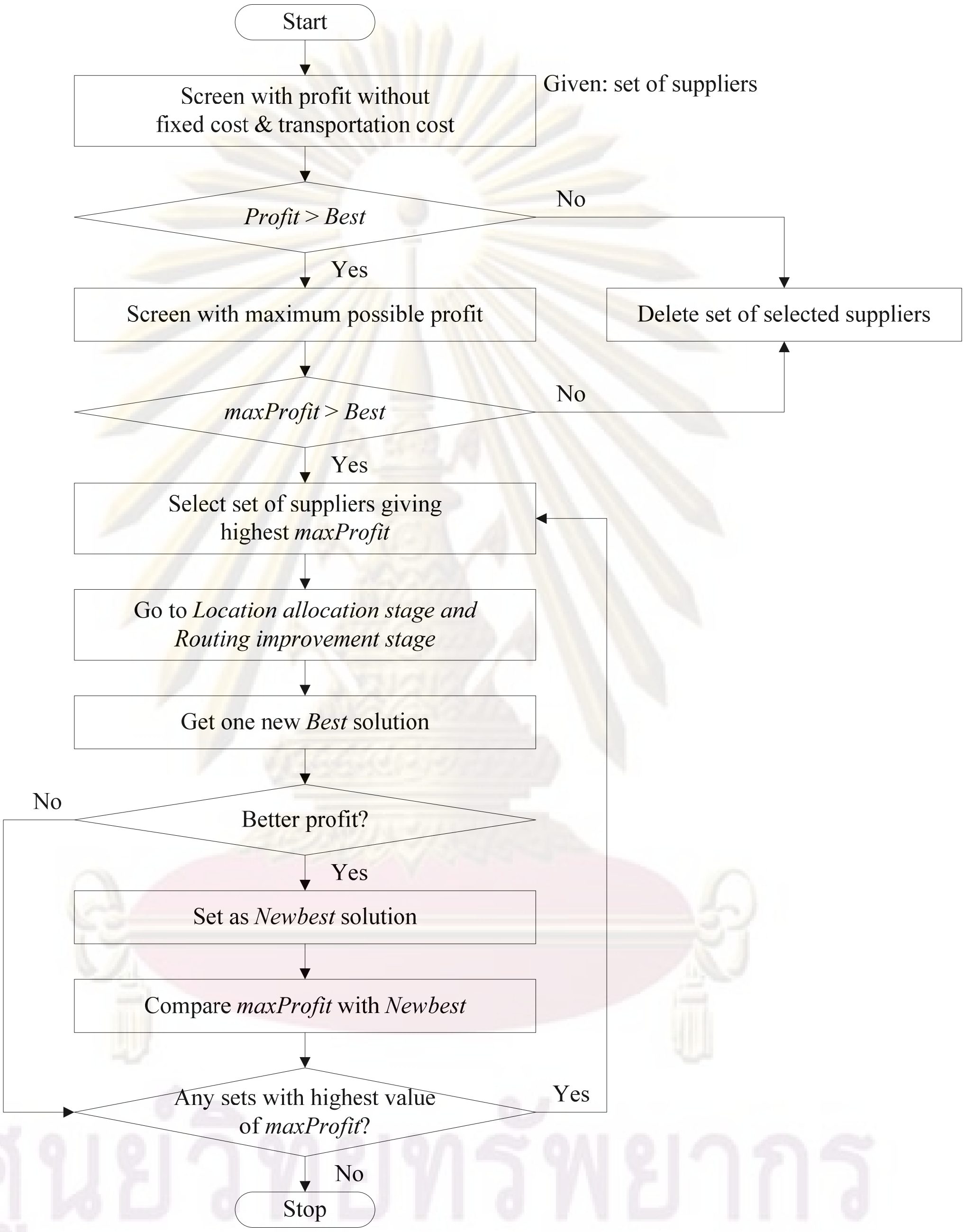


Figure 4.14 The flow chart of supplier screening stage

4.4 Computational Results

(1) Example: 2 collection stations, 10 suppliers, and 3 step–prices

An example containing ten suppliers and two collection stations with three step–prices is provided for illustrative figure of the proposed solution method as in Chapter 3 Section 3.6 example case #2. In this section, we solve the problem considered by using the heuristic solution approach as mentioned previously. The solutions from location allocation stage, routing improvement stage, and supplier screening stage are reported in Table 4.1, 4.2, and 4.3, respectively.

