# A MILK RUN TRANSPORTATION SYSTEM FOR A LARGE-SCALE NETWORK OF SUPPLIERS AND FACTORIES

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Engineering Management
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*ระบบการขนส่งแบบมิลค์รันสำหรับเครือข่ายขนาดใหญ่ของผู้จัดหาและโรงงาน*

นายณชดิช อุทยานัง



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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| Field of Study | Engineering Management |
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ณชดิช อุทยานัง : ระบบการขนส่งแบบมิลค์รันสำหรับเครือข่ายขนาดใหญ่ของผู้จัดหาและโรงงาน (A MILK RUN TRANSPORTATION SYSTEM FOR A LARGE-SCALE NETWORK OF SUPPLIERS AND FACTORIES) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. นระเกณฑ์ พุ่มชูศรี, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ผศ. ดร. มานพ เรี่ยวเดชะ, 173 หน้า.

*ปัจจุบันภาคอุตสาหกรรมในประเทศไทยได้มีการเติบโตอย่างรวดเร็ว ดังนั้นกลยุทธ์ต่างๆ อาทิเช่น การลดค่าใช้จ่ายจึงถูกนำมาใช้มากขึ้น โดยกิจกรรมที่โรงงานต่างๆนิยมลดค่าใช้จ่ายได้แก่การขนส่ง โรงงานที่มีขนาดใหญ่หรือมีอำนาจการต่อรองสูงได้ใช้ระบบการขนส่งแบบมิลค์รัน* (Milk Run System) *ในการจัดการการขนส่ง ในขณะที่โรงงานขนาดกลางและขนาดเล็กใช้ผู้รับจ้างขนส่งจากภายนอก* (Third party transportation provider) *ในการทำหน้าที่รวบรวมวัตถุดิบจากผู้จัดหามาสู่โรงงานแต่ละโรงงาน ดังนั้นงานวิจัยฉบับนี้จึงมีวัตถุประสงค์เพื่อพัฒนาระบบการทำงานของผู้รับจ้างขนส่งให้มีประสิทธิภาพยิ่งขึ้น โดยระบบการทำงานที่ได้ทำการพัฒนาประกอบด้วย ระบบการประมาณจำนวนรถคู่สัญญาที่ต้องใช้รายปี และระบบการจัดเส้นทางรถรายวัน*

*งานวิจัยฉบับนี้ได้ทำการออกแบบระบบการประมาณจำนวนรถคู่สัญญาที่ผู้รับจ้างขนส่งต้องใช้เพื่อรองรับความต้องการการขนส่งในแต่ละวันและมีค่าใช้จ่ายคงที่จากการให้บริการที่ต่ำ ซึ่งระบบการประมาณจำนวนรถคู่สัญญานั้นได้ประยุกต์ใช้หลักการของค่าคาดหวัง* (Expected Value) *ในการหาจำนวนรถที่เหมาะสม นอกจากนั้นงานวิจัยฉบับนี้ยังได้ออกแบบระบบการจัดเส้นทางรถในแต่ละวันเพื่อให้ตัวผู้รับจ้างขนส่งมีค่าใช้จ่ายการขนส่งที่ต่ำ โดยใช้จำนวนรถคู่สัญญาที่ได้มาจากระบบการประมาณจำนวนรถประกอบการพิจารณา ซึ่งระบบการจัดเส้นทางรถนั้นได้ประยุกต์หลักการคอลัมน์เจนเนอร์เรชั่น* (Column generation) *และวิธีการต่อขยายแบบเป็นชั้น* (Layer Shortest Path)

*จากผลการทดสอบระบบที่ได้นำเสนอในงานวิจัยฉบับนี้ พบว่าระบบสามารถช่วยลดค่าใช้จ่ายของผู้รับจ้างขนส่งจากภายนอกได้อย่างมีประสิทธิภาพ อีกทั้งยังแสดงให้เห็นถึงผลของการมองระบบเป็นระบบเดียว ดังนั้นผู้รับจ้างขนส่งภายนอกสามารถนำแนวคิดของงานวิจัยฉบับนี้ไปประยุกต์ใช้กับธุรกิจของตนเองได้ โดยอาจต้องมีการปรับระบบ* (Configuration) *ให้เหมาะสมกับสภาวการณ์ของแต่ละผู้รับจ้างเพื่อให้ระบบทำงานได้อย่างเต็มประสิทธิภาพ*




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| ภาควิชา | ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต | ลายมือชื่อนิสิต | ................................ |
| สาขาวิชา | การจัดการทางวิศวกรรม | ลายมือชื่อ อ.ที่ปรึกษาหลัก | ................................ |
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NACHADICH UDHAYANANG: A MILK RUN TRANSPORTATION SYSTEM FOR A LARGE-SCALE NETWORK OF SUPPLIERS AND FACTORIES. ADVISOR: ASST. PROF. NARAGAIN PHUMCHUSRI, Ph.D., CO-ADVISOR: ASST. PROF. MANOP REODECHA, Ph.D., 173 pp.

At present, Thailand's industrial segment is growing rapidly. Many strategies have been used by factories to gain the competitive advantage. One of the most commonly used strategies is cost reduction, and the major cost needed to be reduced is transportation cost. Hence, many big and high bargaining power factories have applied the Milk Run System to operate their transportations. On the other hand, small factories have hired a third party transportation provider to collect required materials for them. Thus this research developed the systems, the vehicle estimation system and the routes planning system, with an objective to help the provider handing over their services to the customers efficiently.

The vehicle estimation system aims to determine the number of needed contract vehicles beforehand for satisfying the transportation requirements of the upcoming year with low total service cost. The expected value concept is applied in the estimation system. Moreover, this research also develops the routes planning system to plan the routes for serving serve customers efficiently. The planning system applies the column generation and layer shortest path concepts to create routes.

From the result of the experiments, the proposed systems improve the provider’s transportation cost significantly, and also emphasize the effect of the united system consideration. As a result, the interested providers could apply the research ideas and concept together with some configurations to fit in their business.

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| Department: | Regional Centre for | Student's Signature | ..................................... |
| | Manufacturing Systems | Advisor's Signature | ..................................... |
| | Engineering | Co-Advisor's Signature | ..................................... |
| Field of Study: | Engineering Management | | |
| Academic Year: | 2015 | | |

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My Sincere Thanks,

Nachadich Udhayanang

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# Chapter 1

# Introduction

## 1.1. Background of the research

Nowadays, Thailand has been transitioned from an agricultural country to an industrial country. Many renowned companies are utilising Thailand as the main manufacturing location, especially automobile companies. Many Japanese automobile companies such as Toyota, Honda, Nissan or Isuzu are producing, manufacturing, and assembling cars and motorcycles in Thailand. In 2013, more than 1.5 million automobiles were produced in Thailand. When considering a supply chain of the automobile industry in Thailand, there are many stakeholders as shown in Figure 1 (Bryan Cave (Thailand) Co.). In addition, the National Science and Technology Development Agency also categorised the supply chain's stakeholders into 2 groups which are core activities providers: assemblers, 1st tier suppliers, 2nd tier suppliers, and nth tier suppliers, and supportive activities providers: upstream industries (iron, glass, plastic, and rubber providers), machines, tools and equipment providers, service industrial companies, and supportive policy groups.

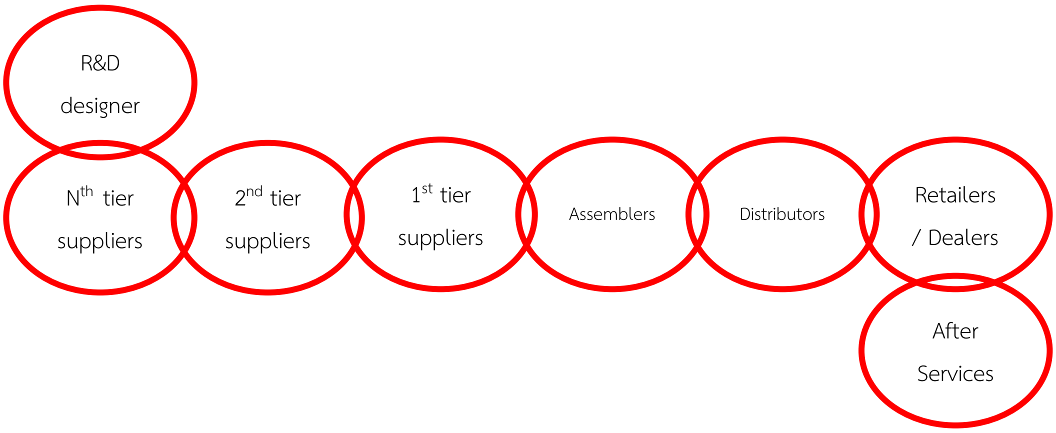


*Figure 1 stakeholders in an automobile industry's supply chain.*

Recently, those Japanese automobile companies are not competing with each other individually anymore. They concern about competing their supply chain with other supply chains. Thus, managing the supply chain effectively could lead to the competitive advantages of companies. In the automobile's supply chain, there are several involved companies, from big famous assemblers (e.g., Toyota) to small SMEs which produce small parts (e.g., nuts, bolts, and gaskets). To strengthen the supply chain, everybody in the supply chain must have commitments and consider themselves as parts of the chain.

There are many strategies that are used to increase the efficiency of a supply chain such as outsourcings, partnerships, or cost controlling. According to Lieb and Bentz, an effective approach used by many companies in USA was hiring third party logistics providers to operate some non-core activities. They conducted surveys asking about the use of third party logistics providers in American top companies annually. They found that the top three services of the third party logistics providers were direct transportation services, customs brokerage services, and freight payment services (Lieb and Bentz, 2005).

Refer to Goh and Pinaikul, the average logistics cost in Thailand is less than in USA due to the long term investments in high technology systems of US companies. They also stated that most Thai companies spend more than 30% of their logistics cost on transportations. They mentioned that about 70% of the firms was using leased vehicles or third party transportation providers (Goh and Pinaikul, 1998). As a result, reducing the transportation cost could increase competitive advantages of a company.

Recently, Toyota is using The Milk Run System to transport raw materials from suppliers. Because Toyota has large number of suppliers, it is difficult to manage the flow of materials at Toyota's places (Nemoto et al., 2010). The key success factors in The Milk Run System of Toyota are mentioned by Gosol (Desilatham, 2011), which are staffs, packages, technology support systems, factory traffic policies, and size and weight of delivered materials. Seeing Toyota as an example, some 1st tier and 2nd tier suppliers tried to establish The Milk Run System in their business processes. Unfortunately, a few of them succeeded due to lacking of power, authority, and knowledge. As a result, The Milk Run System is only an ideal system for many companies.

For the lower tier suppliers' transportation system, i.e., 2nd, 3rd tier, 4th tier, and nth tier, they use their suppliers' vehicles to transport materials from their suppliers to them. Letting the suppliers transport materials to the factories by themselves could have some drawbacks as follows.

1. The factories could not control the arrival time of materials.

2. Because of the uncontrollable arrival time, the factories may end up in storing too many materials in order to produce on schedule.

3. There is a risk of materials shortage.

4. The factories may encounter traffic problems, if too many suppliers arrive at the same time.

5. Some suppliers may require full-truck-load requirements in order to make worthwhile transportation.

From the drawbacks, some factories hire a third party transportation provider to gather materials for them. In Thailand, there are few transportation providers offering this kind of service, i.e., pickup and delivery materials services. This service can be called The Milk Run Service. Recently, those milk run service providers operate the milk run system for a factory individually. For example, if a milk run service provider has 3 customers, the provider will establish the transportation routes for each customer separately.

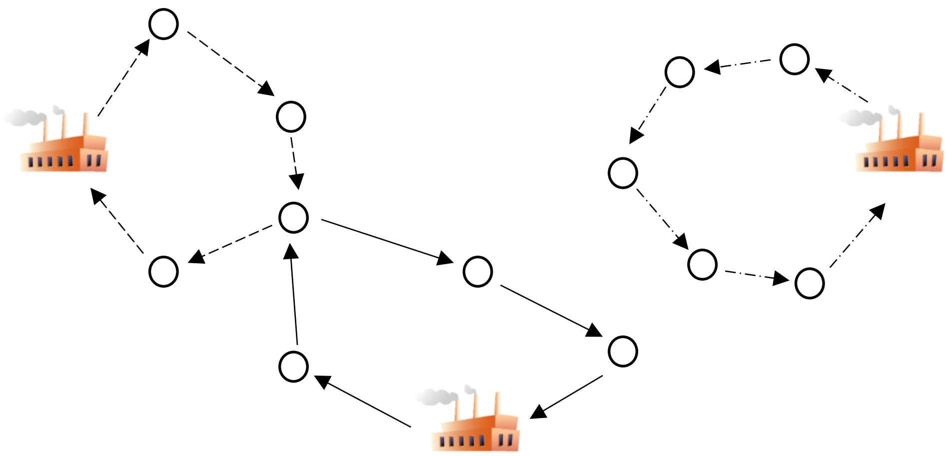

*Figure 2 an example of the milk run system provided by a third party transportation provider.*

In Figure 2, a third party transportation provider has 3 customers represented as factory pictures. Each customer has their own suppliers represented as circles. Some customers may have shared suppliers and some may not. From the figure, various drawbacks of considering each customer separately can be identified as follows.

1. The number of vehicles that are used in the whole system is high and inefficient.

2. The routes in the system may overlap with other routes because of the separated system.

3. The utilisation of each vehicle is literally low, because each vehicle is planned to serve only one customer.

Also, there are 2 types of the third party transportation providers, the companies that own vehicles and the companies that do not own vehicles. The first type uses their own vehicles to provide services, while the other type makes contracts with freelance vehicle owners. Using owned vehicles is more flexible and controllable than using freelance vehicles, but the providers must bear with many fixed costs such as maintenance cost, depreciation cost, and insurance cost. On the other hand, using freelance vehicles will eliminate those costs, but the providers must pay vehicles' owners a service cost. Some providers may have both owned vehicles and contract vehicles in the system to optimise their costs.

As a result, this research will propose a logistic management system for a third party transportation provider to operate The Milk Run System for customers. The system will determine the number of vehicles that are needed to serve the customers and generate routes for transporting materials from the customers' suppliers to the customers.

## 1.2. Statement of problem

This research is designed for third party transportation providers which offer The Milk Run Service to customers. The customers, in this research, are companies which are parts of the automobile supply chains in Thailand. Because this research is for SMEs providers, the providers are assumed to use only freelance vehicles which make them free from some ownership costs.

In the research, there are 3 stakeholders which are 1.customers (Companies in automobile supply chains, especially upper tier suppliers), 2.customers' suppliers, 3.a third party transportation provider. Each of the customers in this research has many suppliers, and those suppliers may be shared suppliers, i.e., the suppliers which supply materials for more than one customer. In addition, there is only one provider in the system, and the provider has tasks to deliver materials from customers' suppliers to customers. Customers must inform the provider about their suppliers' locations.

Every stakeholder, except the provider, must be either the suppliers or the customers (cannot be both). Also, there is only one delivery direction in the system which means the customers are always be the materials receivers, while the suppliers are the givers.

Because some big assemblers, e.g., Toyota, have a fixed production schedule for the whole year, called a yearly plan, most of the upstream companies could approximately acknowledge upcoming requirements of the year. This plan flows up the supply chain, and each of assemblers' upstream suppliers (customers in our system) will notice their approximate requirements and briefly plan their capacity afterwards. The actual requirements sent from assemblers will come in a short notice, i.e., from one day to a few months depending on the customers' products, and the customers must operate their production lines effectively to meet those requirements. In conclusion, the customers receive 2 plans which are a yearly plan and an exact plan. The customers usually use the yearly plan to prepare resources used in that year, while the exact plan is used for planning actual production schedules. In the system, we assume that the customers have both plans and are willing to share with the provider. The yearly plan informs about number of days that a customer will send a materials requirement to each of their suppliers in each month and the estimated number of needed materials from each supplier, while the exact plan informs about materials used in a customer's production lines in a particular day; materials suppliers, number of required materials, and deliveries' time window of materials.

Since the provider's vehicles are freelances, the provider must make a contract with them. In this context, the provider is using yearly contract. The provider must calculate number of needed vehicles in a particular year carefully, because if the number of contract vehicles are too small, the provider will hire outsourcing vehicles which are more expensive to operate additional materials transportation requirements. Moreover, there is a minimum monthly delivery trip in the contract which means if the provider uses contract vehicles lower than the minimum trip, the provider must pay guarantee cost to the vehicles' owners. In conclusion, the provider has to determine number of vehicles that are going to be used as a contract vehicles at the beginning of a particular year. Each of vehicles has limited daily working hour and capacity, and must respect “The Land Traffic Act of Thailand” in term of speed, driving time, etc.

After the number of contract vehicles is determined, daily transportation service will be operated. In the pickup and delivery operation, because vehicles do not belong to any particular location, it can pick up and deliver materials in any order as long as vehicles’ capacity and delivery time constraints are not violated. Also, vehicles neither begin at the provider location nor return, because they are not owned by the provider. The vehicles will begin the operation at one of the suppliers’ locations, and the last visited location must be one of the customers’ locations.

The transportation cost in this research consists of the service cost (fixed cost) and distance cost (variable cost). The fixed cost is a cost per trip of each vehicle, and the fixed cost of a contract vehicle is lower than an outsourcing vehicle. In contrast, the variable cost depends on the travelled distance of a vehicle, thus both contract and outsourcing vehicles’ variable cost are calculated with the same rate. In addition, a contract vehicle also has the guarantee cost, paid when the use of a contract vehicle is less than minimum trip. Vehicle service cost is the total service cost of needed vehicles, service cost of entire vehicles in the system.

As a result, this research is separated into 2 systems which are the vehicle estimation system and the routes planning system. The vehicle estimation system will determine the number of contract vehicles for a particular year by using the yearly plan. The routes planning system will design routes to satisfy customers’ materials requirements in a particular day by using the exact plan.

Illustrations of the system are shown as in Figures 3 - 7.

1. There are 3 stakeholders in the system.

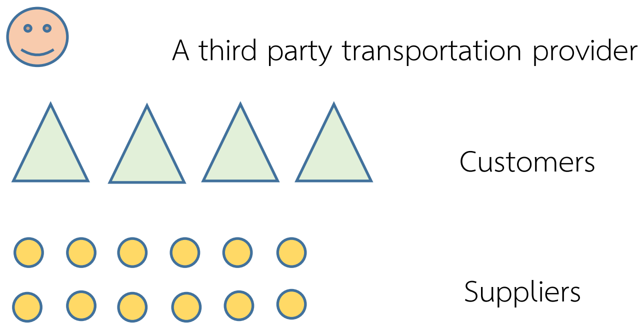


*Figure 3 stakeholders of the system.*

2. At the beginning of each particular year, customers send their yearly plans to the provider.

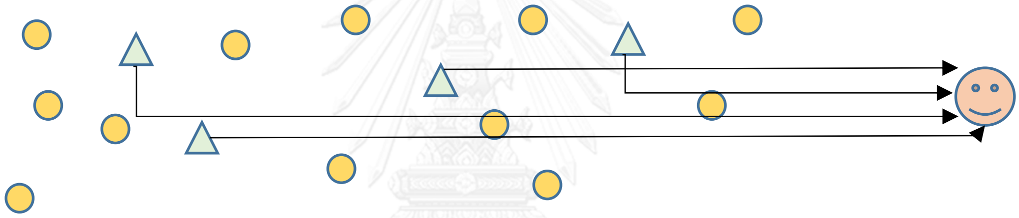

*Figure 4 customers send yearly plans to the provider.*

3. The provider uses the yearly plan along with other suppliers' information, e.g., suppliers' location, to determine the number of contract vehicles.

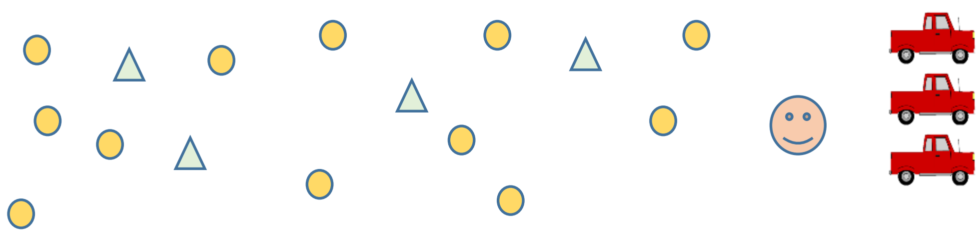

*Figure 5 the provider determines the number of contract vehicles.*

4. In each particular day, the customers inform their exact plans, materials transportation requirements, to the provider.

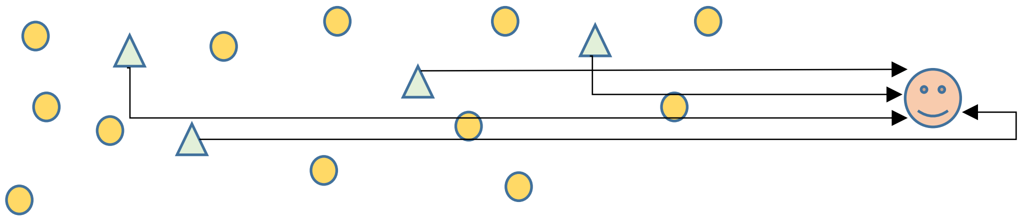

*Figure 6 customers inform their materials transportation requirements to the provider.*

5. The provider design routes for each vehicle.

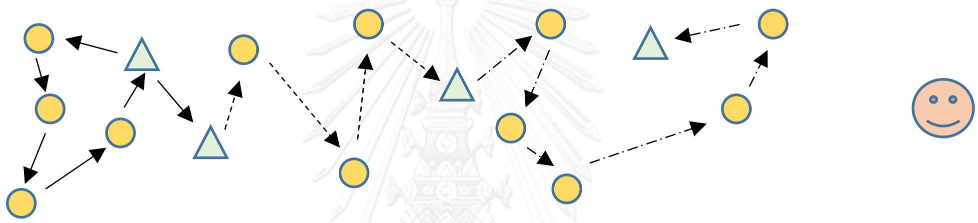

*Figure 7 the provider constructs the route for each vehicle.*

## 1.3. Assumptions

### Main assumptions

1. Every vehicle in the systems is homogeneous.

2. Every predicted and actual materials requirement from the customers' yearly and exact plans is less than truckload.

3. The capacity constraint is considered in only 2 dimensions which are volume and weight, the shape of materials is not considered.

4. Every material can be delivered together, no materials restriction.

5. Every contract vehicle has the same service cost per day, similarly, every outsourcing vehicle also has the same service cost per day.

6. Distances between locations are represented as displacement.

7. Travelled times between locations have linear relationship with distances.

8. Every vehicle is driven at the same and constant speed.

**The vehicle estimation system assumptions**

1. The number of contract vehicles determined in this system can be used for the whole upcoming year.

2. The vehicle service cost in the system consists of 2 components which are service cost per day of a contract vehicle and service cost per day of an outsourcing vehicle.

3. The number of working days of customers in each month is the same.

4. Every customer has the same working day.

5. The guarantee cost is specified in the contract. The cost comes in the monthly form, e.g., if a vehicle usage is lower than 15 days in a particular month, the provider needs to pay 1000 baht per day for the opportunity cost (if a vehicle operate 12 days, the provider needs to pay guarantee cost for 3 days).

**The routes planning system assumptions**

1. The transportation cost in the system consists of at least 2 components which are service cost and distance cost. The guarantee cost will be paid when the number of contract vehicles is too high.

2. The rate of the distance cost of contract vehicles is the same as outsourcing vehicles

3. The loading/unloading time at any location is the same.

Every vehicle in the system has the same working hour under the regulations of The Labour Relation Act of Thailand.

4. The number of vehicles in the system is unlimited. But when the number of contract vehicles is not sufficient, the outsourcing vehicles will be hired

5. The considered routes do not include a journey to/from the vehicles owners' places. The considered routes start at one of suppliers' locations and finish at one of customers' locations. It is assumed that the vehicles must be ready to operate at a starting location at the beginning of a working day.

6. The finishing locations of the previous days are not dependent with today starting locations.

## 1.4. Objective of the research

To develop an efficient heuristic for a third party transportation provider's operation. The operation consists of 2 systems which are the vehicle estimation system and the routes planning system. The objective of each system is as follows.

1. The vehicle estimation system has an objective to minimise the vehicle service cost by estimating the proper number of contract vehicles from given customers' yearly plans.

2. The routes planning system has an objective to minimise the transportation cost in a particular day by designing efficient routes for serving customers' materials transportation requirements.



## 1.5. Scopes of the research

1. The systems in this research are the vehicle estimation system and the routes planning system. The contract management procedure and outsourcing negotiation policies are not involved in the systems.

2. The considered costs in the systems are service cost (fixed), distance cost (variable) and guarantee cost. Contract vehicles' fixed cost is lower than outsourcing vehicles. Meanwhile, the variable cost is calculated from distance of designed routes for both contract and outsourcing vehicles (Calculate by the same rate).

3. Customers and suppliers in the system are static. The system will not consider any emerging supplier or customer.

4. There are 2 types of constraints in the system which are capacity constraints in terms of weight and volume, and time constraints including working hour and deliveries' time window.

5. The systems consist of only 1 provider.

6. Elements in designed routes must be paths between suppliers and suppliers, suppliers and customers, or customers and customers.

7. Result in this research bases on the heuristic procedure which may not guarantee the optimal solution because of the computational time, and computer's memory.

8. This research consider only the inbound materials transportation for customers.

## 1.6. Decision Variables

The research is separated into 2 systems; the vehicle estimation and the routes planning. Both systems aim to improve efficiency of the provider's services in terms of cost. Each system has its own objective and decision variable as shown in Table 1.

*Table 1 objective and decision variable of the systems*

| System | Objective | Decision Variable |
|---|---|---|
| Vehicle estimation system | To minimise vehicle service cost of the system by estimating the proper number of contract vehicles from given customers' yearly plan. | Number of contract vehicles that the provider should prepare to operate the routes planning system. |
| Routes planning system | To minimise the transportation cost in a particular day by designing efficient routes for serving customers' materials transportation requirements. | Planned route for each vehicle. |

## 1.7. Inputs

Both systems require several inputs for operating effectively. Some inputs are used in both system, while some are used in one of the systems. Also, the result from the vehicle estimation system is used as an input for the routes planning system. The inputs are shown in Table 2.

*Table 2 inputs of the systems*

| Vehicle estimation system inputs | Routes planning inputs |
|---|---|
| Suppliers and customers' location | Suppliers and customers' location |
| Estimated number of required materials from customers' yearly plan | Number of required materials from customers' exact plan |
| Number of days that a customer will sent a materials requirement to each of their suppliers in each month | Delivery's time window of each materials transportation requirement |
| Customers' number of working days | Number of contract vehicles (Result from the vehicle estimation system) |
| Capacity of vehicles in terms of weight | Capacity of vehicles in terms of weight |
| Capacity of vehicles in terms of volume | Capacity of vehicles in terms of volume |
| Service cost (fixed cost) per day of each contract vehicle | Service cost (fixed cost) per day of each contract vehicle |
| Service cost (fixed cost) per day of each outsourcing vehicle | Service cost (fixed cost) per day of each outsourcing vehicle |
| Average speed of vehicles | Average speed of vehicles |
| Working hours per day of vehicles | Working hours per day of vehicles |
| | Rate of distance cost (variable cost) in unit of Baht per kilometre |
| | Guarantee cost per day of contract vehicles |
| | Distance between locations |
| | Time between locations |

## 1.8. Constraints

Constraints in both system are limited to vehicle capacity constraints in terms of weight and volume, and vehicles' working hour (driver) constraint. In addition, the routes planning system also has the materials deliveries' time window constraint. Table 3 shows the constraints of both system.

*Table 3 constraints of the system*

| **Vehicle estimation system constraints** | **Routes planning system Constraints** |
|---|---|
| Capacity constraint in terms of weight | Capacity constraint in terms of weight |
| Capacity constraint in terms of volume | Capacity constraint in terms of volume |
| Time constraint in terms of vehicles' working hour | Time constraint in terms of vehicles' working hour |
| | Time constraint in terms of deliveries' time window |



## 1.9. Expected results

1. A method to estimate number of contract vehicles using customers' yearly plan.

2. A heuristic to construct efficient routes in terms of transportation cost.

## 1.10. Expected benefits

From customers' point of view:

1. The controllable materials' arrival time.

2. The reserved materials in warehouses could be reduced.

3. The risk of materials shortage could be relieved.

4. The traffic situation in the customers' place is better.

5. The customers could spend their resources on their core activities.

6. The transportation cost of the customers could be decreased.

From the third party transportation provider's point of view:

1. The total number of vehicles could be decreased.

2. The utilisation of vehicles could be increased.

3. The transportation cost, i.e., service cost and distance cost, could be reduced significantly.

## 1.11. Research Methodology

This section is going to show steps of this research from the beginning to the final. Each step has its own objective and outcomes. Tables 4 - 7 exhibit our research methodology.

*Table 4 research methodology (1)*

| Research Process | Methodology | Expected outcomes |
|---|---|---|
| 1. Collect basic information of an automobile supply chain in Thailand | We interviewed people who work in factories in an automobile supply chain about their company, opinion about the supply chains, and problems that they have encountered with. | ● Thailand automobile supply chain framework.<br>● List and relationship of stakeholders |
| 2. Analyse the supply chain | We determined areas in the supply chains that could be improved, and analyse the improvements whether it will impact supply chain efficiency or not. | ● List of areas that could be improved.<br>● Assessment summary |
| 3. Collect important information in the area of transportation in an automobile supply chain | We observed and studied the transportation procedure of stakeholders in the supply chain. | ● Thailand automobile transportation's framework.<br>● Key constraints and stakeholders in transportation area. |

*Table 5 research methodology (2)*

| Research Process | Description | Expected outcomes |
|---|---|---|
| 4. Define a problem | We analysed all of the observed information and identified a problem that we found in the transportation procedure. | ● Statement of problem. |
| 5. Set the direction of the research | We set the objective to clarify our research direction and identified reasonable scopes and assumptions. | ● Research's objective<br>● Research's scopes<br>● Research's assumptions |
| 6. Explore literatures relating to the research | We reviewed researches in several areas to collect as much information as we could. The reviewed fields are listed as follows:<br>- Supply chain strategy<br>- Fleet sizing problem<br>- Vehicle routing problem<br>- Pickup and delivery problem<br>- Fleet sizing and mixed vehicle routing problem | ● List of concepts that are appropriate to apply to our research. |

*Table 6 research methodology (3)*

| Research Process | Description | Expected outcomes |
|---|---|---|
| 7. Construct the conceptual design of our research | We decided to use the heuristic method to solve our research problem. In order to start constructing heuristics, concepts of heuristic must be designed. | ● Framework of our heuristics in a concept flow chart. |
| 8. Construct the detailed design of our research | We thoroughly constructed our heuristic following the designed concepts. | ● Complete heuristics for both systems. |
| 9. Assess the proposed systems computationally | We developed experiments in order to evaluate the performance of our heuristics. | ● Factors affecting our heuristics.<br>● Heuristics behaviour. |

*Table 7 research methodology (4)*

| Research Process | Description | Expected outcomes |
|---|---|---|
| 10. Assess the implementation of the proposed systems | We conducted the interview with some experts of the related field to validate and evaluate the application of our systems. | ● Comments and opinions of our systems from the experts. |
| 11. Conclude the research | We write the research report including 5 chapters which are introduction, related theories and literatures review, systems methodology, systems measurements, and conclusion. | ● Printed research report. |

# Chapter 2

# Related theories and Literatures review

This chapter discusses about the related theories and literatures. The objective of this chapter is to explore and review concepts and ideas used by other researchers to solve their problems which are analogous to our research problem. We aim to apply some reviewed literatures' concept to our research. This chapter consists of 2 parts which are the related theories, and the literatures review parts. The related theories part will describe and illustrate the theories that are going to be used in this research, and the literatures review part will explore and discuss the related researches extensively.

## 2.1. Related theories

This section are divided into 3 sub-sections which are the column generation algorithm, LSP heuristic, and tabu search concept.



### 2.1.1. The column generation algorithm

This sub-section begins with the introduction of the set covering problem and description of the set covering problem's model which is going to be used in the column generation algorithm. Next, the flow chart exhibiting the column generation core processes is shown, followed by the thorough explanation of each core process (An example and illustration will be given in every process).

To understand the concept of column generation algorithm successfully, the set covering problem will be introduced.

The set covering problem has an objective to minimise the number of elements in a set of universe's subsets that covers every element in the universe.

Example 1:

Let the universe has elements as follows.

U = {1, 2, 3, 4, 5}

There are several sets of universe's subsets covering every element in the universe.

Such as

{{1, 2}, {1, 2, 3}, {4, 5}} *Set of Universe's Subsets 1*

Or

{{1, 2, 3}, {4, 5}} *Set of Universe's Subsets 2*

The problem aims to identify which set of universe's subsets covers every element in the universe and has the lowest number of elements inside it. In Example 1, Set of Universe's Subsets 1 has 3 elements, while Set of Universe's Subset 2 has 2 elements. So, the answer for the example is {{1, 2, 3, 4, 5}} which has only 1 element.

The model of the set covering problem is shown in Model 1.

Model 1

Let

U be the universe

S be the set of universe's subsets

$x_s$ be the decision variable of an universe's subset s in set S

$a_{rs}$ be the parameter indicating whether element r including in subset s or not

$$a_{rs} = \begin{cases} 1 & \text{if element r including in subset s} \\ 0 & \text{otherwise} \end{cases}$$

Objective:

To minimise $\sum_{s \in S} x_s$ *(1.1)*

Subject to:

$$\sum_{s \in S} a_{rs}x_s = 1 \quad \text{for all r in U} \qquad (1.2)$$

$$x_s \in \{0, 1\} \quad \text{for all s in S} \qquad (1.3)$$

Equation *(1.2)* indicates that, in the final solution (set of universe's subsets), every element must be contained in exactly 1 subset, and equation *(1.3)* considers the selection of universe's subsets to be either 1 (selected), or 0 (not selected).

The set covering problem's model is the main model used in the column generation algorithm. There is also a relaxation model for the set covering problem's model. The relaxation model is almost similar to the original model, only *(1.3)* is different. In the original model, *(1.3)* indicates that the value of $x_s$ must be either 0 or 1, but in the relaxation model the value of $x_s$ can be any real number between 0 and 1 as shown in Model 2.

Model 2

Let

U be the universe

S be the set of universe's subsets

$x_s$ be the decision variable of an universe's subset s in set S

$a_{rs}$ be the parameter indicating whether element r including in subset s or not

$$a_{rs} = \begin{cases} 1 & \text{if element r including in subset s} \\ 0 & \text{otherwise} \end{cases}$$

Objective:

$$\text{To minimise} \quad \sum_{s \in S} x_s \qquad (2.1)$$

Subject to:

$$\sum_{s \in S} a_{rs} x_s = 1 \quad \text{for all r in U} \qquad (2.2)$$

$$x_s \in [0, 1] \quad \text{for all s in S} \qquad (2.3)$$

The column generation algorithm is the approach used for solving complex problems, such as NP hard problems, by generating feasible columns (solutions). The algorithm contains a sub-problem, pricing problem, inside it. The pricing problem is a knapsack problem used for generating new columns (Most of methods used for solving the pricing problem are heuristics). The algorithm begins with the initial process constructing initial columns. The initial columns will be solved in the set covering problem's relaxation model (See Model 2) to obtain dual variables (See Definition 1). Next, the pricing problem process will be executed. The algorithm will generate new feasible columns by solving the pricing problem using reduced costs (See Definition 2). After that, in the dual variables obtaining process, every generated columns, including initial columns, will be solved in the set covering problem's relaxation model to obtain new dual variables. Then, the algorithm will repeat the pricing problem process iteratively until the stopping criteria are met. Lastly, the final solving process will be operated by using every generated column to solve the set covering problem's original model one last time. The solution from the solved model will be the final solution of the algorithm. Figure 8 shows the flow chart of the column generation algorithm's core processes.

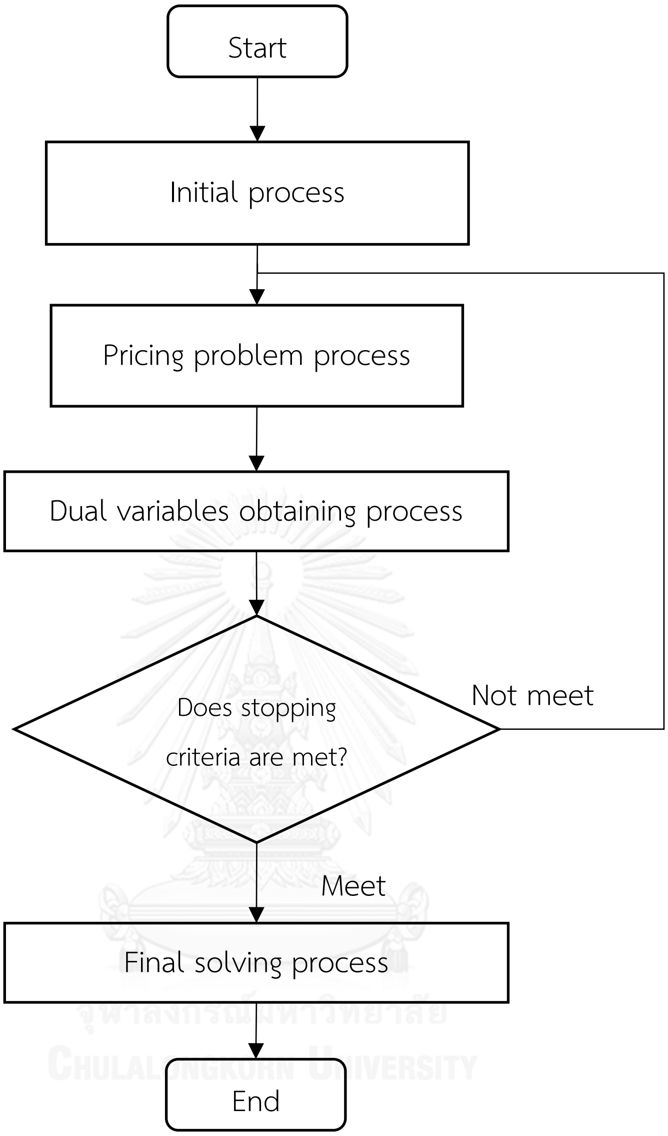


*Figure 8 core processes flow chart of the column generation algorithm*

The column generation algorithm will be explained thoroughly by using <u>Example 2</u> as a demonstrator.