Table 4.1 The result from location allocation stage

Total profit = 495.417, solve time = 0.02 sec., total selected suppliers = 10

Open collection station	Allocated supplier
1	1 3 4 5 6 8 9 10
2	2 7

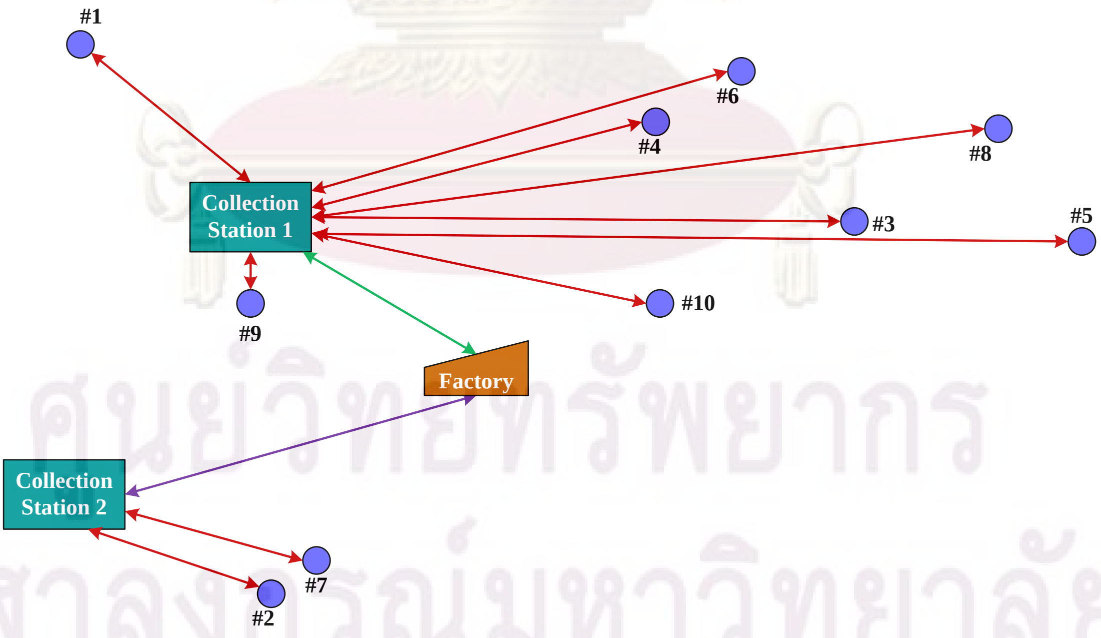


Figure 4.15 The result from the location allocation stage

The result from the first stage is reported as the set of open collection stations, the set of selected suppliers and the allocation of selected suppliers to open collection stations. Ten suppliers still keep in the collection system.

Table 4.2 The result from routing improvement stage

Total profit = 331.2214, solve time = 0.03 sec.

Collection station	Route	Total distance	Total load	Total time
1	S1-4-6-S1	228.2331	397	238.1581
	S1-3-5-S1	224.5449	394	234.3949
	S1-8-S1	207.1618	158	211.1118
	S1-1-S1	206.8139	190	211.5639
	S1-9-10-S1	136.3459	417	146.7709
2	S2-2-7-S2	116.1116	462	127.6616

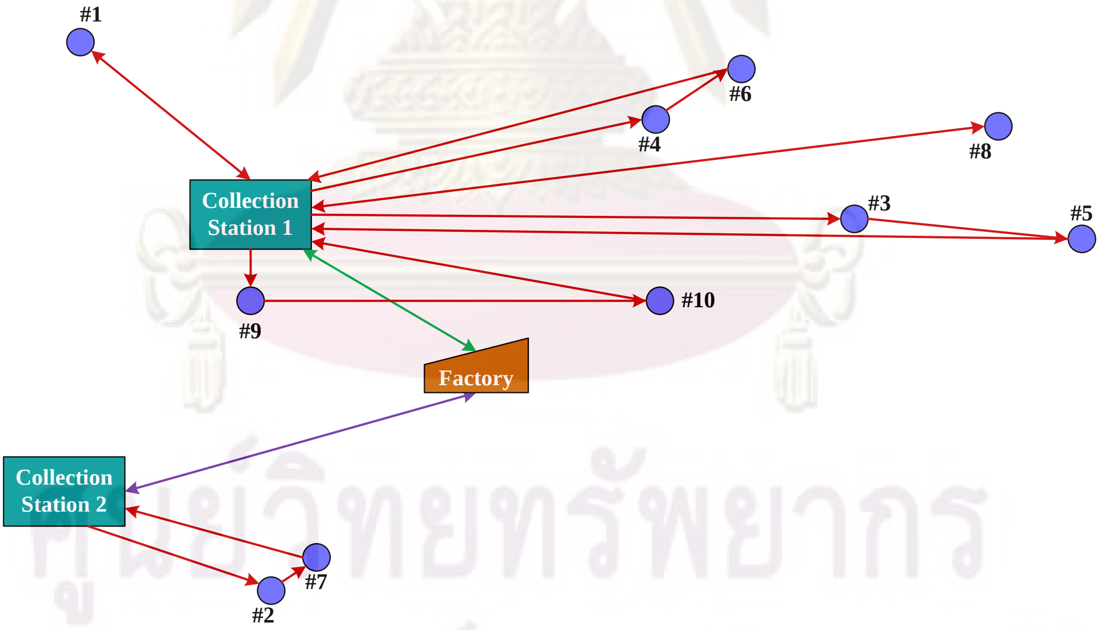


Figure 4.16 The result from the route improvement stage

The result from the second stage is provided with the complete solution for the problem considered, which includes the set of open collection stations, the set of selected suppliers, the allocation of selected suppliers to open collection stations, and finally the routing solution. Profit at this stage is the best result for the problem.

Table 4.3 The result from supplier screening stage

Solve time = 3.0343 sec.

Combination sets of suppliers	Profit without Fixed & Transport cost		Maximum possible profit		
	Deleted set	Remain set	Deleted set	Remain set	Max. profit
1023	512	510	489	21	421.0392

Table 4.4 The solution from each iteration

Iteration	UFLP (with dummy station)			LRP		Deleted Supplier	Max. Profit
	CPU (sec)	Profit	Selected Supplier	CPU (sec)	Profit		
0	0.0200288	495.417	10	0.0300432	331.2214	-	421.0392
1	0.0300432	464.036	9	0.0400576	331.8401	1	387.3805
2	0.0300432	478.116	9	0.0300432	345.9203	8	385.7954
3	0.0200288	480.722	9	0.0400576	267.1844	6	384.7196
4	0.0300432	456.569	9	0.1101584	254.4374	3	382.475
5	0.0300432	438.601	9	0.050072	333.2254	10	373.9518
6	0.0200288	456.046	9	0.0300432	324.1391	5	364.2664
7	0.0100144	416.697	9	0.050072	212.9714	9	358.2797
8	0.0200288	421.961	9	0.050072	326.6538	2	357.4519
9	**0.0300432**	**446.735**	**8**	**0.0300432**	**346.5391**	**1 8**	**352.1366**
10	0.0200288	449.341	8	0.0400576	267.8032	1 6	351.0608
11	0.0200288	463.421	8	0.0400576	281.8833	6 8	349.3757
12	0.0200288	425.188	8	0.0400576	255.0561	1 3	348.8162
13	0.0200288	431.804	9	0.0400576	232.3171	4	347.9394