Example 2:

A problem asks to identify a set of universe's subsets containing every universe's element, and has the lowest number of elements inside it by using the column generation algorithm.

Let U be the universe U = {1, 2, 3, 4, 5}

**The initial process**

First of all, the initial process will be executed. The initial process aims to generate initial columns for obtaining the dual variables (See Definition 1). The process consists of 3 steps listed as follows.

1. Generate initial columns.
2. Solve the set covering problem's model using the initial columns.
3. Obtain the dual variables.

*Generate initial columns*

Normally, the initial columns are simple solutions which are easy to be generated. In Example 2, we use the one element subsets as the initial columns. Note that, the every universe's element must be included in the initial columns.

Initial Columns: {1}, {2}, {3}, {4}, {5}

Let {1} be Initial Column Number 1, {2} be Initial Column Number 2, and so on.

*Solve the set covering problem's model using the initial columns*

This step solves the set covering problem's relaxation model (See Model 2) using the initial columns from the previous step. In Example 2, the substituted set covering problem's relaxation model is shown in Example Model 2.1

<u>Example Model 2.1</u>

Let

U be the universe

S be the set of generated columns

$x_s$ be the decision variable of an universe's subset s in set S

$a_{rs}$ be the parameter indicating whether element r including in subset s or not

$$a_{rs} = \begin{cases} 1 & \text{if element r including in subset s} \\ 0 & \text{otherwise} \end{cases}$$

Objective:

To minimise $\sum_{s \in S} x_s$ *(2.1.1)*

Subject to:

$(1)X_1 + (0)X_2 + (0)X_3 + (0)X_4 + (0)X_5 = 1$ *(2.1.2)*

$(0)X_1 + (1)X_2 + (0)X_3 + (0)X_4 + (0)X_5 = 1$ *(2.1.3)*

$(0)X_1 + (0)X_2 + (1)X_3 + (0)X_4 + (0)X_5 = 1$ *(2.1.4)*

$(0)X_1 + (0)X_2 + (0)X_3 + (1)X_4 + (0)X_5 = 1$ *(2.1.5)*

$(0)X_1 + (0)X_2 + (0)X_3 + (0)X_4 + (1)X_5 = 1$ *(2.1.6)*

⇨ 5 constraints from 5 elements in the universe

⇧ 5 columns from 5 initial columns in S

$x_s \in [0,1]$ for all s in S *(2.1.7)*

The value of $a_{11}$ is 1, because Initial Column Number 1 has element "1" in it. In contrast, values of $a_{21}$, $a_{31}$, $a_{41}$, and $a_{51}$ are 0, because Initial Column Number 1 does not have elements "2", "3", "4", or "5" in it. The other parameters' values are determined by the same concept.

This relaxation model, Example Model 2.1, can be solved by general solvers such as Excel Solver, or CPLEX.

*Obtain the dual variables*

Definition 1: The dual variable, sometimes called the "shadow price", is the value indicating the change in the objective value, if the right hand side of the constraint representing that element is increased by 1. Each element has its own dual variable. Normally, the dual variables are identified automatically by solvers after a model has been solved.

In Example 2, after Example Model 2.1 has been solved, 5 dual variables are identified. We assume $d_1$, $d_2$, $d_3$, $d_4$, and $d_5$ be the dual variables of elements "1", "2", "3", "4", "5", and "6" consecutively.

**The pricing problem process**

The pricing problem is a knapsack problem inside the column generation algorithm. The sub-problem aims to generate some feasible columns that tend to improve the objective value using obtained dual variables. To clarify which columns tend to improve the objective value, the reduced cost is introduced. The calculation of reduced cost is shown in Example 3.

Definition 2: The reduced cost is defined as the changing of the objective value from the selection of a column in the objective solution. Each column has its own reduced cost calculated from the dual variables.

Example 3:

Let

A be a generated column

$d_r$ be the dual variable of element r

$$\text{Reduced cost} = 1 - \sum_{r \in A} d_r \qquad (3.1)$$

From the definition of the reduced cost of a column, the smaller of the reduced cost means the lower objective value (if that column is selected in the objective solution). So, for a minimisation problem, negative reduced cost columns are favourable in the pricing problem process. As a result, the key point of this step is to design an effective procedure to generate negative reduced cost columns for minimisation problems, and positive reduced cost columns for maximisation problems. To generate columns that have negative reduced cost, many methods have been proposed. Most of the methods are based on a heuristic procedure. A heuristic procedure is a method used for solving complex problems. The procedure aims to find the acceptable solution, instead of the optimal solution, because identifying the optimal solution may take drastically long computational time.

In Example 2, we assume that we use a heuristic to solve pricing problem, and the heuristic generates these subsets (columns): {1, 3}, {1, 5}, {3, 4}, {4, 5}, and {1, 3, 4}. To find which columns are favourable, the reduced costs must be calculated using equation *(3.1)*.

Reduced cost of {1, 3} = 1 – ($d_1$ + $d_3$)

Reduced cost of {1, 5} = 1 – ($d_1$ + $d_5$)

Reduced cost of {3, 4} = 1 – ($d_3$ + $d_4$)

Reduced cost of {4, 5} = 1 – ($d_4$ + $d_5$)

Reduced cost of {1, 3, 4} = 1 – ($d_1$ + $d_3$ + $d_4$)

Next, we assume that the reduced costs of {1, 3} and {1, 4} are positive, while the others are negative. As a result, only 3 columns are added to the set of generated columns (S). Set of generated columns now consists 8 columns (5 initial columns, and 3 from solving the pricing problem) - {1}, {2}, {3}, {4}, {5}, {3, 4}, {4, 5}, {1, 3, 4}.

**The dual variables obtaining process**

This process is executed after the set of generated columns has been updated in the previous process. The process aims to obtain new dual variables for every element by solving the set covering problem's relaxation formulation (See Model 2).

In Example 2, the substituted set covering problem's relaxation model is shown in Example Model 2.2

Example Model 2.2

Let

U be the universe

S be the set of generated columns

$x_s$ be the decision variable of an universe's subset s in set S

$a_{rs}$ be the parameter indicating whether element r including in subset s or not

$$a_{rs} = \begin{cases} 1 & \text{if element r including in subset s} \\ 0 & \text{otherwise} \end{cases}$$

Objective:

To minimise $$\sum_{s \in S} x_s \qquad (2.2.1)$$

Subject to:

$$(1)X_1 + (0)X_2 + (0)X_3 + (0)X_4 + (0)X_5 + (0)X_6 + (0)X_7 + (1)X_8 = 1 \quad (2.2.2)$$

$$(0)X_1 + (1)X_2 + (0)X_3 + (0)X_4 + (0)X_5 + (0)X_6 + (0)X_7 + (0)X_8 = 1 \quad (2.2.3)$$

$$(0)X_1 + (0)X_2 + (1)X_3 + (0)X_4 + (0)X_5 + (1)X_6 + (0)X_7 + (1)X_8 = 1 \quad (2.2.4)$$

$$(0)X_1 + (0)X_2 + (0)X_3 + (1)X_4 + (0)X_5 + (1)X_6 + (1)X_7 + (1)X_8 = 1 \quad (2.2.5)$$

$$(0)X_1 + (0)X_2 + (0)X_3 + (0)X_4 + (1)X_5 + (0)X_6 + (1)X_7 + (0)X_8 = 1 \quad (2.2.6)$$

| ⇧ | ⇧ | ⇧ | ⇧ | ⇧ | ⇧ | ⇧ | ⇧ |
|---|---|---|---|---|---|---|---|
| {1} | {2} | {3} | {4} | {5} | {3, 4} | {4, 5} | {1, 3, 4} |

$$x_s \in [0, 1] \quad \text{for all s in S} \quad (2.2.7)$$

After the model has been solved, new dual variables will be determined. As always, there are only 5 dual variables, but these variables' value is not the same as solving from the initial process.

**Check for stopping criteria**

The stopping criteria are used for terminating the algorithm's reiteration processes, without the stopping criteria the algorithm will iterate infinitely. If the stopping criteria are not met, the algorithm repeat back to the pricing problem process, otherwise the final solving process will be operated.

In Example 2, we assume a stopping criterion is met when one of the generated columns consists of every element. So that, the stopping criterion is met when column of {1, 2, 3, 4, 5} is generated.

**The final solving process**

This process solves the set covering problem's model using the current set of generated columns to determine the final solution of a problem. The chosen columns in the solution are the final answer for the problem.

The column generation algorithm helps to find the favourable columns, instead of randomly search from scratch. The efficiency of the column generation algorithm depends on the procedure used for generating columns in the pricing problem process.

### 2.1.2. LSP heuristic

LSP, Layered Shortest Path, heuristic was introduced by Namboothiri and Erera (Namboothiri and Erera, 2004) for generating solutions of work sequencing problems that have high number of feasible solutions. The heuristic avoids generating too many solutions, and try to get rid of seemingly unfavourable solutions. The heuristic starts with the initial process setting up initial work sequences. After that, the layer extended process is executed. The second process gradually extends obtained work sequences from the previous process and eliminates seemingly inefficient work sequences. The heuristic will be terminated when every extended work sequence (after elimination) consists of every work. Figure 9 shows the core processes flow chart of LSP heuristic.

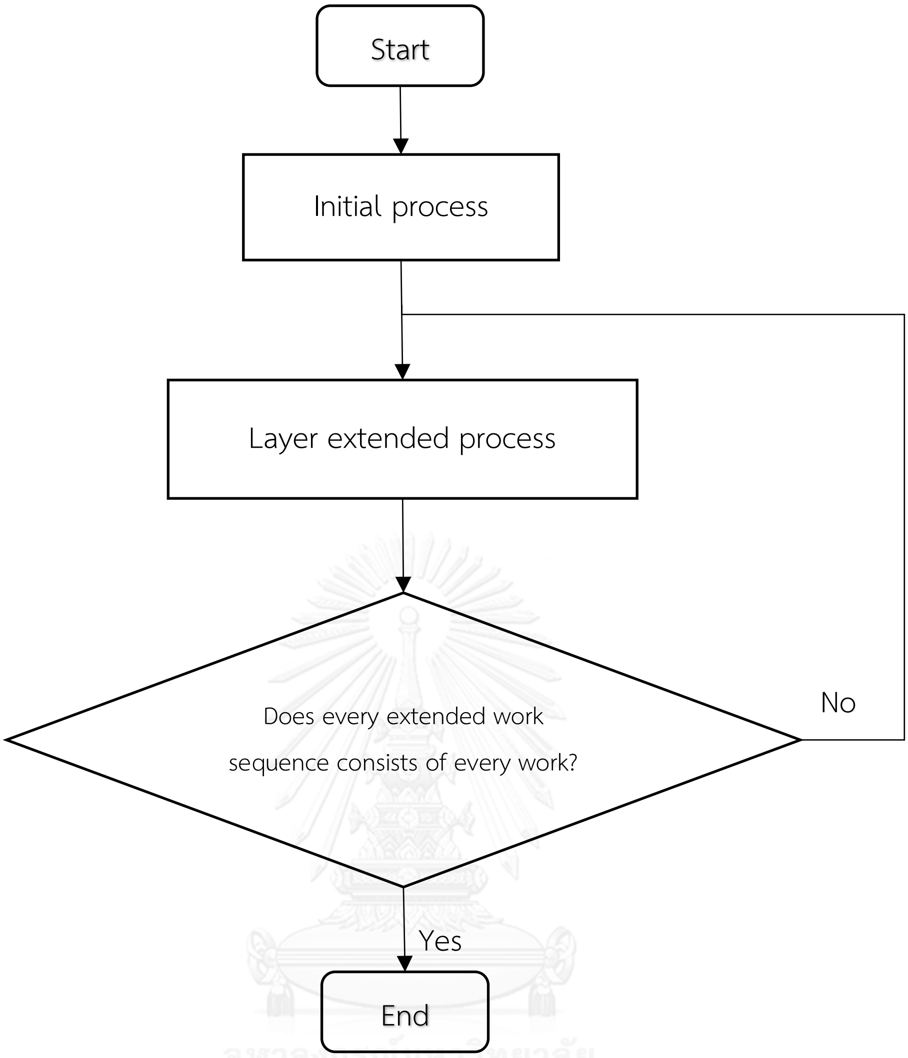


*Figure 9 core processes flow chart of LSP heuristic*

As mentioned, the heuristic can be separated into 2 core processes: the initial process, and the layer extended process. The heuristic will be explained thoroughly using Example 4 as a demonstrator.

Example 4

There are 5 customers (Customer Numbers 1 to 5) requiring a package delivery service from a distribution centre (DC). The example asks to design the most efficient delivery route in terms of distance by using LSP heuristic.

**The initial process**

The initial process is used for initiating the sequencing. The process starts with the number of initial work sequences determination. An initial work sequence is the work sequence containing only 1 work. To cover as many possibilities as we can, the number of initial work sequences should be equal to the number of works. The first work of each work sequence can be called Layer 1 of that work sequence.

In Example 4, there are 5 customers (works), so there will be 5 initial work sequences beginning with different customer as shown in Figure 10 and Table 8. Also, DC is assigned as Layer 0 of all initial work sequences.

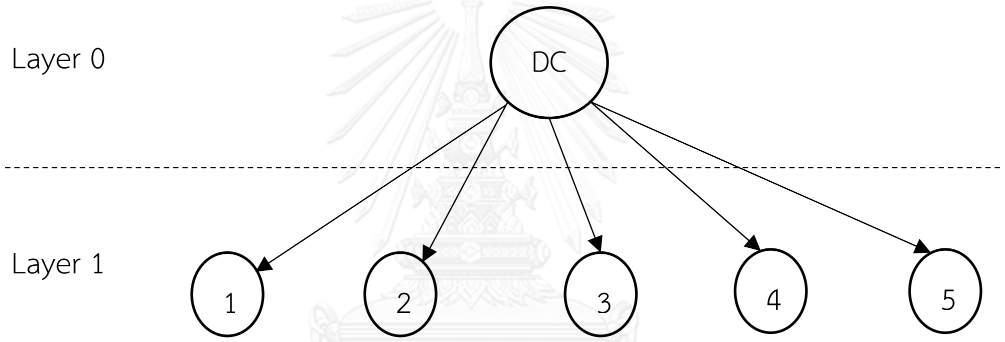


*Figure 10 the initial process of Example 4*



*Table 8 the initial work sequence of Example 4*

| Initial Work Sequence Number | Layer 0 | Layer 1 |
|---|---|---|
| 1 | DC | 1 |
| 2 | DC | 2 |
| 3 | DC | 3 |
| 4 | DC | 4 |
| 5 | DC | 5 |

**The layer extended process**

This process obtains the work sequences from the previous process, extends it, and eliminates the seemingly inefficient extended work sequences. From Figure 9, the previous process can be either the initial process or the layer extended process itself. If the previous process is the initial process, the initial work sequences will be obtained, otherwise the extended work sequences will be obtained. After the obtaining, the process can be separated into 2 steps listed as follows.

1. Extend the obtained work sequences.
2. Eliminate the seemingly inefficient extended work sequences.

*Extend the obtained work sequences*

This step extends each obtained work sequence by adding that work sequence's unassigned works to it. Before extensions, each work sequence's assigned works are considered, and the unassigned works will be determined. Each work sequence is considered individually. For each work sequence, an unassigned work will be added to form an extended work sequence. The extended work sequences must have more number of assigned works (layer) than the obtained work sequences.

In Example 4, the extension of Initial Work Sequence Number 1 is shown in Figure 11 and Table 9. The assigned customer of Initial Work Sequence Number 1 is Customer Number 1, while the unassigned customers are Customer Numbers 2, 3, 4, and 5. Each of the unassigned customers will be added to Initial Route Number 1 individually to form an extended work sequence.

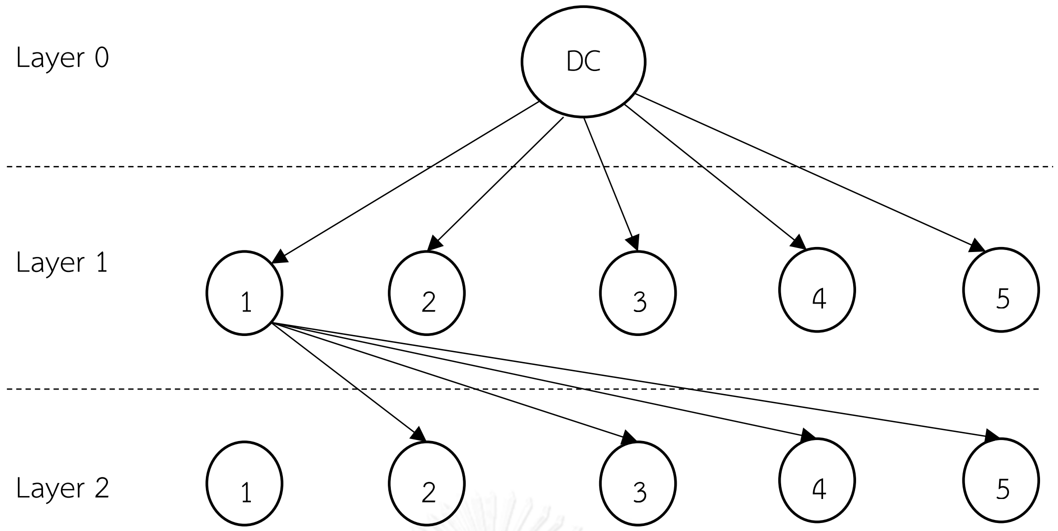


*Figure 11 an extension of Initial Work Sequence Number 1 of Example 4*

*Table 9 the extended work sequence from Initial Work Sequence Number 1 of Example 4*

| **Extended work Sequence Number** | **Initial Work Sequence Number 1** | | **Layer 2** |
|---|---|---|---|
| 1 | DC | 1 | 2 |
| 2 | DC | 1 | 3 |
| 3 | DC | 1 | 4 |
| 4 | DC | 1 | 5 |

As shown in Figure 11 and Table 9, 4 extended work sequences are created from Initial Work Sequence Number 1. The other initial work sequences are extended the same way as the extension of Initial Work Sequence Number 1. As a result, there will be 20 extended work sequences.

*Eliminate the seemingly inefficient extended work sequences*

From the previous step, a lot of work sequences are created. This step aims to identify seemingly inefficient extended work sequences and eliminate them to avoid creating too many work sequences. The efficiency of work sequences depends on the context of problem; the work sequences' efficiency may measure by cost, time, distance, etc. After the efficiency of each extended work sequence has been determined, the extended work sequences will be arranged by the recently added work. The most efficient extended work sequences of each group will not be eliminated, while the others will be waived. We called them the seemingly inefficient work sequences, because the work sequences are inefficient at the current situation. However, they might be the efficient work sequences in the future--- the next extension process (if we has not eliminated it).

In Example 4, the efficiency of the work sequences is measured by distance. First, the 20 extended work sequences from the previous step will be arranged into 5 groups, because there are 5 recently added customers. Figure 12 and Table 9 shows the group of work sequences that have Customer Number 2 as the recently added customer.

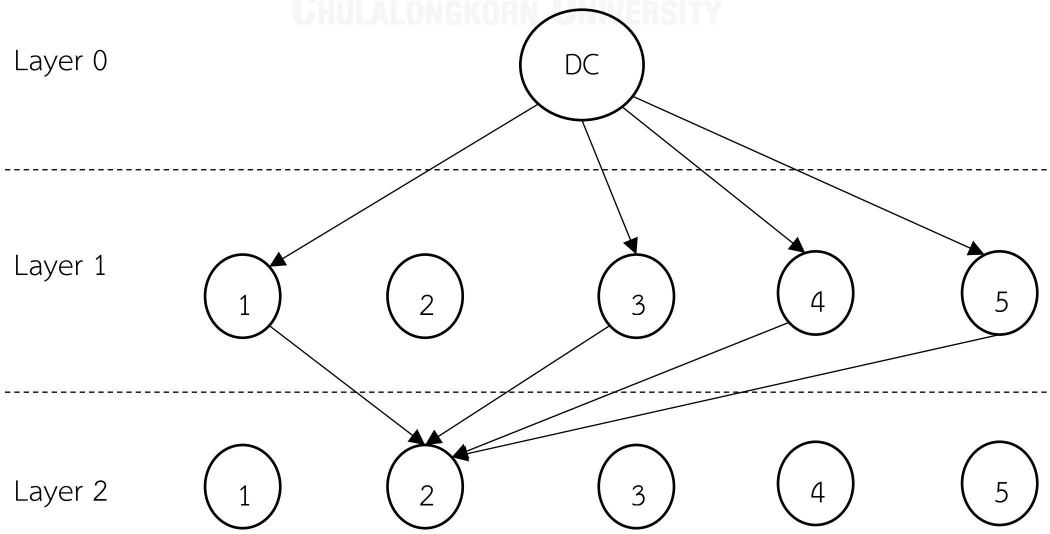


*Figure 12 work sequences that have Customer Number 2 as a recently added customer*

*Table 10 work sequences that have Customer Number 2 as a recently added customer*

| Work Sequence Number | Layer 0 | Layer 1 | Layer 2 (Recently added) |
|---|---|---|---|
| 2.1 | DC | 1 | 2 |
| 2.2 | DC | 3 | 2 |
| 2.3 | DC | 4 | 2 |
| 2.4 | DC | 5 | 2 |

We assume that Work Sequence Number 2.3 is the most efficient work sequence of the group in terms of distance, so that, the others (Work Sequence Number 2.1, 2.2, and 2.4) will be eliminated. The other groups will executed the elimination step in the similar way. As a result, from 20 extended work sequences, there will be only 5 work sequences with different recently added customer left.

**Check for the elements in work sequences**

After the elimination, every remaining work sequences' elements will be considered. If every work sequence contains every works, the heuristic will be terminated. Otherwise, the heuristic will repeat back to the pricing problem process again.

Subsequently, after the termination, every left work sequence is the answer of a problem solving by LSP heuristic.

In Example 4, the heuristic will terminate when every work sequence consists of 5 customers (layer).

LSP heuristic is suitable for problems that have large number of feasible solutions, and the operation system cannot handle and consider every solution. If Example 4 has been enlarged to 100 customers, there would be 100! solutions.

### 2.1.3. Tabu Search Concept

Tabu Search concept is an approach preventing system from being trapped in recursive operations. In Tabu's operation, there is Tabu list prohibiting the system from acquiring the same solution (every solution that are in Tabu list is not allowed to be selected), in other words, trapped in the local optimum. Tabu list encourages the system to explore other solutions from other areas in the search space.

## 2.2. Literatures Review

From the problem statement, this research is separated into 2 systems, the vehicle estimation and routes planning systems. The vehicle estimation system is similar to the fleet sizing problem, while the route planning system is comparable to the vehicle routing problem. So, those 2 problems will be discussed separately in this section. Because both problems are quite famous in the academic world, there are a lot of researches in those areas. So, we narrow down the review scope and consider only significantly related researches in terms of objective, statement of problem, and the method used for solving problems. In addition, we also briefly review the fleet sizing and mixed vehicle routing problem, i.e., the problem that combines the fleet sizing problem and the vehicle routing problem together.

### 2.2.1. Research in the area of the fleet sizing problem

According to Zak et al., the fleet sizing problem concentrates on the matching between demands and supplies in a transportation system. The problem aims to determine the number of vehicles for fulfilling materials requirements with low cost. There are a lot of proposed models in the fleet sizing problem field. The classification of the models was illustrated and discussed by Zak et al (Zak et al., 2008).

Most of the fleet sizing literatures studied in a car rental industry (Li and Tao, 2010, Pachon et al., 2003). In a car rental service, customers come to a rental hub, then rent a car, and drive to their destination, so the availability of cars at the hub is very important. To satisfy the upcoming demands, car rental companies usually allocated their cars during the night.

Li and Tao proposed an optimisation method for fleet sizing in a Chinese car rental company. Their objective was to maximise the expected income. They determined number of cars along with setting up the fleet allocation policies (Li and Tao, 2010). Pachon et al.'s work was also in the area of car rental industry. Their work had the same objective as Li and Tao's work, i.e., to maximise the expected income, but their objective function was separated into 2 components which were the expected price from the availability of cars and the allocation cost between rental hubs during the night. They separated their work into 2 independent parts. The first part aimed to maximise income from the fleet sizing problem, while the other part was to minimise the cost of allocations. They used the tactical fleet planning heuristic to reduce the gap between the solution that came from the separated problem, and the solution that came from the non-separated problem (Pachon et al., 2003). Both Li and Tao, and Pachon et al.'s works operate fleet sizing in the deterministic demand context, the same as most fleet sizing literatures. One of a few papers that considered demands as stochastic is the work of Diana et al. They proposed a probabilistic model to determine the number of vehicles from the distribution of demands associated with time windows, and pickup and delivery locations. In their problem, the vehicles are required to pick up and deliver customers within a specific time window. They determined the number of vehicles from the expected value of demands per vehicle. The expected value came from the multiplication of the number of requests and the summation of the quotient of the requests per vehicle and their probabilities. The probabilities were calculated from pickup and delivery's time windows (Diana et al., 2006).

Most of the fleet sizing literatures worked with a problem that has available predicted upcoming demand (assumed to be deterministic), and estimate the number of vehicles for that demand. That estimated number of vehicles will be used to satisfy that predicted demand. In the next day, when the predicted upcoming demand is changed, the estimated number of vehicles will be change. In contrast, our vehicle estimation system estimates the number of vehicles from the given customers' yearly plan. The number of estimated vehicle cannot be changed, due to the yearly contract, and the provider must operate the routes planning system with this number of vehicles for the whole year, our system has lower flexibility than the literatures' system. In other words, the fleet sizing literatures focused on the estimation of fleet for the next day, while our vehicle estimation system concentrates on the estimation of fleets for the next year.

### 2.2.2. Research in the area of the vehicle routing problem



For the routes planning system which is comparable to the vehicle routing problem (VRP), the related literatures are plentiful, and there are a lot of proposed models. Thus, we will discuss only the significant literatures that are related to our research problem.

The vehicle routing problem was described by Laporte as the planning of routes for vehicles delivering packages to other locations. The routes usually start from depots, deliver packages to other locations by concerning on several constraints, and return to the depot. The VRP is a worldwide renowned problem and are applied for operating many transportation system such as milk run system. According to Laporte, the VRP can be categorised into several types depending on constraints of the problems. The capacitated VRP is the VRP that has capacity constraints (CVRP), while the VRP with time window constraints is called the VRP with time windows (VRPTW). The VRP that has more than one depot in the problem is called the multi-depot VRP (MD-VRP). Normally in VRP, vehicles usually perform either pick up only or deliver only on its routes, but there is a special type of the VRP that allows vehicles to send packages to customers and collect packages from customers, called the VRP with pickup and delivery (VRPPD). Another unique type of VRP is the open VRP which has no finishing location restriction, i.e., vehicles do not need to return to the depot (Laporte, 1992).

There are a lot of methods to solve the VRP. Nassar and El-Sherbeny (El-Sherbeny, 2010) separated those methods into 3 types, namely, the exact methods, the heuristic methods, and the meta-heuristic methods.

The exact methods are divided into 2 categories: classical methods and modern methods (Toth and Vigo, 2014). The examples of the classical methods are branch and bound algorithm, set partitioning algorithm, and branch and cuts algorithm. The modern methods are based on the column generation algorithm combined with the branch and cuts algorithm, i.e., the branch and cut and price algorithm proposed by Fukasawa et al. (Fukasawa et al., 2006). Although solving the VRP by the exact methods might guarantee an optimal solution, but the methods are not able to solve large size problems.

The heuristic methods are more popular for solving the VRP, and are separated into 2 categories, exactly the same as the exact methods, which are classical heuristics and meta-heuristics (Cordeau et al., 2007). The classical heuristics are classified by Laporte and Semet into 3 sub-categories (Laporte and Semet, 2001). The first one is the route construction heuristics which are routes construction algorithms that usually start from scratch and construct routes iteratively until every materials transportation requirements are served. The examples of this type of heuristic methods are Clark and Wright Saving heuristics (Clarke and Wright, 1964) and the sequential insertion heuristics (Mole and Jameson, 1976). Secondly, the heuristics that separate the problem into 2 parts, clustering part and routing part, are defined as the two phase heuristics. The clustering part separates a problem into small sub-problems, and the routing part solves the sub-problems separately. One of the famous clustering heuristics is Sweep algorithm (Gillett and Miller, 1974). The last sub-category is the route improvement heuristics which often bring the solutions from the route construction heuristics and improve it, e.g., swap heuristic and $\lambda$-opt heuristic (Lin, 1965).

The metaheuristic methods usually bring solutions from the classical heuristic and search scrupulously in a search space to improve them with a system of logics. The examples of the methods are simulated annealing (Osman, 1993), Tabu Search (Semet and Taillard, 1993, Taillard et al., 1997), genetic algorithm (Homberger and Gehring, 1999), and ant colony optimisation (Gambardella et al., 1999).

Our research problem, in the routes planning system, is classified as a VRP with pickup and delivery, because we have both pickup and delivery operations in the system.



According to Salhi and Nagy, the VRP with pickup and delivery can be categorised into 3 types which are delivery-first-pickup-second, mixed pickup and delivery, and simultaneous pickup and delivery (Nagy and Salhi, 2005). Specifically, our research problem is equivalent to the mixed pickup and delivery type, because the pickup and delivery operations can be operated in any order. Refer to Salhi and Nagy, the mixed-pickup and delivery VRP researches are not plentiful. Most of the researches in this area used insertion heuristics. Golden et al. used the heuristic inserting pickup customers into the routes that had been constructed by delivery customers by considering the number of delivery customers arranged after the insertion point (Golden et al., 1985). Furthermore, the insertion heuristic that considers items delivered to customers as the insertion cost of the system before inserts pickup customers into the routes which had been constructed by delivery customers was proposed by Casco et al. (Casco et al., 1988). Salhi and Nagy also proposed the concept of strong and weak feasibility to cope with the mixed and simultaneous pickup and delivery VRP (Nagy and Salhi, 2005).

In contrast, the general pickup and delivery problem was surveyed by Parragh et al., (Parragh et al., 2008) .According to Parragh et al., our research problem is classified as the classical pickup and delivery problem. There are many variants in the pickup and delivery problem, e.g., vehicle characteristics and demand characteristics. The vehicle characteristics could be homogeneous fleets (Khanh et al., 2015), heterogeneous fleets (Xu et al., 2003), and even configurable capacity fleets (Qu and Bard, 2013). The demand characteristics could be deterministic and stochastic. Huang proposed a modified Tabu Search algorithm to solve the stochastic multi-items demands of the problem (Huang, 2015), while the multiple stacks with last-in-first-out loading constraints was studied in the work of Cherkesly et al. (Cherkesly et al., 2016). There are a lot of methods that are used to solve the general pickup and delivery problem; exact methods, e.g., branch and cut and price algorithm (Ropke and Cordeau, 2009), 2 branch and cut algorithm (Ropke et al., 2007), and column generation algorithm (Dumas et al., 1991), heuristic methods, e.g., column generation based heuristic (Xu et al., 2003) and cheapest insertion and local search improvement (Mitrovic-Minic and Laporte, 2006)), and meta-heuristic methods, e.g., genetic algorithm (Jung and Haghani, 2000), tabu search with simulated annealing (Li and Lim, 2003), and adaptive large neighbourhood search (Ropke and Pisinger, 2006).

Refer to both Salhi and Nagy, and Parragh et al., the next discussion of the literatures will be the detailed reviews of recent related researches which studied in the field of the pickup and delivery problem.

The work of Namboothiri and Erera is directly related to this research (Namboothiri and Erera, 2008). They extended an unconstraint drayage problem (UDP) into an access control drayage problem (ACDP). Their problem was about transportations between a port and customers, for exports and imports. The port had limited amount of accessible vehicles for each timeslot (Note that, every time slot was equivalent to each other). Each request had the same quantity which was 1, and the vehicles had only 1 unit of capacity too, because they were drays that carried a container. The transportation sequences were not strict, but it must respect to the capacity and time slot constraints. Their objective was to minimise the number of routes. Also, the vehicles were needed to return to the depot, where it had been started, at the end of the day. Comparing their problem to our research problem, the demands of our research problem are always less than truck load, and are not always equal to 1. Namboothiri and Erera proposed an optimisation-based heuristic that utilised the column generation algorithm. However, the pure column generation algorithm could generate too many column due to the number of feasible solutions, so they proposed a fast heuristic for generating column: Layered Shortest Path heuristic (LSP). The heuristic does not guarantee the improvement of the objective value. The heuristic does not fully search all of the feasible neighbourhood solutions, only some seemingly efficient neighbourhood solutions are selected. Their problem size was less than 100 customers.

Vidović et al. proposed the optimisation and heuristic methods for solving the transportation of containers problem. In their problem, vehicles could carry one or two containers at a time depending on the size of containers (Vidović et al., 2011). There were 2 types of containers in their problem, 20 ft. and 40 ft., and each vehicle had the maximum capacity of two 20 ft. or one 40 ft. container. Also, there were 2 types of request in their problem which were the delivery requests that required the transportations of containers from a depot/terminal to customers, and the pickup requests that required the transportations of containers from customers to a depot/terminal. Note that, each node must be either pickup or delivery location. From the capacity constraint and the characteristics of requests, the number of feasible solutions was quite low, so it could be solved by the exact methods. As a result, they developed an optimisation approach with the objective to minimise cost by merging the requests in each route. Their optimisation model was based on a set covering problem's model which, as a result, led to only one constraint, i.e., each request must be served exactly one time. They also developed a heuristic method for solving larger size problems. The heuristic used the vehicle's utilisation to construct routes.

Moreover, the pickup and delivery problem is quite similar to the roll-on/roll-off routing problem (ROROR) which has many literatures in the field of waste collection industry. The ROROR problem is literally the same as the previous drayage problem, only 1 unit of capacity is available for a vehicle. The work of Hauge et al. introduced a heuristic to cope with more than 1 capacity of ROROR problem respecting to the time constraints (Hauge et al., 2014). The problem of Hauge et al. was about the transportation of Skip containers which were used for waste collection. The wastes which were produced by customers must be transported to one of the dump sites by a vehicle. There were more than one depots and dump sites in the system. Also, there were more than one types of containers, but there was no container restriction which meant different types of container could be delivered together. The number of vehicles was limited and the operating time was restricted. Their objective was to minimise the cost of transportation which was calculated from transportation time. There were 4 types of orders, and each type required different task sequences. Any order could be combined together but with respect to the task sequences and the type of containers. Hauge et al. proposed an optimisation-based method, i.e., the hybrid column generation approach. Similar to the idea of Namboothiri and Erera, they introduced the heuristic method to solve the column generation's pricing problem, i.e., Tabu Search. Their method performed quite well in their generated instances (up to 100 orders) and the real world instances.

Another important variant related to our research is the open route characteristic, because the vehicles do not need to return to a depot. The open vehicle routing problem is not as rich as the pickup and delivery problem. Brandao (Brandão, 2004) stated that this problem was a NP-hard problem. Sariklis and Powell (Sariklis and Powell, 2000) proposed a heuristic to solve the open VRP problem. They separated their heuristic into 2 phases which were clustering phase and routing phase. They considered the capacity constraint while performing the clustering phrase and also balancing the clusters afterwards. In routing phase, they used the minimum spanning tree approach as an initial algorithm. Next, they modified the spanning tree by using penalties. Lastly, they tried to convert the infeasible solutions into feasible one by consider costs. Brandao used 2 initiation methods which are the nearest neighbour heuristic and the pseudo lower bound method. After using those 2 constructive heuristics, Brandao improved the solutions by using Tabu search. At last, he encouraged that Tabu Search Algorithm was very efficient to the problem.



The works that applied the open vehicle routing concept to the picking and delivery are quite scarce as stated in the survey of Caceres-cruz (Caceres-Cruz et al., 2015). Sakalli et al. proposed the bubble heuristic for solving the pickup and delivery problem with an extension (Sakalli et al., 2013). Their problem considered the transportation between distribution centres, and the extension was the condition that vehicles did not need to return to the same location where it had started. In their problem, every location could be a pickup location and/or delivery location, and vehicles could finish at any location. Their instances was quite small, only 90 orders were performed with only 10 locations. The work of Lindsey et al. also considered their problem as an open pickup and delivery problem, but with crossdocks (Lindsey et al., 2013). The vehicles in their problem were outsourcing vehicles which meant the vehicles did not need to return to the origin. In their system, there were several crossdocks. In addition, feasible routes were limited to 3 types of route sequencing characteristics. The first one was the routes that were not associated with crossdock. It must pick up items from suppliers first then delivery to its destinations in LIFO order (related to the pickup sequence). The routes that were associated with crossdocks can be classified into the routes that were destined to a crossdock, and originated from a crossdock. The routes that were destined to a crossdock must perform only pickup tasks from any origin, and, in the same way, the routes that were originated from a crossdock must perform only delivery tasks of the already pickup items. They generated a set of potential high quality solutions by inserting and generating sets of orders that could be transported together. They solve the problem by using an integer programming for small problems. The most related work in this field is the work of Ceselli (Ceselli et al., 2009). They used column generation algorithm to solve the pickup and delivery problem with some routes allowed to have an open end. They used the bounded bidirectional dynamic programming to solve the pricing-sub problem. Their algorithm generated and joined 2 routes which were created from forward and backward procedures. The generated routes begin at a depot and deliver items to customers while considered many constraints; maximum weight, maximum volume, maximum operating time and distance, etc. At the end of routes, some types of vehicles must return to the depot, otherwise were not necessary. In conclusion, the routes only came back to the depot when every items in the vehicle were delivered (or not for some types of vehicles). They worked on the real-world instance of 461 delivered items and the result was good in reasonable time.