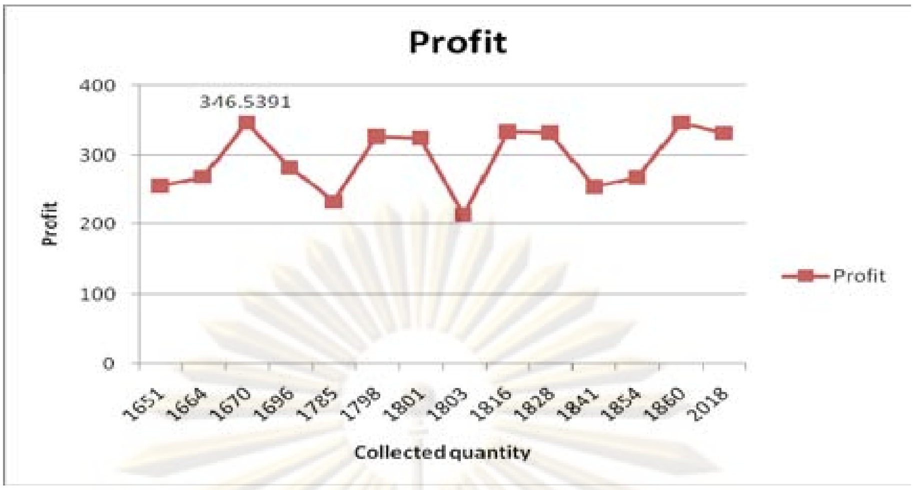


Figure 4.17 Profit from each iterative

Table 4.4 shows that only 8 suppliers are included in the raw material collection system. This can be testified that not all suppliers give the best solution. Final result of the problem considered is shown in Table 4.5. The comparison of heuristic solution and mathematical model solution of this example is presented in Table 4.6. Percentage of difference (% Difference) is calculated as follows:

$$\%\ \text{Difference} = \frac{|Heu - Opt|}{Opt} \times 100 \tag{4.15}$$

Where Heu is the profit value or time solved, obtained from heuristic solution approach, and Opt is the profit value or time solved obtained by solving mathematical model solution approach.

Table 4.5 The result of the problem (10 suppliers, 2 collection stations, and 3 step–prices)

Collection station	Route	Total distance	Total load	Total time
1	S1-4-6-S1	228.2331	397	238.1581
	S1-3-5-S1	224.5449	394	234.3949
	S1-9-10-S1	136.3459	417	146.7709
2	S2-2-7-S2	116.1116	462	127.6616

Table 4.6 The solution comparison between mathematical model and heuristic method for the example

	Mathematical solution	Heuristic solution	% Difference
Profit	556.838	346.5391	37.77%
Time (sec)	17058.9	4.025654	99.97%

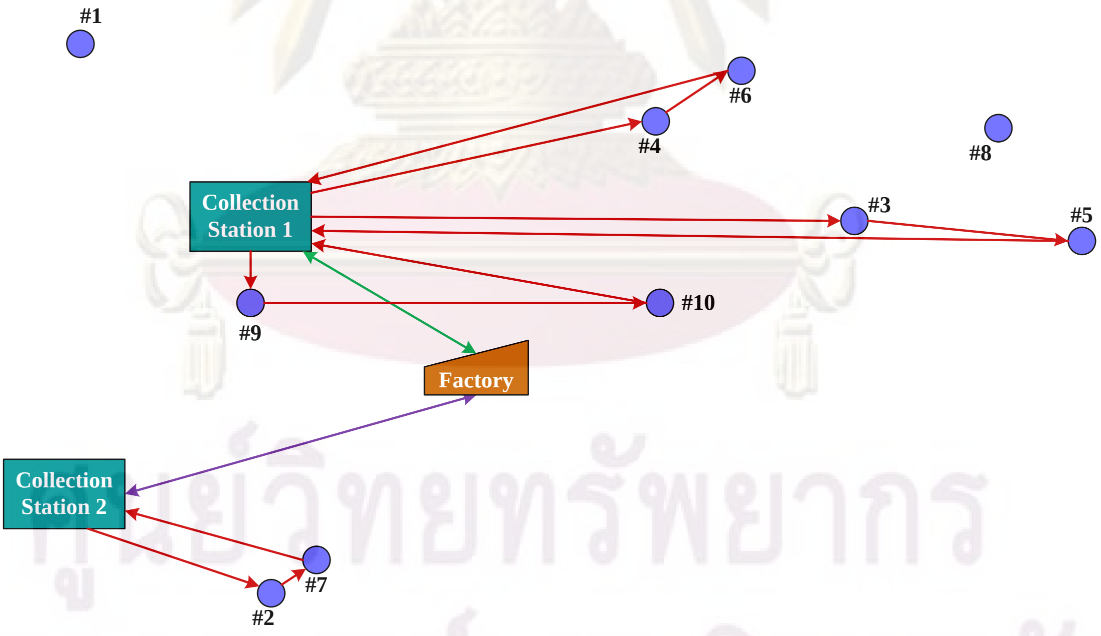


Figure 4.18 The result of an example

(2) Results by varying sizes of problems

We consider more instances whose data characteristics are set as same as that explained in chapter 3, but number of possible suppliers and number of potential collection stations are changed.