In our research's routes planning system, the system is comparable to the open pickup and delivery with time window. Many literatures focused on a problem that has full truck load materials requirements --- the drayage problem, the ROROR problem. Moreover, only few researches have considered the pickup and vehicle with the open route variant (vehicles do not need to return to the starting location). The variant affects routes planning in terms of pattern; the variant encourages the system to plan routes in form of a line, otherwise the routes usually plan in a form of a circle. Unlike other open pickup and delivery researches, our system also has time window and does not have restriction for routes sequence. Most of the open pickup and delivery researches have constraints that restrict routes to visit pickup locations until a vehicle is almost full then visit delivery locations afterwards. The routes restriction may lead to high vehicles' utilisation, but in our research the utilisation is not our priority concerns.

### 2.2.3. Research in the area of the fleet sizing and mixed vehicle routing problem

There are several literatures that mix the fleet sizing problem with vehicle routing problem. The combined problem is called the fleet sizing and mixed vehicle routing problem. The beginning of this field started from the work of Golden et al. in 1984 (Golden et al., 1984). They proposed the modified-saving heuristic, and the giant tour algorithm to solve this problem. There are many algorithms that were developed to cope with the problem such as the Matching Based Savings Algorithm (Desrochers and Verhoog, 1991), insertion-based heuristic (Liu and Shen, 1999), or sweep based algorithm (Renaud and Boctor, 2002). Unfortunately, the fleet sizing and mixed vehicle routing problem's concept cannot apply to our research, because the problem is solved simultaneously.

In conclusion, many fleet sizing problem and fleet sizing and mixed vehicle routing problem literatures mainly focus on the short-term fleet management, estimating number of fleet for 1 day period of utilisation, while our vehicle estimation system aims to determine number of fleet for the long-term (1-year) utilisation. For our routes planning system, most of pickup and delivery literatures did not concern about the open system variant. And, many of the related researches focus on routes restriction, to maximise vehicles' utilisation, while our research does not consider the utilisation as the first priority (our first priority is transportation cost). As a result, for the vehicle estimation system, we apply the concept idea of Diana et al. (Diana et al., 2006) to determine the number of vehicles for stochastic demands. For the routes planning system, we apply the concept of column generation from the work of Namboothiri and Erera (Namboothiri and Erera, 2008) to plan routes in each day. We also adapt their LSP heuristic concept to plan routes in the system, because their proposed heuristic is applicable to large system as ours.

# Chapter 3

# Systems Methodology

As mentioned from the previous chapters, our research are separated into 2 systems, the vehicle estimation system and the routes planning system.

The first system that will be executed is the vehicle estimation system. The system operates once a year, at the beginning of the year as shown in Figure 13 (red oval). The system uses the customers' yearly plan to determine the number of contract vehicles needed for the upcoming year.

The other system is the routes planning system. The system operates every working day at the beginning of each day as shown in Figure 13 (big blue arrow line). The system plans the routes for vehicles using the customers' exact plan informing about materials transportation requirements in that day. If the number of contract vehicles (result from the vehicle estimation system) cannot satisfy every materials transportation requirement in a particular day, outsourcing vehicles will be hired only for that day.



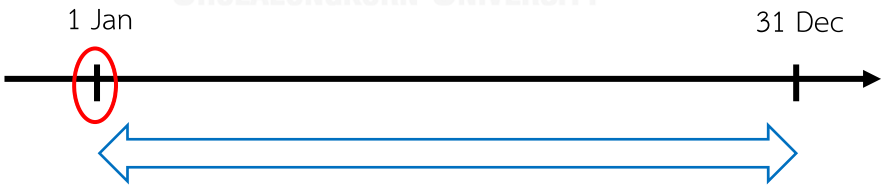


*Figure 13 timeline of the systems.*

## 3.1. The vehicle estimation system

The vehicle estimation system in this research means the determination of the number of contract vehicles by using the customers' yearly plan. The system applies concept of expected values to identify the appropriate number of contract vehicles. Because, if the number of contract vehicles is too small, the provider will hire outsourcing vehicles to satisfy additional materials transportation requirement. The outsourcing vehicles are more expensive than the contract vehicles in terms of service cost (fixed cost). In contrast, if we have too many contract vehicles, some may not be used in every working day. The provider needs to pay those unused contract vehicles for the opportunity cost --- called the guarantee cost. As a result, the number of contract vehicles should not be too large or too small.

This section starts with system description including objective, scopes, assumptions, constraints, and inputs. After that, the core processes of the system are discussed and illustrated. Subsequently, detail of the core processes is explained thoroughly. An example demonstrating every process is given after the explanation.

### 3.1.1. System description

In this sub-section, the objective of the vehicle estimation system will be proposed along with the decision variable. The scopes and assumptions are informed afterwards. Subsequently, the system's constraints and inputs are notified.



System's objective

To minimise vehicle service cost of the system by estimating the proper number of contract vehicles from the given customers' yearly plan.

System's decision variable

Number of contract vehicles that the provider should prepare to operate the routes planning system.

Scopes of the vehicle estimation system

1. The vehicle estimation system is the system for determining the appropriate number of contract vehicles signed to operate in the upcoming year.

2. The outcome of the system is the number of contract vehicles.

3. The vehicle estimation system does not include the contract management system, and the contract negotiation management.

4. There are 2 types of locations in the system which are suppliers and customers; each location must be either supplier or customer.

Assumptions of the vehicle estimation system.

1. The number of contract vehicles determined from this system can be used for the whole upcoming year.

2. Every vehicle in the system is homogeneous.

3. Every informed materials requirement in the customers' yearly plan is less than truckload.

4. The capacity constraint is considered in only 2 dimensions which are volume and weight, the shape of the materials are not considered.

5. Every material can be delivered together, no materials restriction.

6. The vehicle service cost in the system consists of 2 components which are service cost per day of a contract vehicle and service cost per day of an outsourcing vehicle.

7. Every contract vehicle has the same service cost per day, similarly, every outsourcing vehicle also has the same service cost per day.

8. The number of working days of customers in each month is the same.

9. Every customer has the same working day.

10. The distances between locations are represented as displacement.

11. The travelled times between locations have linear relationship with distances.

12. Every vehicle is driven at constant speed.

13. The guarantee cost is specified in the contract. The cost come in the monthly form, e.g., if a vehicle usage is lower than 15 days in a particular month, the provider needs to pay 1000 baht per day for the opportunity cost (if a vehicle operate 12 days, the provider needs to pay guarantee cost for 3 days).

System's constraints

1. Capacity constraint in terms of weight.

2. Capacity constraint in terms of volume.

3. Time constraint in terms of vehicles' working hour.

System's inputs

1. The location of every stakeholder.

2. Estimated number of required materials from customers' yearly plan. Note that, the number of required materials normally informs in units, so the provider needs to transform those units into weight (kg) and volume ($m^3$) by themselves. This number indicates the estimate number of required materials from a particular supplier in the upcoming year. For example, Customer Number 1's yearly plan states that "In the upcoming year, each time we place an order to Supplier A, the number of required materials is around 20 units".

3. Predicted number of days that a customer will sent a materials requirement to each of their suppliers in each month. In the yearly plan of a customer, the number of day that the materials requirement will be sent to each supplier must be informed. The yearly plan only shows the number of day, but it does not specify which days the requirements will be sent. Table 11 shows an example of this input

from a customer's yearly plan, assumed to be Customer Number 1. The customer has 5 suppliers. Each number informs about the number of day that the customer will sent materials requirement to one of their supplier in a particular month. For example, Customer Number 1's yearly plan informs that in January of the upcoming year, Customer Number 1 predicts to send materials requirements to Supplier Number 1 four times as shown in Table 11.

*Table 11 the predicted number of day that Customer Number 1 will sent requirement to suppliers*

| Customer Number 1 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Supplier Number 1 | 4 | 11 | 9 | 15 | 4 | 9 | 17 | 15 | 11 | 20 | 7 | 3 |
| Supplier Number 2 | 7 | 20 | 8 | 4 | 17 | 0 | 2 | 3 | 12 | 0 | 4 | 6 |
| Supplier Number 3 | 20 | 0 | 4 | 5 | 5 | 10 | 20 | 16 | 6 | 16 | 4 | 2 |
| Supplier Number 4 | 1 | 6 | 9 | 14 | 1 | 15 | 12 | 3 | 5 | 8 | 3 | 1 |
| Supplier Number 5 | 8 | 18 | 1 | 10 | 9 | 12 | 13 | 12 | 0 | 6 | 0 | 16 |

4. The number of working days of customers.
5. Capacity of vehicles in terms of weight.
6. Capacity of vehicles in term of volume.
7. Service cost (fixed cost) per day of each contract vehicle
8. Service cost (fixed cost) per day of each outsourcing vehicle
9. Average speed of vehicles
10. Working hours per day of vehicles

### 3.1.2. Conceptual design of the system

This sub-section explains about the concepts and core processes of the system. The vehicle estimation system consists of 3 core processes which are the preparation process, the vehicle estimation process, and the final number of contract vehicles calculation process. After customers' yearly plans has been obtained, the system will be initiated with the preparation process. The preparation process intends to rearrange information in the received plans into the form that appropriate for the next process's operations. Subsequently, the vehicle estimation process will be operated using the rearranged information from the previous process. Each supplier will be considered individually. The process will estimate the number of needed contract vehicles for each month of a supplier, then the most efficient number in terms of vehicle service cost will be chosen to be the representative of that supplier. After every supplier has been considered, the number of representatives will be equal to the number of suppliers. The last process will bring every representative together and calculate the proper number of needed contract vehicles. Figure 14 demonstrates the flow chart of the vehicle estimation system's core processes.

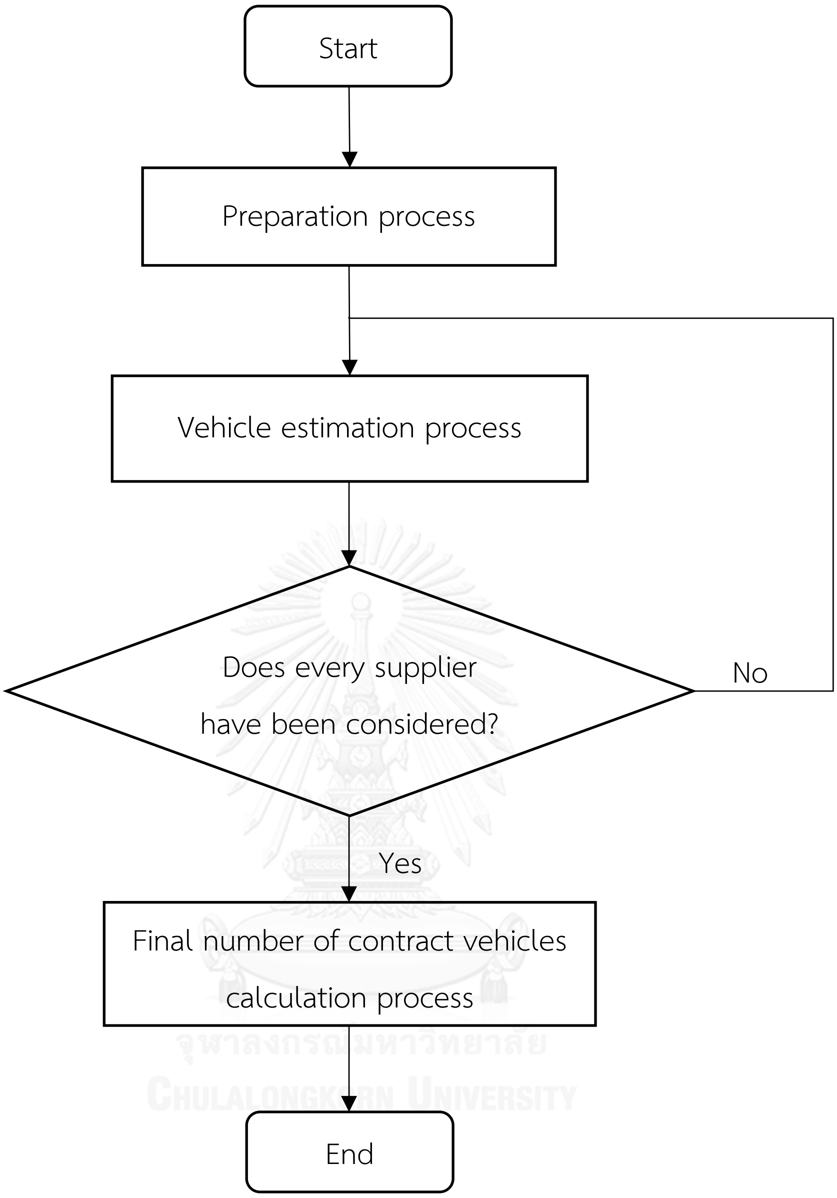


*Figure 14 core processes flow chart of the vehicle estimation system*

### 3.1.3. Detailed design of the system

This sub-section is going to explain and describe each of the core processes intensively. The explanation will use <u>Example 5</u> as a demonstrator.

Example 5

There are 5 customers (Customer Numbers 1, 2, 3, 4, and 5) in the system, each has 1 supplier. The example asks to determine the number of contract vehicles for the system (More information will be given during the explanations).

**The preparation process**

The preparation process aims to rearrange the given information for the next processes. This process consists of 3 steps listed as follows.

1. Assign a number to every supplier and materials requirement in the system.
2. Determine the capacity usage of each requirement.
3. Prioritise the capacity constraints.

*Assign number to every supplier and materials requirement in the system*

The supplier number is assigned to each supplier in an increasing order. The supplier number starts with the number of customers plus one to prevent confusion. For example, if there are 6 customers in the system, the supplier number will be started from 7.

The materials requirement number is assigned to each requirement in an increasing order as the supplier number, but the requirement number start from 1.

In Example 5, we assume that each customer has only 1 materials requirement from their only supplier. The supplier number will start from 6 since there are 5 customers. The supplier number and requirement number are shown in Table 12.

*Table 12 assigned supplier and requirement number of Example 5*

| Requirement Number | Supplier Number | Customer Number |
|---|---|---|
| 1 | 6 | 1 |
| 2 | 8 | 2 |
| 3 | 7 | 3 |
| 4 | 9 | 4 |
| 5 | 6 | 5 |

As shown in Table 12, Requirement Number 1 is the materials requirement sending from Customer Number 1 to Supplier Number 6. Note that a supplier can supply more than one customer.

*Determine the capacity usage of each requirement*

Each requirement will be considered and calculate the capacity usage in terms of weight and volume. Normally, the weight and volume of each requirement are informed by the customers. But, if the customers do not inform the capacity usage, the provider must estimate by themselves.

In Example 5, the capacity usage of each requirement are informed in Table 13.

*Table 13 capacity usage of each requirement of* *<u>Example 5</u>*

| Requirement Number | Supplier Number | Customer Number | Weight (kg) | Volume ($m^3$) |
|---|---|---|---|---|
| 1 | 6 | 1 | 680 | 1.52 |
| 2 | 8 | 2 | 770 | 2.54 |
| 3 | 7 | 3 | 750 | 0.90 |
| 4 | 6 | 4 | 800 | 2.25 |
| 5 | 9 | 5 | 910 | 3.56 |

*Prioritise the capacity constraint*

There are 2 dimensions of vehicles' capacity which are weight and volume. In the vehicle estimation system, we decide to choose only a significant dimension to consider. Most of the materials are made from metal. Thus, the weight constraint tends to be violated before the volume constraint, so weight is the primary capacity constraint of the system.



**The vehicle estimation process**

The vehicle estimation process aims to determine the number of contract vehicles for each suppliers. The process uses the concept of expected values to calculate the vehicle service cost, and select the appropriate number of contract vehicles to be the representative of each supplier. Each supplier will be considered individually. This process can be divided into 2 sub-process which are the monthly vehicle estimation sub-process and the yearly vehicle estimation sub-process. The first sub-process' propose is to identify a representative number of vehicles of each month of a supplier. The second sub-process selects the most efficient representative in terms of vehicle service cost to be the representative of a supplier. Before executing the monthly vehicle estimation sub-process, one of suppliers that has not been considered must be chosen. Figure 15 shows the flow chart of the vehicle estimation process.

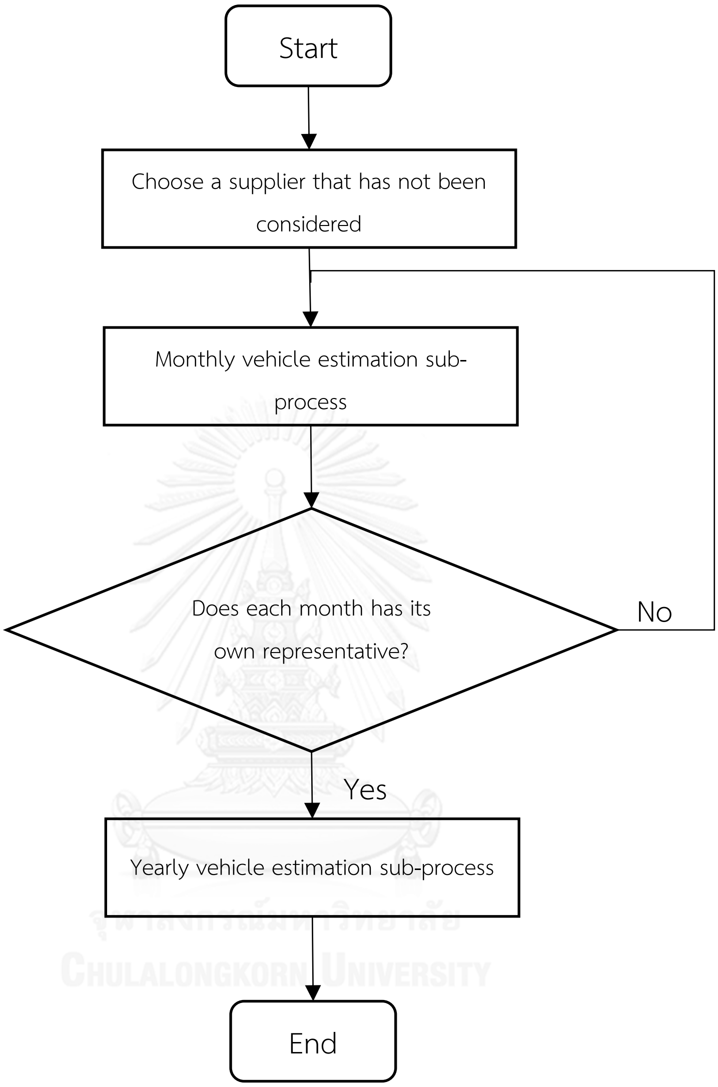


*Figure 15 sub-process flow chart of the vehicle estimation process*



**The monthly vehicle estimation sub-process**

After a supplier has been chosen, the monthly vehicle estimation sub process will be executed. As mentioned, the sub-process aims to identify a representative number of contract vehicles of each month of the chosen supplier. The sub-process is started in January. In Example 5, Supplier Number 6 has been chosen.

The sub-process consists of 4 steps listed as follows.

1. List every possible capacity usage case of the chosen supplier.
2. Determine the probability of each capacity usage case.
3. Calculate the vehicle service cost of each capacity usage case.
4. Choose the representative

*List every possible capacity usage case of the chosen supplier*

This step identifies every possible demand that the chosen supplier can received from the customers in a particular day. Next, those possible demands will be transformed into capacity usages.