Given the same number of potential collection stations, and varied the number of possible suppliers, the comparison of the solving time between the mathematical model solution and the heuristic solution method (as given in Figure 4.19) shows that the solving time from the mathematical model solution grows exponentially higher than the solving time from the heuristic solution method. However, the profit value from heuristic solution method slightly differs from the mathematical model solution (as given in Figure 4.20).

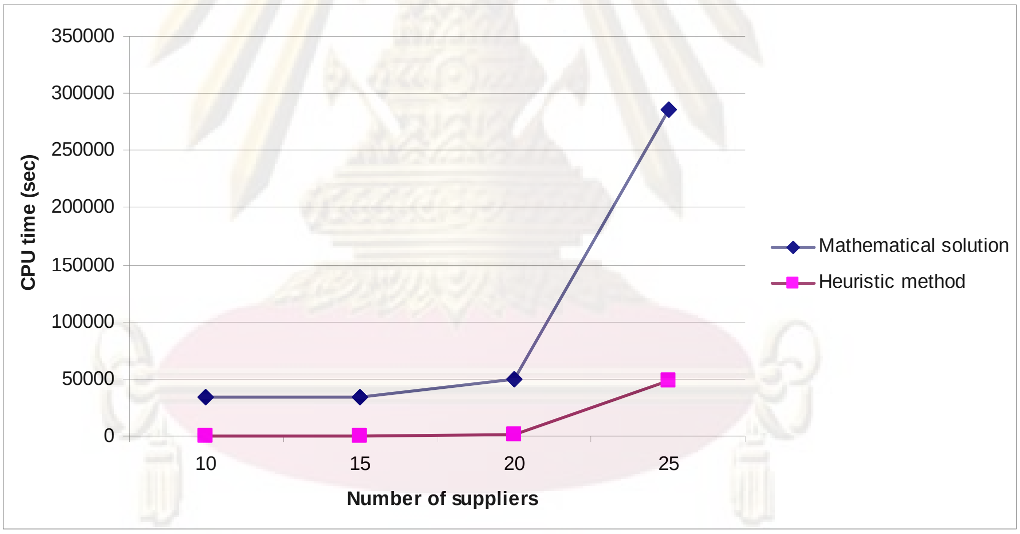


Figure 4.19 The comparison of solving time between the mathematical model and the heuristic method (varied number of suppliers)

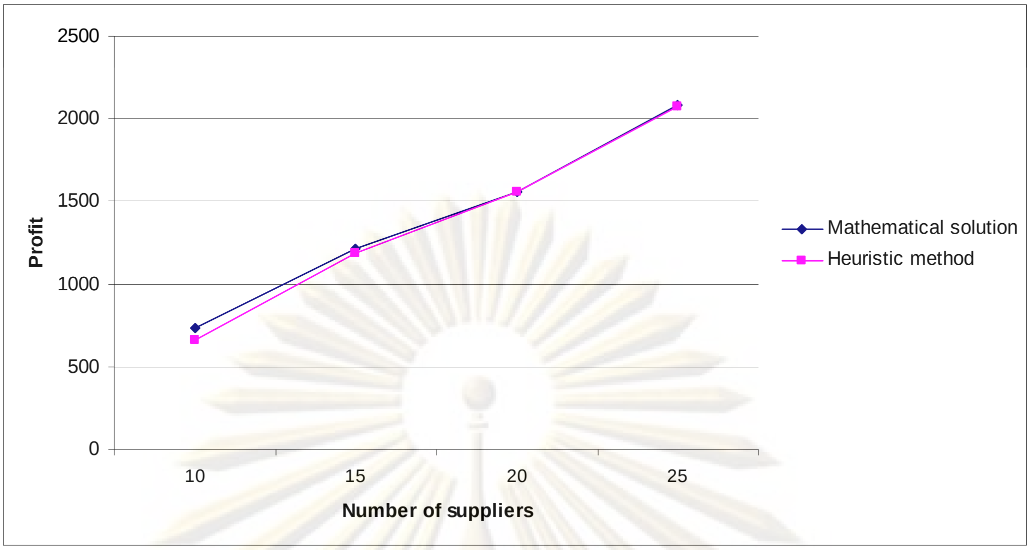


Figure 4.20 The comparison of profit value between the mathematical model and the heuristic method (varied number of suppliers)

Given the same number of possible suppliers, and changing the number of potential collection stations, comparison results of solving time and the profit value are presented in Figure 4.21 and Figure 4.22, respectively. In Figure 4.21, the solving time of the heuristic solution method is significantly different from the mathematical model solution while in Figure 4.22, the profit value of the heuristic solution method differs less from the profit value of the mathematical model solution.

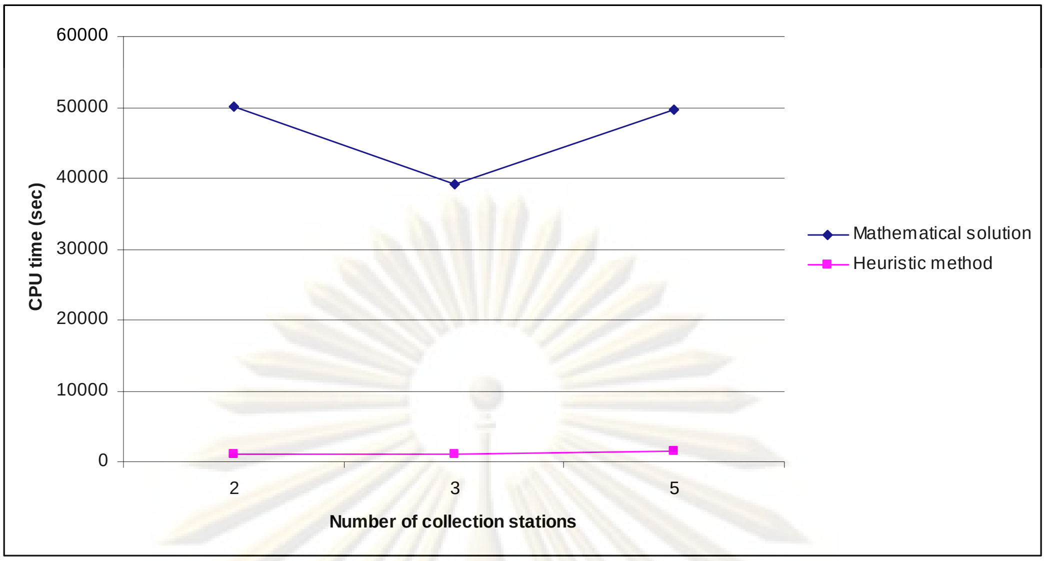


Figure 4.21 The comparison of solving time between the mathematical model and the heuristic method (varied number of collection stations)

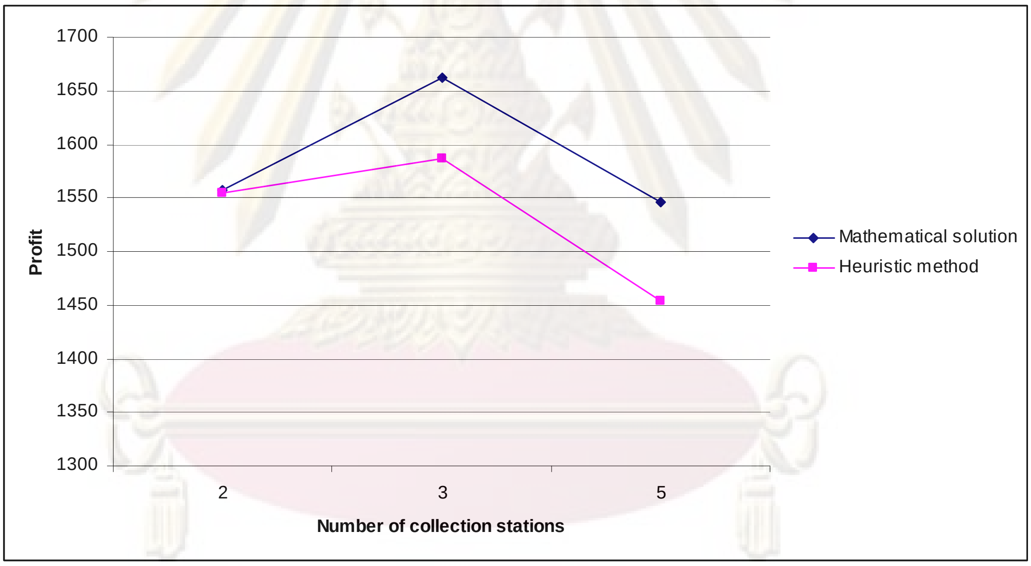


Figure 4.22 The comparison of profit value between the mathematical model and the heuristic method (varied number of collection stations)

(3) Results by varied parameters

Tables from 4.7 to 4.10 report more computational results of varied parameters such as vehicle capacity, time duration, unit transportation cost, and supplier supply.

Table 4.7 The solution comparison by varied vehicle capacity

Profile	Profit			Time (sec)		
	Model	Heuristic	% Diff	Model	Heuristic	% Diff
1	623.897*	560.574	10.15%	160802	3.765	100%
2	758.638	657.118	13.38%	11206.9	2.25	99.97%
3	1463.8*	1456.084	0.53%	87388.1	1004.016	98.85%
4	760.851*	714.14	6.14%	301647	1.875	100%
5	1557.64*	1554.054	0.23%	50168.1	1009.844	97.99%
6	820.296	731.415	10.83%	7563.27	1.891	99.97%

* = feasible solution

Table 4.8 The solution comparison by varied time duration

Profile	Profit			Time (sec)		
	Model	Heuristic	% Diff	Model	Heuristic	% Diff
1	758.638	657.118	13.38%	20220.8	2.25	100%
2	758.638	657.118	13.38%	18742.8	2.2188	100%
3	758.638	657.118	13.38%	17668.6	2.2188	100%
4	758.638	657.118	13.38%	20443.7	2.2188	100%

Table 4.9 The solution comparison by varied unit transportation cost between a collection station and a supplier

Profile	Profit			Time (sec)		
	Model	Heuristic	% Diff	Model	Heuristic	% Diff
1	758.638	657.118	13.38%	11206.9	2.25	99.97%
2	859.538	758.018	11.81%	18169.5	2.406	100%
3	571.028	379.317	33.57%	16711.3	0.53125	100%
4	671.928	464.117	30.93%	15670.7	0.9375	100%

Table 4.10 The solution comparison by varied supplier supply

Profile	Profit			Time (sec)		
	Model	Heuristic	% Diff	Model	Heuristic	% Diff
1	758.638	657.118	13.38%	11206.9	2.25	99.97%
2	1165.12*	1524.888	30.88%	71030.2	2.234	100%

* = feasible solution

(4) The effect of the price change

In this section, we examine the case in which raw material price at the collection stations is varied in order to evaluate the effect of price change on the decisions of the model. Given the same problem size and same parameters, the effect of changing raw material price is reported in Table 4.11.