In Example 5, Supplier Number 6 has been chosen. The requirements that are associated with the supplier are shown in Table 14.

*Table 14 the requirements associated with Supplier Number 6 of Example 5*

| Requirement Number | Supplier Number | Customer Number | Weight (kg) | Volume ($m^3$) |
|---|---|---|---|---|
| 1 | 6 | 1 | 680 | 0.09 |
| 4 | 6 | 4 | 800 | 0.10 |

Every possible capacity usage case, transformed from every possible demand that Supplier Number 6 can receive, will be listed in Table 15.

*Table 15 possible capacity usage of Supplier Number 6 of Example 5*

| Case Number | Weight (kg) | Volume ($m^3$) |
|---|---|---|
| 1 | 0 | 0 |
| 2 | 680 | 0.09 |
| 3 | 800 | 0.1 |
| 4 | 1480 | 0.19 |

In Example 5, each time Supplier Number 6 receives materials requirement from Customer Number 1 and Number 3 with the estimated capacity usage will be 680 and 800 kg. (0.09 and 0.1 $m^3$) consecutively. With the uncertainty of the yearly plan, the capacity usage could be 0 unit if both customers do not place the materials requirement to Supplier Number 6. If Customer Number 1 is the only customer placing the materials requirement, the capacity usage will be 680 kg. If Customer Number 4 is the only customer placing the materials requirement, the capacity usage will be 800 kg. Lastly, there will be 1480 kg. of capacity usage, if both customers place the requirements.

*Determine the probability of each capacity usage case*

This step determines the probability of each possible capacity usage case listed in the previous step. The probability is calculated by using the given number of working days. Each possible capacity usage case's probability will be calculated individually. Equations *(3.1.1)* and *(3.1.2)* will be used in the probabilities determination.

$$\text{The probability that a customer will not place a requirement} = \frac{W - P}{W} \quad (3.1.1)$$

$$\text{The probability that a customer will place a requirement} = \frac{P}{W} \quad (3.1.2)$$

W is the given working day of each month

P is the predicted number of days that a customer will sent a materials requirement to the chosen supplier a particular month.

In Example 5, we assume that the given working days is 20 day, and the predicted number of days that Customer Number 1 will place a materials requirement to Supplier Number 6 in January is 10 days. The predicted number of days that Customer Number 3 will place a materials requirement to Supplier Number 6 in January is 15 days.

Next, each case number (See Table 15) will be considered individually. The probability calculation of Case Numbers 1 and 2 are shown in Example Calculation 5.1.

Example Calculation 5.1

Case Number 1:

The probability that Customer Number 1 will not place the requirement = $\frac{20 - 10}{20} = 0.5$

The probability that Customer Number 3 will not place the requirement = $\frac{20 - 15}{20} = 0.25$

The total probability that both customers will not place the requirements = 0.5 x 0.25 = 0.125

Case Number 2:

The probability that Customer Number 3 will place the requirement = $\frac{10}{20} = 0.5$

The probability that Customer Number 1 will not place the requirement = $\frac{20 - 15}{20} = 0.25$

The total probability that only Customer Number 3 will place the requirement =0.5 x 0.25=0.125



The other 2 cases are calculated in the same way as the Example Calculation 5.1. The probabilities of each case are 0.125, 0.125, 0.375, and 0.375 consecutively. Note that, the summation of the probabilities must be equal to 1.

*Calculate the vehicle service cost of each capacity usage case*

The vehicle service cost per day of each capacity usage case will be determined in this step. The cost consists of the service cost of using contract vehicle and the service cost of using outsourcing vehicle. Each case will be considered individually. The considered case represents the number of contract vehicles needed to be served that amount of capacity usage. For example, if the capacity usage case of 800 kg is considered, it means that, the provider considers to hire contract vehicles for serving only 800 kg of capacity usage. The additional capacity usage will be served by outsourcing vehicles.

First of all, every possible capacity usage case is grouped into 2 groups: the group containing the cases that are lower and equal to the considered case in terms of capacity usage, and the other group. The cases in the first group are the cases that can be served by contract vehicles, while the cases in the second group are the cases that require outsourcing vehicle to serve its additional capacity usage.

Next, the vehicle service cost of the considered case is calculated using equation *(3.1.3)*

$$\text{Vehicle service cost} = \left(\frac{J}{A}\right) C_r + \sum_{k \in M} p_k\left(\frac{d_k - J}{A}\right) C_o \qquad (3.1.3)$$

M is the set of the cases in the second group

J is the considered case's capacity usage (primary capacity constraint)

A is the actual capacity of vehicles

$C_r$ is the service cost per day per contract vehicle

$C_o$ is the service cost per day per outsourcing vehicle

$p_k$ is the probability of case k

$d_k$ is the capacity usage of case k

The first term of equation *(3.1.3)* indicates the service cost per day of needed contract vehicles. In this step, we assume that a vehicle can be partitioned. For example, the service cost per day of a contract vehicle is 2000 baht, and the actual capacity of a vehicle is 6000 kg. If the considered case has 600 kg. of capacity usage, it means that we use only one tenth of a contract vehicle. As a result, the actual needed contract vehicles' service cost of this case is only 200 baht. The probability of using the contract vehicle for serving 600 kg. of capacity usage is 1, because the contract has already been made (if there is no transportation requirement in that day, the provider still needs to pay the guarantee cost).

The second term of equation *(3.1.3)* indicates the service cost per day of needed outsourcing vehicles. The actual needed outsourcing vehicles' service cost is calculated the same way as the contract vehicles. Note that, the provider uses outsourcing vehicle for serving only the additional capacity usage. There is a probability in this term, because the provider does not have to pay for any guarantee cost (unlike contract vehicles).

Each case's vehicle service cost must be identified in this step.

In Example 5, we assume that we choose to consider Case Number 3 (See Table 15), and the primary constraint is weight. As a result, Case Numbers 1, 2, and 3 are in the same group, while Case Number 4 is in the other group. The considered case has 800 kg. of capacity usage, so we will hire contract vehicles for serving only 800 kg. of capacity usage. In Case Number 4, there are 1480 kg. of capacity usage, so the hired contract vehicles are not sufficient. The additional 1480 – 800 = 680 kg. of capacity usage will be served by outsourcing vehicle.

We assume a contract vehicle's service cost per day is 2000 baht, and an outsourcing vehicle is 4000 baht. The actual capacity of a vehicle is 6000 kg.

Using equation *(3.1.3)*, the vehicle service cost of Case Number 3 in Example 5 is calculated in Example Calculation 5.2.

Example Calculation 5.2:

$$\text{Vehicle service cost} = \left(\frac{800}{6000}\right)\left(2000\right) + \left(0.375\right)\left(\frac{1480\text{-}800}{6000}\right)\left(4000\right)$$

$$= \left(0.13\right)\left(2000\right) + (0.375)(0.113)(4000)$$

= 429.5

The considered case is Case Number 3, so that, the number of contract vehicles that are needed to serve 800 kg. of capacity usage is 0.13 (assume to be able to partition). The service cost per day of that number of contract vehicles is 0.13 X 2000=260 baht. Unfortunately, with that number of contract vehicle, there is a chance that the number of contract is insufficient (if Customer Numbers 1 and 3 place a materials requirement in the same day, Case Number 4). As a result, there is a chance of 37.5% that outsourcing vehicles are needed. But there are the contract vehicles that could serve the capacity usage of 800 kg., so that, the additional capacity usage needed to be served by outsourcing vehicles is equal to 1480 – 800 = 680 kg. The number of outsourcing vehicles that must be hired to suffice the capacity usage of 680 kg. is 0.113. An outsourcing vehicle's service cost is 4000 baht per day, but only 0.113 kg. is needed so the actual needed outsourcing vehicles' service cost will be 0.113 X 4000 = 452 baht per day, and the chance that Case Number 4 could be occurred is 37.5%. Finally, the service cost per day of the needed outsourcing vehicles is 0.375 X 0.113 X 4000 = 169.5 baht. As a result, for this considered case, Case Number 3, the transportations cost per day is 429.5 baht.



*Choose the representative*

After every capacity usage case's vehicle service cost has been identified. The case that has the lowest vehicle service cost will be the representative of the chosen supplier in a particular month.

In Example 5, we assume that Case Number 2 has the lowest vehicle service cost, so that the representative in January of Supplier Number 6 is the capacity usage of 680 kg.

<u>**Does every month has its own representative?**</u>

The monthly vehicle estimation process repeats until December's representative of the chosen supplier is determined. The number of representatives must be 12.

In <u>Example 5</u>, the monthly vehicle estimation process is repeated until the representative capacity usage in December of Supplier Number 6 is determined.

<u>**The yearly vehicle estimation sub-process**</u>

This sub-process selects the most efficient representative, in terms of yearly vehicle service cost, to be the representative of the chosen supplier. This process consists of 3 steps listed as follows.

1. Calculate the yearly service cost for each representative.
2. Select the most efficient representative.
3. Calculate the number of needed contract vehicles for the chosen supplier.

*Calculate the yearly service cost for each representative*

This step calculates cost for the whole year of each representative using equation *(3.1.4)*.

$$\text{Yearly vehicle service cost} = \sum_{m \in M} X_m W \qquad (3.1.4)$$

M is the set of month --- {January, February, March, ..., December)

W is the given working day of each month

$X_m$ is the vehicle service cost per day (calculated from equation *(3.1.3)*) of month m

In <u>Example 5</u>, we assume that the set of Supplier Number 6's representatives from the previous sub-process is {680, 800, 680, 800, 800, 0, 800, 680, 1480, 800, 680, 800}. Each representative's yearly vehicle service cost is calculated. The set of calculated yearly vehicle service cost is {400000, 600000, 400000, 600000, 600000, 1200000, 600000, 400000, 1000000, 600000, 400000, 600000}. The first element of the set of calculated yearly vehicle service cost, 400000, represents the service cost in the upcoming year, if the provider hires contract vehicles for serving only 680 kg., January's representative, of capacity usage.

*Select the most representative*

After the each representative's yearly vehicle service cost has been calculated, this step will select the representative that has the lowest cost to be the representative of the chosen supplier.

In Example 5, the capacity usage of 680 kg. gives the lowest yearly vehicle service cost, 400000 baht. So it will be the representative of Supplier Number 6.

*Calculate the number of needed contract vehicles for the chosen supplier*

This step is going to calculate the number of needed contract vehicles using the selected representative of the chosen supplier from the previous step. The number of needed contract vehicles is calculated using equation *(3.1.5)*.

$$\text{Number of needed contract vehicles} = \frac{\text{The chosen supplier's representative}}{\text{Actual capacity of vehicles}} \qquad (3.1.5)$$

In Example 5, the representative of Supplier Number 6 is 680 kg., and the actual capacity of vehicles is 6000 kg. So, the number of needed contract vehicles is $\frac{680}{6000}$ =0.11.

**Does every supplier have been considered?**

The vehicle estimation process will be repeated until every supplier has been considered and has its own number of needed contract vehicles. When every supplier has been considered, the final number of contract vehicles calculation process will be executed.

**The final number of contract vehicles calculation process**

This process is going to the final number of needed contract vehicles using the number of needed contract vehicles of each supplier. Next, the final number will be rounded up, because the contract vehicles must be hired in integer number.

In Example 5, we assume the representatives of Supplier Number 6 to 9 are 0.11, 0.70, 0.88, and 0.48 respectively. The final number of needed contract vehicles is 0.11 + 0.70 + 0.88 + 0.48 = 2.17. After rounding up, the final number of needed contract vehicle of Example 5 is 3.

In conclusion, the detailed flow chart including every step of the system is shown in Figure 16.

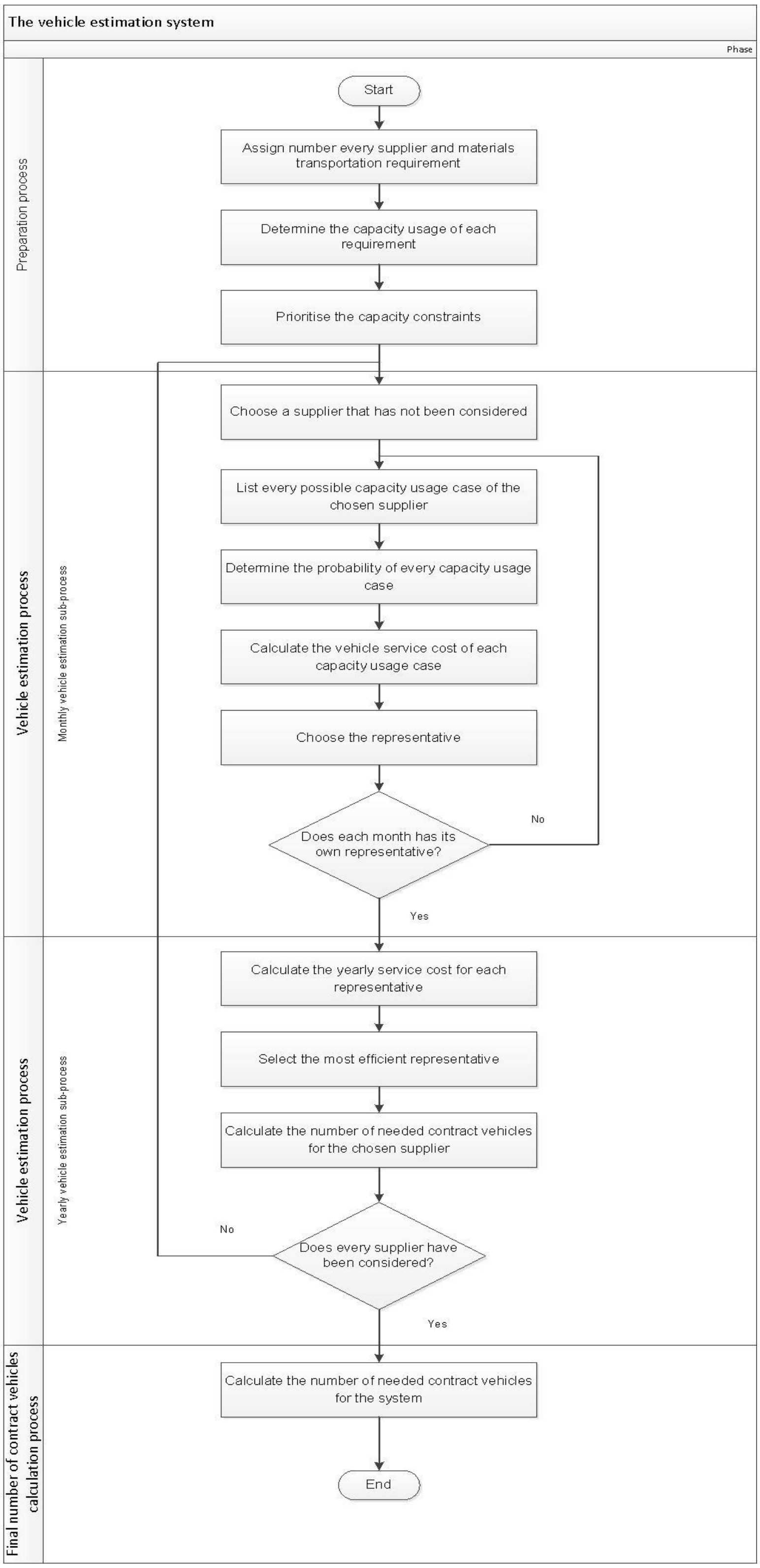


*Figure 16 the detailed flow chart of the vehicle estimation system*

### 3.1.4. Example of the system

This sub-section gives an example, Example 6, to illustrate every process of the vehicle estimation system.

Example 6

There are 20 requirements, 3 customers, and 15 suppliers, and each vehicle has a capacity of 6,000 kg and 40 $m^3$. We assume the average speed of vehicle is 60 km/ hr. The service cost of contract vehicle is 2,250 baht per day, while the outsourcing's service cost is 2,700 baht per day.

The locations of stakeholders are displayed in the (X, Y) coordinate in Table 16.

*Table 16 locations of stakeholders of Example 6*

| | Number | X | Y |
|---|---|---|---|
| Customer | 1 | 83 | 57 |
| | 2 | 76 | 118 |
| | 3 | 136 | 127 |
| Supplier | 4 | 7 | 55 |
| | 5 | 91 | 106 |
| | 6 | 149 | 177 |
| | 7 | 164 | 160 |
| | 8 | 156 | 142 |
| | 9 | 96 | 85 |
| | 10 | 24 | 82 |
| | 11 | 85 | 59 |
| | 12 | 177 | 173 |
| | 13 | 170 | 143 |
| | 14 | 7 | 80 |
| | 15 | 52 | 60 |
| | 16 | 115 | 46 |
| | 17 | 113 | 16 |
| | 18 | 152 | 156 |

Note that, the each customer and supplier has been assigned number already.

After the customers inform about their yearly plans, the requirements capacity usage are shown in Table 17. The primary capacity constraint is weight.

*Table 17 capacity usage of each requirement of Example 6*

| Requirement Number | Supplier Number | Customer Number | Weight (kg) | Volume ($m^3$) |
|---|---|---|---|---|
| 1 | 13 | 3 | 600 | 0.09 |
| 2 | 5 | 2 | 840 | 0.10 |
| 3 | 8 | 1 | 600 | 0.07 |
| 4 | 10 | 1 | 720 | 0.11 |
| 5 | 18 | 2 | 840 | 0.06 |
| 6 | 4 | 3 | 780 | 0.50 |
| 7 | 12 | 2 | 780 | 0.60 |
| 8 | 16 | 2 | 600 | 0.78 |
| 9 | 12 | 3 | 660 | 0.12 |
| 10 | 6 | 1 | 780 | 0.15 |
| 11 | 7 | 1 | 900 | 0.96 |
| 12 | 4 | 1 | 840 | 1.50 |
| 13 | 17 | 2 | 780 | 0.63 |
| 14 | 10 | 2 | 840 | 0.78 |
| 15 | 6 | 2 | 720 | 0.77 |
| 16 | 11 | 2 | 600 | 0.85 |
| 17 | 10 | 3 | 900 | 0.32 |
| 18 | 13 | 1 | 900 | 0.07 |
| 19 | 7 | 3 | 900 | 0.05 |
| 20 | 18 | 3 | 840 | 0.78 |

The given yearly plans also includes the number of days that each requirement will be placed per month. The number of days is given in the form shown in .Table 11. The provider needs to rearrange it by the assigned requirement numbers as shown in Table 18.

*Table 18 predicted number of days that each requirement will be placed to the supplier*

| Requirement Number | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 18 | 16 | 3 | 1 | 9 | 12 | 4 | 1 | 5 | 0 | 15 | 15 |
| 2 | 8 | 19 | 15 | 14 | 0 | 8 | 15 | 15 | 4 | 1 | 16 | 5 |
| 3 | 20 | 8 | 3 | 17 | 11 | 10 | 11 | 19 | 19 | 17 | 16 | 13 |
| 4 | 20 | 9 | 20 | 20 | 3 | 20 | 4 | 8 | 3 | 4 | 5 | 3 |
| 5 | 4 | 11 | 17 | 12 | 3 | 5 | 12 | 17 | 20 | 18 | 1 | 1 |
| 6 | 8 | 8 | 10 | 16 | 10 | 16 | 16 | 11 | 2 | 1 | 15 | 12 |
| 7 | 8 | 15 | 11 | 4 | 17 | 8 | 1 | 16 | 2 | 0 | 13 | 0 |
| 8 | 13 | 19 | 15 | 13 | 4 | 20 | 13 | 1 | 7 | 18 | 12 | 16 |
| 9 | 9 | 8 | 19 | 7 | 8 | 14 | 0 | 2 | 17 | 5 | 3 | 9 |
| 10 | 14 | 7 | 20 | 12 | 17 | 6 | 19 | 8 | 15 | 10 | 3 | 11 |
| 11 | 1 | 3 | 7 | 3 | 9 | 13 | 4 | 10 | 3 | 16 | 15 | 8 |
| 12 | 10 | 14 | 8 | 9 | 0 | 11 | 3 | 8 | 16 | 6 | 20 | 18 |
| 13 | 0 | 1 | 5 | 1 | 20 | 4 | 0 | 20 | 5 | 7 | 6 | 5 |
| 14 | 7 | 17 | 14 | 4 | 0 | 14 | 5 | 19 | 12 | 11 | 2 | 2 |
| 15 | 18 | 10 | 7 | 4 | 6 | 16 | 16 | 16 | 4 | 10 | 3 | 7 |
| 16 | 7 | 2 | 11 | 20 | 15 | 16 | 2 | 2 | 8 | 3 | 2 | 3 |
| 17 | 18 | 20 | 7 | 2 | 0 | 0 | 5 | 9 | 19 | 3 | 4 | 10 |
| 18 | 17 | 17 | 13 | 10 | 12 | 11 | 1 | 18 | 14 | 6 | 17 | 19 |
| 19 | 2 | 6 | 4 | 16 | 8 | 0 | 15 | 15 | 8 | 4 | 7 | 7 |
| 20 | 8 | 14 | 15 | 3 | 4 | 14 | 9 | 4 | 19 | 1 | 2 | 18 |

We choose to consider Supplier Number 4.

In January, the possible capacity usage case (in terms of weight) of Supplier Number 4 are {0, 780, 840, 1620} with the probability of {0.3, 0.2, 0.3, 0.2} respectively. Note that the requirements associated with Supplier Number 4 are Requirement Numbers 6 and 12.

The vehicle service cost of each case is {329.4, 376.2, 385.2, 607.2} respectively. As a result, the capacity usage of 0 will be the representative of Supplier Number 4 in January.

Next, we calculate the representative for every month. The representatives are as shown in Table 19.

*Table 19 representative capacity usage of Supplier Number 4*

| Month | Representative |
|---|---|
| 1 | 0 |
| 2 | 780 |
| 3 | 780 |
| 4 | 780 |
| 5 | 780 |
| 6 | 780 |
| 7 | 780 |
| 8 | 780 |
| 9 | 780 |
| 10 | 780 |
| 11 | 840 |
| 12 | 840 |



Subsequently, we calculate the yearly vehicle service cost of each representative. Table 20 shows the yearly vehicle service cost of each representative.

*Table 20 the yearly vehicle service cost of each representative*

| Representative | Yearly vehicle service cost |
|---|---|
| 0 | 120,784 |
| 780 | 96,020 |
| 780 | 96,020 |
| 780 | 96,020 |
| 780 | 96,020 |
| 780 | 96,020 |
| 780 | 96,020 |
| 780 | 96,020 |
| 780 | 96,020 |
| 780 | 96,020 |
| 840 | 98,099 |
| 840 | 98,099 |

As a result, the capacity usage of 780 kg. is chosen to be the representative Supplier Number 4.

Then, we calculate the number of needed contract vehicle for Supplier Number 4 using its representative. The number of needed contract vehicle for Supplier Number 4 is 0.13.

After that, we choose another supplier to be considered, until every supplier has been considered. Note that, there can be some suppliers that are in the customers' supplier list, but the customers do not require materials from them in the upcoming year.

The number of needed contract vehicles of each supplier is shown in Table 21.

*Table 21 the number of needed contract vehicles of each supplier*

| Supplier Number | Number of needed contract vehicle |
|---|---|
| 4 | 0.13 |
| 5 | 0.14 |
| 6 | 0.12 |
| 7 | 0.15 |
| 8 | 0.10 |
| 9 | 0 |
| 10 | 0.12 |
| 11 | 0.10 |
| 12 | 0.11 |
| 13 | 0.10 |
| 14 | 0 |
| 15 | 0 |
| 16 | 0.10 |
| 17 | 0.13 |
| 18 | 0.14 |

As a result, the final number of needed contract vehicles is 1.44. Supplier Number 9, 14, and 15 do not receive any requirement from customer this year. Lastly, the number will be rounded up, and the final number of contract vehicles of this example is 2.

## 3.2. The routes planning system

The planning system in this research means the arranging of the locations that vehicles have to visit by using the given exact plans from customers. The system uses the column generation algorithm concept along with LSP heuristic. The system aims to arrange visited locations for each vehicle to minimise the transportation cost. The transportation cost consists of the service cost (fixed cost) including the guarantee cost, and the distance cost (variable cost).

The routes planning system is operated every working day by using the given exact plans. The plans inform about the materials transportation requirements of customers, i.e., suppliers, number of materials, deliveries time window. Every materials transportation requirement must be fulfil within one day, the overnight delivery is restricted. Every vehicle has limited working hour per day due to the Labour Relation Act of Thailand. If the number of the planned routes is more than the number of contract vehicles, estimated from the vehicle estimation system, the outsourcing vehicles will be hired for the additional routes. When a vehicle visit a supplier's location, the materials will be picked up. On the other hand, a vehicle will drop materials off, when visits a customer's location. Every pickup and dropping off activities take time, called loading/ unloading time.



After the routes have been planned, the provider will inform each contract and outsourcing vehicle about their visited locations sequence. Then, the vehicle will performed the pickup and delivery service until every location in the given locations sequence is visited.

This section starts with system description including objective, scopes, assumptions, constraints, and inputs. After that, the core processes of the system is discussed and illustrated. Subsequently, detail of the core processes is explained thoroughly. An example demonstrating every process is given after the explanation.

### 3.2.1. System description

In this sub-section, the objective of the routes planning system will be proposed along with the decision variable. The scopes and assumptions are informed afterwards. Subsequently, the system's constraints and inputs are notified.

System's objective

To minimise the transportation cost in a particular day by designing efficient routes for serving customers' materials transportation requirements.

System's decision variable

Planned route for each vehicle

Scopes of the routes planning system

1. The routes planning system is the system for routes planning in the provider's operations.

2. The outcome of the system is the planned route sequence for each vehicle.

3. The system does not include the drivers' allocation system and fuel management system.

4. Any unexpected incidents such as accidents, vehicle malfunctions, or road closures are not considered in the system.

5. The transportation cost in the system are service cost (fixed cost) and distance cost (variable cost). The service cost of an outsourcing vehicle is more expensive than a contract vehicle.

6. The planned routes always begin at the first visit supplier's location, and finish at the last visit customer's location. The journey from/to a vehicle owner's location is not included in the planned routes.

7. The journeys in the routes can be a journeys between a supplier and a supplier, a journey between a supplier and a customer, or a journey between a customer and a customer.

8. The capacity of vehicles is considered in term of weight and volume only, shape is negligible.

9. The transhipments are not allowed as well as the overnight deliveries.

10. There are 2 types of locations in the system which are suppliers and customers; each location must be either supplier or customer.



Assumptions of routes planning system.

1. Every vehicle in the system is homogeneous.

2. Every informed materials requirement in the customers' exact plan is less than truckload.

3. The capacity constraint is considered in only 2 dimensions which are volume and weight, the shape of the materials are not considered.

4. Every material can be delivered together, no materials restriction.

5. The transportation cost in the system consists of at least 2 components which are service cost and distance cost. The guarantee cost will be paid when the number of contract vehicles is too high.

6. Every contract vehicle has the same service cost per day, similarly, every outsourcing vehicle also has the same service cost per day.

7. The rate of the distance cost of contract vehicles is the same as outsourcing vehicles

8. The loading/unloading time at any location is the same.

9. The distances between locations are represented as displacement.

10. The travelled times between locations have linear relationship with distances.

11. Every vehicle is driven at constant speed.

12. Every vehicle in the system has the same working hour limited to The Labour Relation Act of Thailand.

13. The number of vehicles in the system is unlimited. But when the number of contract vehicles is not sufficient, the outsourcing vehicles will be hired

14. The considered routes do not include a journey to/from the vehicles owners' places. The considered routes start at one of suppliers' locations and finish at one of customers' locations. It is assumed that the vehicles must be ready to operate at a starting location at the beginning of a working day.

15. The finishing locations of the previous days are not dependent with today starting locations.



<u>System's constraints</u>

1. Capacity constraint in terms of weight.

2. Capacity constraint in terms of volume.

3. Time constraint in terms of vehicles' working hour.

4. Time constraint in terms of deliveries' time window. The deliveries time window means the required arrival time window of a materials transportation requirement, informed by a customer.

System's inputs

1. Suppliers and customers' location
2. Number of required materials from customers' exact plan
3. Delivery's time window of each materials transportation requirement
4. Number of contract vehicles (Result from the vehicle estimation system)
5. Capacity of vehicles in terms of weight
6. Capacity of vehicles in terms of volume
7. Service cost (fixed cost) per day of each contract vehicle
8. Service cost (fixed cost) per day of each outsourcing vehicle
9. Average speed of vehicles
10. Working hours per day of vehicles
11. Rate of distance cost (variable cost) in unit of Baht per kilometre
12. Guarantee cost per day of contract vehicles
13. Distance between locations
14. Time between locations

### 3.2.2. Conceptual design of the system

This sub-section explains about the concepts and core processes of the routes planning system. The system applies the column generation algorithm concept to construct the feasible routes (columns) that tend to reduce the transportation cost. The system applies LSP heuristic concept to solve the pricing problem, a sub-problem inside the column generation algorithm. To prevent the system from creating too many routes, the tabu search concept is also applied.

The system can be separated into 7 core processes. First, the preparation process will be initiated to rearrange obtained information, e.g., given exact plans. Next, the initial process will be executed. This process is comparable to the column generation algorithm's initial process (See 2.1.1) which aims to generate initial columns for obtaining the primary dual variables. After the primary dual variables are obtained, modified LSP heuristic (adapted from LSP heuristic) will be operated to solve the pricing problem of the column generation algorithm. The modified heuristic begins with the layer extended process using to extend the obtained routes (columns). Subsequently, the routes screening process (I) will be used to eliminate some seemingly inefficient extended routes. If there is any route left, the routes screening process (II) will be executed; otherwise, the dual variables obtaining process will be done. The system will always repeat the layer extended process, after the route screening process (II) has been executed. On the other hand, if the dual variables obtaining process has been executed, the system will considered the stopping criteria. If the system does not meet the stopping criteria, the layer extended process will be repeated; otherwise, the final solution identifying process will be completed. The core processes' flow chart is shown in Figure 17.

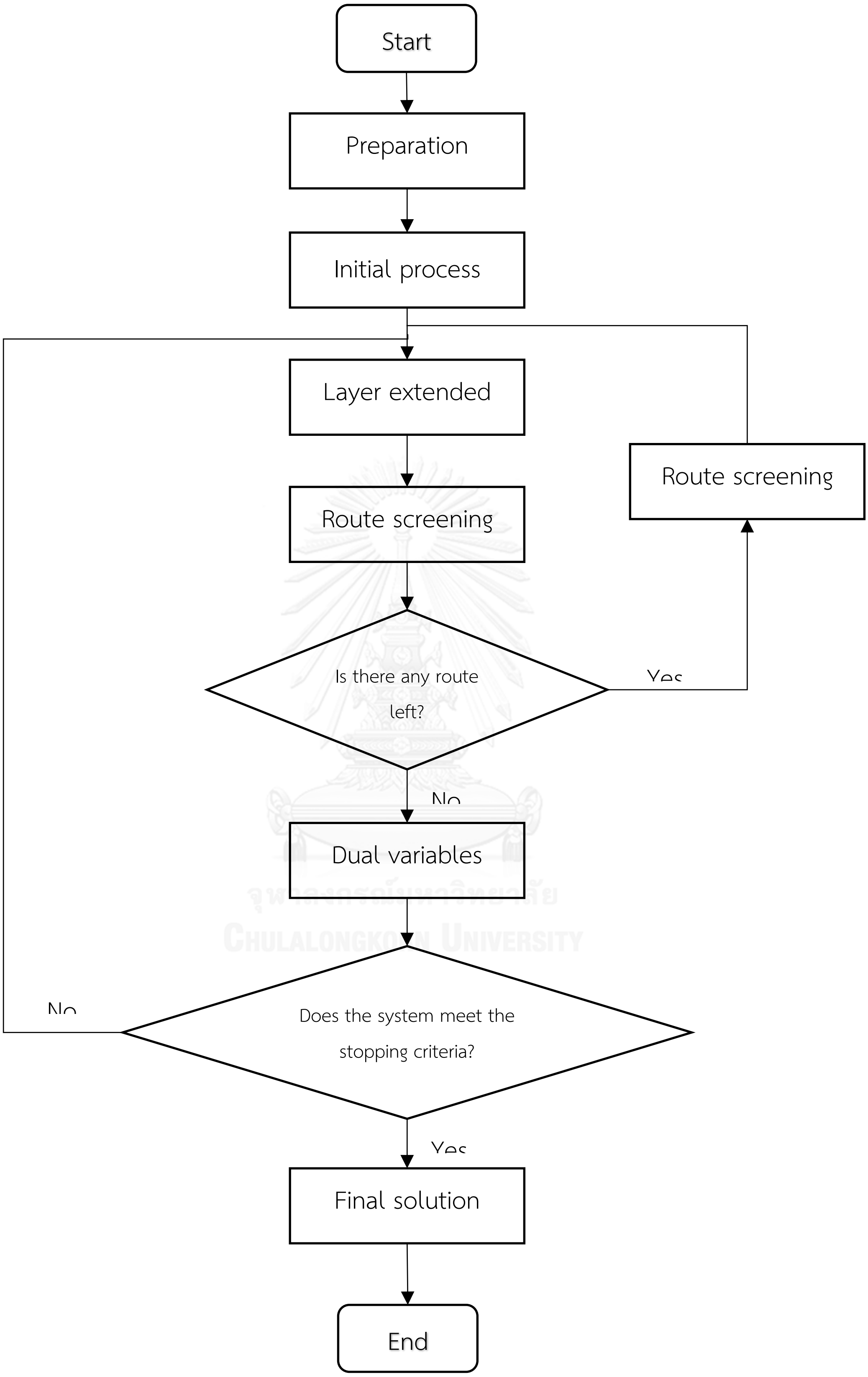


*Figure 17 core processes' flow chart of the routes planning system*

### 3.2.3. Detailed design of the system

This sub-section is going to explain and describe each of the core processes intensively. The explanation will use Example 7 as a demonstrator.

Example 7

There are 2 customers (Customer Numbers 1 and 2), and 3 suppliers (Supplier Numbers 3, 4, and 5) in the system. Note that, the numbers have been assigned to every customers and suppliers from the vehicle estimation system (More information will be given during the explanations).

**The preparation process**

This process aims to rearrange the information from the given exact plans from customers. The information in a customer's exact plan consists of materials transportation requirements including suppliers' names, number of required materials, and arrival time windows. Also, the system's stopping criteria and the tabu list (See Definition 3) criteria are set in this process.

Definition 3: A tabu list in this research context is the list containing routes. The routes in the tabu list are prohibited to use in every process of the system. The purposes of tabu list are to prevent the system from creating too many routes. The routes in the tabu listed can be removed (depends on the removing criteria).

This process comprises of 2 steps listed as follows.

1. Rearrange the received information.
2. Set the system's stopping and tabu list criteria.

*Rearrange the received information*

After customers' exact plans have been informed, each materials transportation requirement will be numbered. A materials transportation requirement notify about supplier's name, number of required materials, and the required arrival time window. The number of required materials will be transformed into the capacity usage in terms of weight and volume (Normally, customers also inform about their weight and volume to the provider). And, supplier's name also transforms to the assigned supplier number. Every supplier has been numbered in the vehicle estimation process.

In Example 7, the obtained customers' exact plans have been rearranged, and shown in Table 22.

*Table 22 rearranged information of Example 7*

| Requirement Number | Supplier Number | Customer Number | Weight (kg.) | Volume ($m^3$) | Delivery time window |
|---|---|---|---|---|---|
| 1 | 3 | 2 | 2000 | 1.84 | 8.00 – 10.00 |
| 2 | 3 | 1 | 3000 | 0.80 | 8.00 – 12.00 |
| 3 | 4 | 1 | 1000 | 1.47 | 14.00 – 17.00 |
| 4 | 5 | 1 | 700 | 1.22 | 13.00 – 15.00 |
| 5 | 5 | 2 | 1500 | 0.98 | 8.00 – 12.00 |



As shown in Table 22, some materials transportation requirement from the same customer can require different delivery time window.

*Set the system's stopping and tabu list criteria*

The stopping criteria are set to prevent the system from operating eternally. The stopping criteria could be any criterion, but it should allow the system to create some promising solutions before being stopped. There can be more than one stopping criterion in the system. Some examples of stopping criterion are listed as follows.

- Stop when the solution does not change for 100 iterations.

- Stop when the created routes do not change for 10 iterations.

- Stop when the recently created routes do not have any impact on the solution for 20 iterations.

The tabu list (See Definition 3) can reduce the number of created routes dramatically. Too large number of created routes may lead to an unsolvable problem. An example of tabu list criteria is listed as follows.

- Routes that have not been appeared in the solution for more than 10 iterations will be put into the tabu list.

**The initial process**

Similar to the initial process of the column generation algorithm (See 2.1.1), this process aims to generate initial routes (columns) to obtain primary dual variables. This process consists of 3 steps listed as follows.

1. Create initial routes.

2. Solve the set covering problem's relaxation model using the initial routes.

3. Obtain the dual variables.



*Create initial routes*

As mentioned in the column generation algorithm concept, the initial routes normally be the routes that are easy to create. In this research, an initial route is the route serving only 1 materials transportation requirement. As a result, the number of initial routes must be equal to the number of materials transportation requirements informed in the customers' exact plans. The route serving only 1 materials transportation requirement must consist only 1 journey, from a supplier to a customer, as shown in Figure 18.


*Figure 18 an initial route illustration*

In Example 7, there will be 5 initial routes according to the number of materials transportation requirement. The initial routes are shown in Table 23.

*Table 23 the initial routes of Example 7*

| **Initial Route Number** | **Visited locations arrangement** | |
|---|---|---|
| 1 | 3 | 2 |
| 2 | 3 | 1 |
| 3 | 4 | 1 |
| 4 | 5 | 1 |
| 5 | 5 | 2 |

Refer to, the visited locations arrangement indicates the order of locations that each initial route needs to visit. For example, Initial Route Number 1 is the route that visits Supplier Number 3 first, then delivers material to Customer Number 2. Note that, locations numbers 1 and 2 are customers, the others are suppliers.