Table 4.11 The effect of price change

Raw material price (p_0)	Profit	% Change in Profit = $\left\| profit_{new} - profit_{old} \right\| \times 100$
10	4584.33	–
15	3151.08	14.33%
20	4584.33	14.33%
p_1 = 10% p_0 , p_2 = 15% p_0 , p_3 = 20% p_0		

From Table 4.11, when the value of raw material price at the collection station (p_0) is changed, the value of profit (objective value) changes definitely. Nonetheless, it is observed that when the value of $p_0 - p_s$ is the same, the solution of the problem gives a similar result. Hence, changing raw material price (p_0) does not affect the change in profit.

Consequently, by applying the proposed heuristic method, the good solution is performed within reasonable time. However, it is observed that when the number of suppliers is increased, the heuristic solution method takes significantly longer time. Although the problem considered is concerned with the problem of setting up of raw material collection system which is a long term plan, the solving time could be allowed longer than daily operation, the heuristic solution method is still limited for solving large–scale problem. Therefore, to handle this situation, one suggestion which can be made for heuristic method is the clustering–based heuristic method.

Clustering–based approach is useful and can vastly approach using the location routing problem (Barreto et al., 2007; Nambiar et al., 1981; Srivastava, 1993). By partitioning supplier set into clusters or groups, each cluster or each grouping suppliers is treated as one supplier with a large supply. The problem considered can then be solved by the proposed heuristic method. One clustering–based method with two *phase hierarchical method* proposed by Barreto et al. (2007) can be suggested for solving the problem. The clustering steps are described briefly as follows:

Step 1: Given set of suppliers, knowing the supply of each supplier (s_i) and the maximum vehicle capacity (L), the minimum number of group (v) is determined as $v = \frac{\sum_{i \in I} s_i}{L}$.

Step 2: The hierarchical grouping method introduced by Johnson (1967) is applied until there are only v groups.

Step 3: Because the lack of capacity constraint probably leads to the formation of groups that violate this constraint, the transferring supplier is performed. Suppliers from groups exceeding vehicle capacity limit will transfer to other groups that can receive.

Step 4: If, however, the violation of capacity still exists, the number of groups is increased by one unit and the procedure is restarted.

For example, if we take 10 collection stations and 100 suppliers, there are 20 groups of suppliers after clustering. These 20 groups refer to 20 suppliers whose supplies are consolidated from suppliers in each group. Following the three stages of proposed heuristic solution method, the final result is reported in Table 4.12.

Table 4.12 The result of the example (20 groups of suppliers and 10 collection stations)

Total profit = 11176.163, solve time = 1012.1124sec.

Collection station	Route	Total distance	Total load	Total time
1	S1-16-20-S1	188.8641	388	198.5641
2	S2-2-11-4-S2	392.0023	9680	634.0023
	S2-8-5-10-14-12-6-17-9-1-3-S2	621.7995	8786	841.4495
3	S3-15-S3	106.7942	317	114.7192
4	S4-13-S4	16.6833	219	22.158.
5	S5-18-7-S5	169.7710	263	176.346
6	S6-19-S6	70.4556	159	174.4306

4.5 Conclusion

According to the development of the model integrating location allocation and vehicle routing with step–price policy problem, the structure of this integrated model is so complicated with interrelated decisions (location decision, supplier selection decision, allocation decision, and routing decision). The developed model might solve this optimally, but definitely consumes much time. Hence the heuristic solution method is more preferable in finding solution for the problem considered.

The heuristic solution approach is based on the concept of location allocation routing (LAR) approach for solving the problem. The sequential heuristic method can be decomposed into three stages such as location allocation stage, routing improvement stage and supplier screening stage. The proposed heuristic method can be defined as Location–Routing–Screening heuristic (LRS). The first stage in constructing the initial solution appears to relax the problem considered from location allocation and vehicle routing problem to uncapacitated facility location problem. Given the solution at the first stage, the second stage deals with the improvement of solution in term of total system cost minimization. The last stage is to search whether any potential set of suppliers gives a better profit or not. Two criteria used are (1) profit without fixed cost and transportation cost and (2) maximum possible profit are proposed. The best solution for this stage will be repeated at the first and second stages for finding a best solution iteratively. The procedure will stop when there is no improvement for a best solution.

The result shows that the solution from heuristic solution method is very close to the mathematical model solution, but computational time is dramatically different. When compared the mathematical model solution with the computational result, it shows that heuristic method gives near optimal solution with faster solving time. With the same problem sizes and same parameters, the mathematical model consumes more solving time than the heuristic.

It is further investigated that the solving time of heuristic solution method is increased when there are increasing number of suppliers. However, the problem considered here is concerned with the problem of setting up of a raw material collection system which is a long term plan; the solving time could be allowed longer than daily operation**.**

As heuristic solution method is limited for solving large size problem, one suggestion that can be made is the application of clustering–based heuristic method for handling this problem. By partitioning supplier set into clusters, each cluster will be treated as one supplier with a large supply then the above problem can be solved by the proposed heuristic method.

CHAPTER V

CONCLUSION

In this chapter, the summarization of the problem studied and the findings related to the research are presented. The advantages and limitations of the research are also addressed. Lastly, the discussions of further study are suggested as well. The aim of this study is to develop location allocation and vehicle routing with step–price policy model. The problematic situation considers step–price environment, vehicle capacity and time duration constraints. The decisions on the model are location decision, supplier selection decision, allocation decision, and routing decision. The basic trade–off of the model is between the revenue from quantity collection and total system cost for the purpose of profit maximization. The heuristic solution approach includes three stages such as location allocation stage, routing improvement stage, and supplier screening stage which are proposed for solving the research problem.

5.1 Conclusion

In this study, chapter I starts with the research problem motivated by a real world situation. Problem description and scopes are explained in this chapter. Chapter II reviews the literature relevant to the research problem. In chapter III, mathematical model related to the research problem is formulated. The location allocation and vehicle routing problem with step–price policy is introduced in this chapter. Since the mathematical model is not practical in solving the problem within a reasonable time, the heuristic solution is proposed in chapter IV. The solution approach and computational results are presented in this chapter. Finally, the conclusion of the research is summarized in chapter V.

The aim of this study is to develop location allocation and vehicle routing with step–price policy model for setting up raw material collection system under the conditions of price–quantity dependence, capacity of vehicle, and collection time duration where the profit of the raw material collection system is maximized. This study analyzes three areas namely, the research problem, the mathematical model, and the solution method.

5.1.1 Research Problem

The research question of this research study addresses a real–life problem that can arise in the collection of raw material with the aim of profit maximization. Raw material collection system involves the collection of raw material from suppliers and then transportation to the factory through the collector system or intermediated channel. Nevertheless, because of the relatively larger demand than supply, most factories have incentive policies for their collectors so as to facilitate more supply quantities to the factories. According to the step–price policy, the purchasing price is fixed while the selling price per unit is varied; a collector has to collect more raw material quantity in order to receive a higher price. To operate raw material collection system with step–price policy, a collector has to collect more raw material quantity by expanding his collection area. The more suppliers the collector visits, the more income he receives; however, when a collector decides to visit more suppliers, traveling distance will be longer which will result in higher transportation cost. Therefore, it can be concluded that by adding one supplier to the system, the total collected quantity certainly increases; however, the profit value may increase or decrease depending on step–prices and set of selected suppliers. It has to be a trade–off between revenue receiving from total collected quantity and total cost both fixed cost and variable cost from expanded collection area if we want to get higher step–price level. As a result, the collector must decide where to collect raw material from and how many of the selected suppliers, how many collection stations, their locations, how many vehicles to be operated in the system, and the routes of each vehicle should take. A collector has to trade the inbound collection strategy off between the revenue from collected supply and the total system costs which include both fixed cost and variable cost. Therefore, the optimum raw material collection system appears to be a challenging task for the collector who has to face.

5.1.2 Mathematical Model

From the research question, a mathematical model that deals with the real–life situation of raw material collection is developed. An integrated model of location allocation and vehicle routing problem with step–price policy problem is provided. The location and the number of collection stations, a set of selected suppliers and the allocation of selected suppliers to collection stations, as well as a set of preliminary routes referring to the number of vehicles so as to maximize the profit of the system considered are investigated in this study. The determination of optimum raw material collection system is conducted under the consideration of price–quantity dependence, the capacity of vehicle, and the collection time duration.

The mathematical model is developed by location and routing models, some formulations are based on flow formulations (Laporte, 1988); furthermore, step function formulations expressed in (Tsai, 2007) are added. It is the extension of the basic location routing model of location allocation and vehicle routing problem in which the supplier selection is considered. The aim of the model is to optimize the raw material collection system in which the profit throughout the system is maximized.

The mathematical model is beneficially used for determining the optimal raw material collection system with a profit maximization criterion under the extension of step–price policy environment. However, the structure of this integrated model is complex with a majority of integer variables and constraints. The developed model might solve it optimally, but consumes much time even for small scale instances. Therefore, this research is proposed the heuristic solution method that can be solved larger instances to near optimality within the reasonable computational time.

5.1.3 Heuristic Solution Approach

The heuristic solution approach is based on the concept of location allocation routing (LAR) approach for solving the problem. The sequential heuristic method decomposes into three stages which are location allocation stage, routing improvement stage and supplier screening stage.

The location allocation stage deals with the construction of initial solution that appears to relax the problem considered from location allocation and vehicle routing problem to uncapacitated facility location problem. The aim at this stage is to find one potential set of selected suppliers that can give a maximum profit. The results from this part are the set of open collection stations, the set of selected suppliers, and the allocation of selected suppliers to open collection stations.

Given initial solution from location allocation stage, the vehicle routing problem is performed in routing improvement stage. At this stage, feasible routes are firstly constructed by applying the cheapest insertion method. Secondly, the constructed routes are improved by applying both between the routes improvement (1–1 exchange, 1–0 move), and within the route improvement (2–OPT). The objective at this stage is to improve the solution by minimizing total system cost. The result at this stage which is a best solution for the problem are the set of open collection stations, the set of selected suppliers, the allocation of selected suppliers to open collection stations and the set of routes presenting the assignment of selected suppliers to each route.

Due to abundant sets of selected suppliers, it is hence needed to investigate only sets of selected suppliers that have good potential of giving better profit. At supplier screening stage, two screening criteria namely; (1) profit without fixed cost and transportation cost and (2) maximum possible profit are proposed to discard non potential sets of suppliers. The screening with profit without fixed cost and transportation cost is firstly performed. The screening with maximum possible profit is secondly determined. The purpose of supplier screening stage is to find potential sets of suppliers with higher profit by comparison with best solution from routing improvement stage. The results from this part are the set of selected suppliers which have the potential of giving better profit.

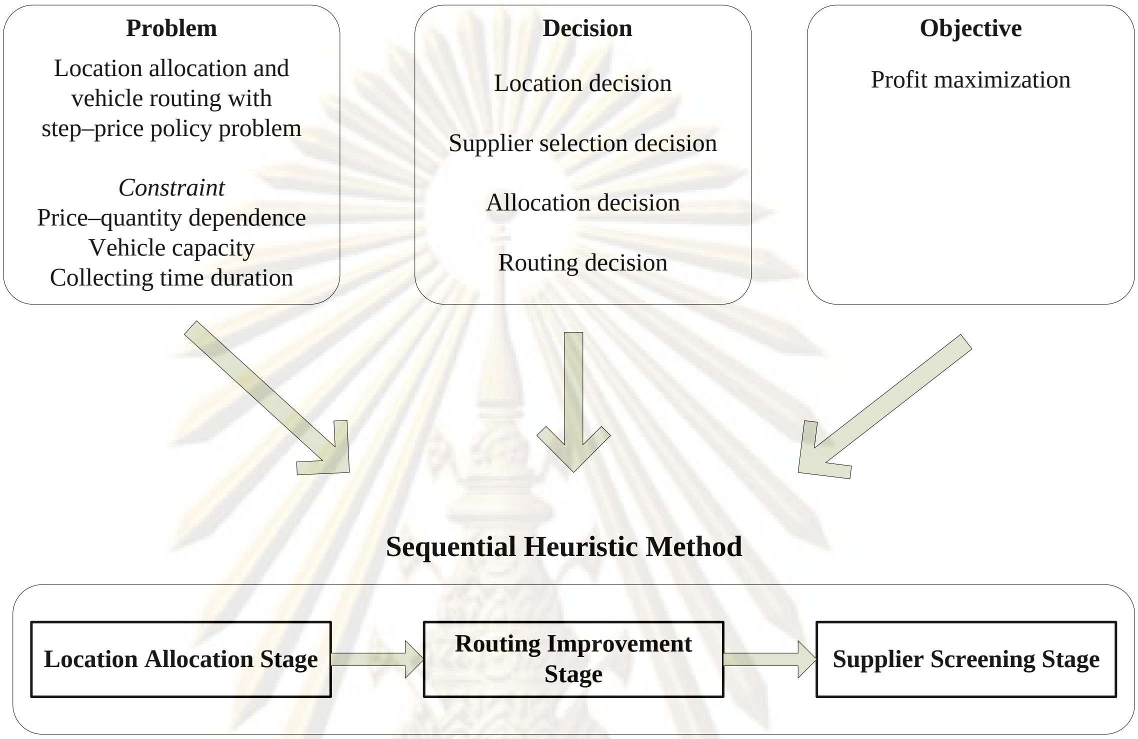


Figure 5.1 The research summary

5.2 Discussion

In this section, strengths and weaknesses of this research are discussed and summarized.

5.2.1 Strengths

The first strength is that the research concerns the integrated problem of location allocation and vehicle routing with step–price policy environment. Very few studies have investigated into this environment. This research introduces new perspective of the model that is the consideration of step–price circumstance. It seems that most of the research studies have attempted to reduce system cost; however, this research determines a diverse view point which will lead to optimize profit of the system.

The second strength of this study is the model formulation. The mathematical model is formulated representing all aspects of the problem considered; furthermore, an optimal solution can be found. As the mathematical model is complex and unpractical for application, the heuristic solution method dealing with all decisions involving the problem considered is proposed. By applying the proposed heuristic method, a good solution is performed within a fast solving time for small and medium size problem, but it is limited for solving large scale problem.

5.2.2 Weaknesses

One of the weaknesses of this study is that even some parameters have been set relying on the real world data, most of parameters still run with assumed data. This may not be comparable to the real situation. Thus, it needs to be further investigated into the varied of parameters and the calculation of data based on the real data in the collection system.

Although the heuristic solution method is performed better than the mathematical model solution, i.e. both solution quality and solving time; however, the heuristic solution method is limited for solving large scale problems. This is because the supplier screening stage works as an exhaustive search of which processed time is regarded as exponential growth. The more suppliers added; the higher solving time processed. To deal with this problem, clustering–based heuristic method is suggested. By partitioning supplier set into clusters, each cluster or each supplier group will be treated as one supplier with a large supply so that the above stated problem can be solved by the proposed heuristic method.

5.3 Future Work

This study has investigated into the real situation of raw material collection system in the natural rubber industry. The mathematical formulation and the heuristic solution method can be applied to other agricultural industries such as vegetable and fruit industries or other industries whose characteristics of the collection system or distribution system is as the same as the problem considered. The outcomes provide with compelling viewpoints for further research.

From research situation perspective, the research can be extended to more realistic situation. The vital and interesting extensions which should further be examined are:

- Though, the capacity of collection station considered in this research is unlimited, collection station capacity should be concerned. The economy of scales should be determined as different sizes cause an affect on the system cost.

- Dynamic planning on the raw material collection system is an important area of the location and routing problem. This is because of the uncertainty of some parameters such as supplier supply, and price.

- The variation of pricing is another crucial aspect that should be considered. The changing of price affects the decisions and the problem which will become stochastics type with risk in price change.

- Another interesting situation is inventory consideration. Due to step–price, to keep raw material for one or two days in order to aggregate more quantity, the situation needs to trade–off between inventory cost or quality cost and revenue.

- Multi–products and multi–quality levels will be other aspects under investigation.

From theoretical research perspective, there is more room for the development both mathematical model and solution approach. The interesting improvements which should further be investigated into are:

- The improvement of mathematical model is the basis of development such as flow formulation, step function, and subtour elimination.
- Input data should be elaborted. The study of effects on different real data should be further examined. Simulated data will be another interesting area.
- As the weakness of the heuristic solution method on supplier selection stage, a search method for finding set of selected suppliers should be improved. Both exact solution method such as Lagrangian algorithm and dual ascent algorithm, and heuristic solution method such as construcitve heuristic and metaheuristic should be applied to solve supplier selection decision.
- Other solution methods used for solving the location allocation problem and the vehicle routing problem can be applied.

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