*Solve the set covering problem's relaxation model using the initial routes*

First, the distance cost (variable cost) of each initial routes must be identified. The set covering problem's relaxation model using in this research is slightly different from the original model (Model 2) as displayed in Model 3. We solve Model 3 using the initial routes as the created routes (set S). Model 3 can be solved by common optimiser, e.g., Excel Solver, CPLEX, etc.

Model 3

Let

U be the set of materials transportation requirements

S be the set of created routes

M be the average service cost of a contract and an outsourcing vehicle

$c_s$ be the distance cost of route s in set S

$x_s$ be the decision variable of a created route s in set S

$a_{rs}$ be the parameter indicating whether requirement r including in created route s or not

$$a_{rs} = \begin{cases} 1 & \text{if requirement r including in created route s} \\ 0 & \text{otherwise} \end{cases}$$



Objective:

To minimise $$\sum_{s \in S} (c_s + M)x_s \qquad (3.2.1)$$

Subject to:

$$\sum_{s \in S} a_{rs}x_s \geq 1 \quad \text{for all r in U} \qquad (3.2.2)$$

$$x_s \in [0, 1] \quad \text{for all s in S} \qquad (3.2.3)$$

Equation *(3.2.1)* indicates the objective function of the model. The term ($c_s$ + M) shows the transportation cost of route s, in other words, if route s is selected in the solution, the provider needs to pay ($c_s$ + M) baht. Also, equation *(3.2.2)* shows that each materials transportation requirement can be contained in more than one routes in the solution. The distance cost ($c_s$) is calculated by the multiplication of distance and transportation rate. The transportation rate is the rate decided by vehicles' owner normally come in unit of baht per kilometre

In Example 7, each initial route's distance cost is calculated. The service cost of a contract vehicle is 2250 baht per day, while the service cost of an outsourcing vehicle is 2700 baht per day. So, the value of M in Model 3 in this example will be 2475. The number of constraints is equal to the number of materials transportation requirements.

*Obtain the dual variables*

After the set covering problem's relaxation model has been solved, the dual variables will be determined automatically by the optimiser. Each dual variable belongs to each materials transportation requirement, so the number of dual variables must be equal to the number of materials transportation requirements (which links to the number of constraints).

In Example 7, we assume that the determined dual variables are $d_1$, $d_2$, $d_3$, $d_4$, and $d_5$ which belong to Requirement Numbers 1, 2, 3, 4, and 5 (See Table 22) respectively.

**Layer extended process**

This process extends the routes obtained from previous processes. As shown in Figure 17, the layer extended process could obtain routes from the initial process, the route screening process (II), or the dual variables obtaining process. The routes from the initial process and the dual variables obtaining process are initial routes (serve only 1 materials transportation requirement), while the routes from the route screening process (II) are screened routes (serve more than 1 materials transportation requirement).

The process applies LSP heuristic concept to extend the obtained routes. First, every obtained route will be numbered, and modified to prepare for the upcoming extending step. The extending step will lengthen the obtained routes using LSP heuristic concept. Next, the extended routes will be numbered. After that, the extended routes will be completed by inserting and adding some locations to the extended routes. Thus, the process consists of several steps listed as follows.

1. Number the obtained routes.
2. Modify the obtained routes.
3. Extend the modified routes.
4. Number the extended routes.
5. Insert customers' locations into the extended routes.
6. Complete the extended routes.

*Number the obtained routes*

This step aims to number every obtained route from the previous process. The route can be the initial routes, if the previous step is the initial step or the dual variables obtaining step, or screened routes, if the previous step is the route screening process (II).

In Example 7, the initial routes from the initial step are obtained (See Table 23). Each obtained route is numbered as shown in Table 24.

*Table 24 the numbered obtain routes of Example 7*

| Obtained Route Number | Visited locations arrangement | |
|---|---|---|
| 1 | 3 | 2 |
| 2 | 3 | 1 |
| 3 | 4 | 1 |
| 4 | 5 | 1 |
| 5 | 5 | 2 |

*Modify the obtained routes*

This step aims to prepare the obtained routes from the previous step for the upcoming extension step. First, we separate an obtained route into 2 part, namely, the first part, and the second part (See Definition 4).

Definition 4: The first part of an obtained route is defined as the journeys from the first visited supplier's location to the last visited supplier's location; while, the second part of an obtained route consists of the journeys from the last visited supplier's location to the last visited customer's location. If an obtained route is consist of only one supplier's location, the route will not contain the first part. Figures 19 and 20 illustrate the obtained route separation.

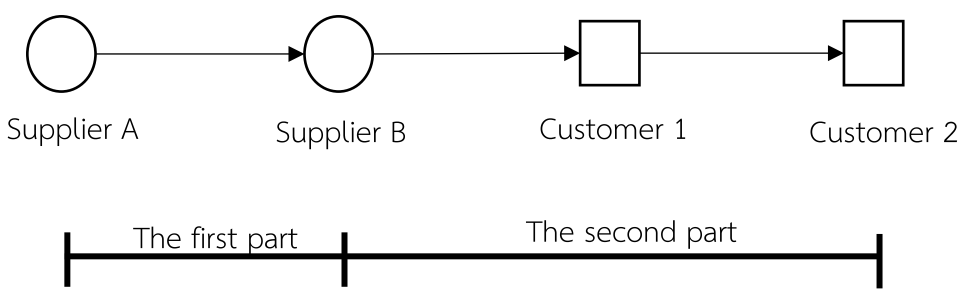


*Figure 19 an example of an obtained route's components when there are more than one supplier locations in it*

The obtained route in Figure 19 contains 2 suppliers, Suppliers A and B, and 2 customers, Customers 1 and 2. The first visited supplier's location is Supplier A, while the last visited supplier's location is Supplier B. The last visit customer's location is Customer 2, so that, the second part consists of the journeys from Supplier B to Customer 1 and from Customer 1 to Customer 2.

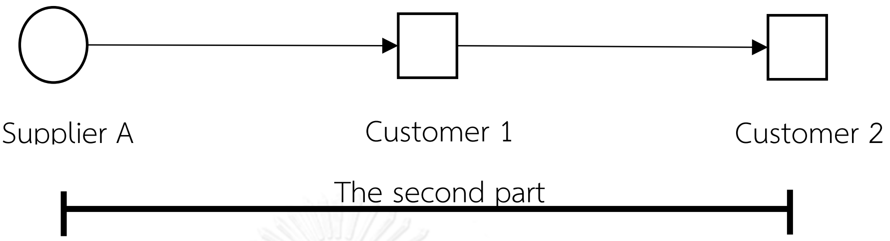


*Figure 20 an example of an obtained route's components when there is one supplier location in it*

The obtained route in Figure 20, contains 1 supplier, Supplier A, and 2 customers, Customers 1 and 2 (We can imply that both customers require materials from the same supplier). From the Definition 4, the obtained route does not have any journey for the first part. Thus, this obtained route contains only the second part.

After the obtained routes first and second parts have been determined, the routes will be modified by removing the second part. Figures 21 and 22 show the modified obtained route from the obtained route in Figures 19 and 20 respectively.

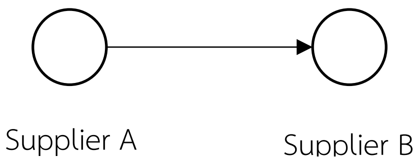


*Figure 21 the modified obtained route from the obtained route in Figure 19*


*Figure 22 the modified obtained route from the obtained route in Figure 20*

In Example 7, each of the obtained routes serve only 1 materials transportation requirement, so the routes contain only the second part. The modification will remove the obtain routes' second part. The modified obtained routes are illustrate in Table 25

*Table 25 the obtained routes after modification of Example 7*

| Modified Route Number | Visited location arrangement after modification |
|---|---|
| 1 | 3 |
| 2 | 3 |
| 3 | 4 |
| 4 | 5 |
| 5 | 5 |

*Extend the modified routes*

This step will extend each modified route by adding an unassigned materials transportation requirement's supplier location individually. First, the unassigned materials transportation requirements of each modified route must be identified. Each unassigned materials transportation requirement's supplier's location will be added to the modified route to form an extended route (one modified route can form several extended routes depending on the number of unassigned materials transportation requirements of that route).

In Example 7, the unassigned materials transportation requirements of each modified route are listed in Table 26.

*Table 26 the assigned and unassigned materials transportation requirements of each modified route of Example 7*

| Modified Route Number | Assigned materials transportation Requirement Number | Unassigned materials transportation Requirements Number |
|---|---|---|
| 1 | 1 | 2, 3, 4, 5 |
| 2 | 2 | 1, 3, 4, 5 |
| 3 | 3 | 1, 2, 4, 5 |
| 4 | 4 | 1, 2, 3, 5 |
| 5 | 5 | 1, 2, 3, 4 |

Each unassigned materials transportation requirements will be added to its modified route individually forming an extended route. Every extended route of Example 7 is shown in Tables 27 and 28.



*Table 27 the extended routes of Example 7 (1)*

| Modified Route Number | Extended route visited location arrangement | | Recently added Requirement Number |
|---|---|---|---|
| 1 | 3 | 3 | 2 |
| | 3 | 4 | 3 |
| | 3 | 5 | 4 |
| | 3 | 5 | 5 |

*Table 28 the extended routes of Example 7 (2)*

| Modified Route Number | Visited locations arrangement after modification | | Recently added Requirement Number |
|---|---|---|---|
| 2 | 3 | 3 | 1 |
| | 3 | 4 | 3 |
| | 3 | 5 | 4 |
| | 3 | 5 | 5 |
| 3 | 4 | 3 | 1 |
| | 4 | 3 | 2 |
| | 4 | 5 | 4 |
| | 4 | 5 | 5 |
| 4 | 5 | 3 | 1 |
| | 5 | 3 | 2 |
| | 5 | 4 | 3 |
| | 5 | 5 | 5 |
| 5 | 5 | 3 | 1 |
| | 5 | 3 | 2 |
| | 5 | 4 | 3 |
| | 5 | 5 | 4 |

*Number the extended routes*

This step numbers every extended route from the previous step. For Example 7, the numbered extended routes are shown in Table 29.

*Table 29 numbered extended routes of Example 7*

| Extended Route Number | Visited locations arrangement after modification | | Recently added Requirement Number | Extend from Obtained Route Number |
|---|---|---|---|---|
| 1 | 3 | 3 | 2 | 1 |
| 2 | 3 | 4 | 3 | |
| 3 | 3 | 5 | 4 | |
| 4 | 3 | 5 | 5 | |
| 5 | 3 | 3 | 1 | 2 |
| 6 | 3 | 4 | 3 | |
| 7 | 3 | 5 | 4 | |
| 8 | 3 | 5 | 5 | |
| 9 | 4 | 3 | 1 | 3 |
| 10 | 4 | 3 | 2 | |
| 11 | 4 | 5 | 4 | |
| 12 | 4 | 5 | 5 | |
| 13 | 5 | 3 | 1 | 4 |
| 14 | 5 | 3 | 2 | |
| 15 | 5 | 4 | 3 | |
| 16 | 5 | 5 | 5 | |
| 17 | 5 | 3 | 1 | 5 |
| 18 | 5 | 3 | 2 | |
| 19 | 5 | 4 | 3 | |
| 20 | 5 | 5 | 4 | |

Note that, some extended routes have the same visited locations, e.g., Extended Route Numbers 1 and 5. The same visited locations indicates that the supplier of the assigned materials transportation requirement of those route is the same. The journey's distance between the same locations is 0.

*Insert the customers' locations into the extended routes*

This step aims to insert customers' locations to some extended routes by considering several factors. The insertion will be occurred before the last visited location of an extended route. The factors used for insertion's consideration are listed as follows.

1. Capacity in terms of weight and volume.
2. Nearby locations.
3. Customers' locations of undelivered materials transportation requirements

Each extended route will be considered individually. The capacity factor will be examined first. If an extended route violate any capacity constraint, at least one customer's location must be inserted before the recently added requirement's supplier's location. Next, the customers' locations factor will be considered. If the recently added requirement's customer's location is the same as one of the undelivered materials transportation requirements, there will be no insertion. Otherwise, the nearby location factor will be checked. If at least one of the undelivered materials transportation requirements' customers' locations situates in the nearby area (See Definition 5), at least one of undelivered requirements' customers' locations will be inserted before the recently added requirement's supplier's location. Otherwise, there will be no insertion. The decision flow of the insertion consideration is displayed in Figure 23. Note that, the undelivered materials transportation requirements of the extended route do not include the recently added requirement.

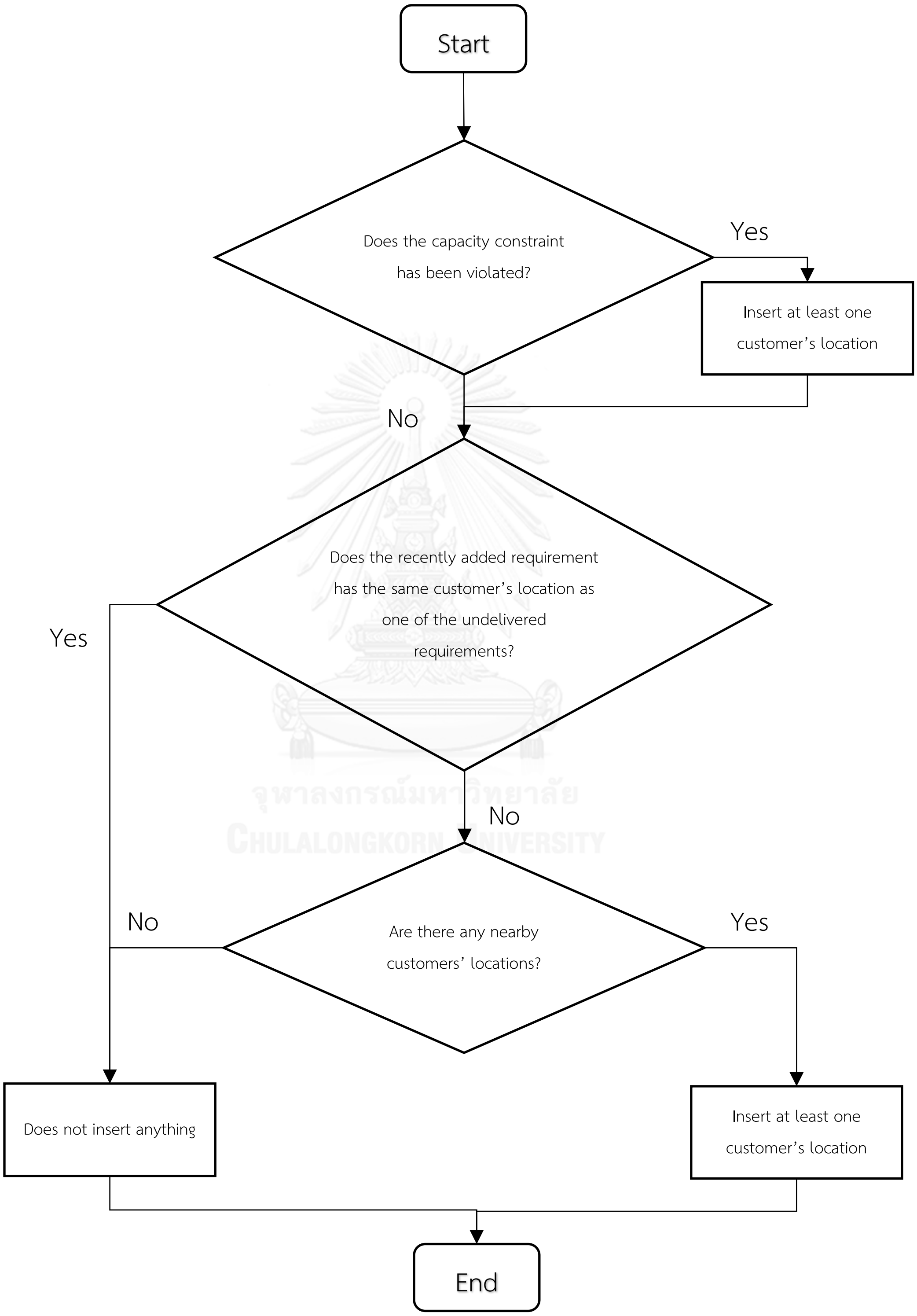


*Figure 23 the decision flow of the insertion’s consideration*

The first decision in Figure 23 is the consideration of the capacity constraint. If the constraint is violated, at least one of the undelivered materials transportation requirements' customers' locations will be inserted between the last location of a modified route and the supplier's location of the recently added requirement. The insertion position is illustrated in Figure 24.

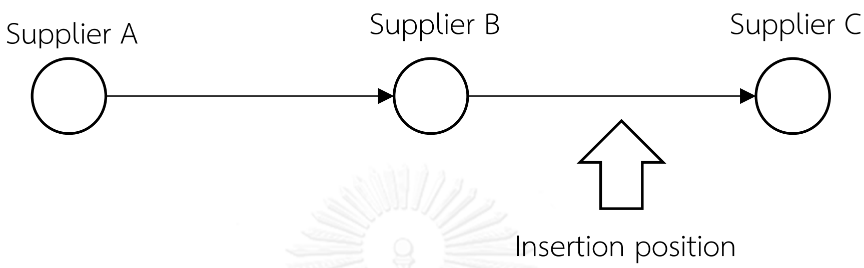


*Figure 24 an illustration of the insertion position*

In Figure 24, Supplier C is assumed to be the recently added materials transportation requirement's supplier's location, so the insertion position is between Supplier B and Supplier C

To choose which customers' locations are going to be inserted, every undelivered requirements' customers' location will be ranked by distance and capacity usage. In terms of distance, we means the distance between an undelivered requirement's customer's location and the last location of a modified route (or Supplier B in Figure 24). The nearest customer's location will be ranked as the first. In terms of capacity usage, we means the primary capacity constraint (See 3.1.3). In this research, the primary capacity constraint is weight. The customer's location that has highest capacity usage (determine from the weight of undelivered requirements) will be ranked as the first. The summation of both ranks will be the representative rank of each customer's location. The customer's location that has the lowest representative rank will be inserted to an extended route at the insertion position. If two customers' locations have the same representative rank, the one that has lowest rank in terms of distance will be preferable. After inserting one of the customers' locations to an extended route, if the capacity constraint is still violated, the next rank will be inserted at the insertion position (after the recently inserted customer's location).

Example 8

There are 2 undelivered materials transportation requirements, Requirements Numbers 81 and 82 in an extended route. The recently added requirement is Requirement Number 83. The vehicle capacity are 9000 kg. and 40 $m^3$. Some necessary information are shown in Table 30 and Figure 25.

*Table 30 requirement information of Example 8*

| Requirement Number | Supplier's location | Customer's location | Weight (kg.) | Volume ($m^3$) |
|---|---|---|---|---|
| 81 | A | X | 5000 | 0.5 |
| 82 | B | Y | 3000 | 5.0 |
| 83 | C | Z | 2000 | 7.5 |

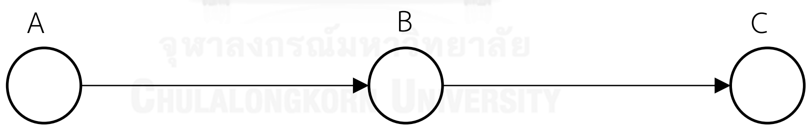


*Figure 25 the extended route of Example 8*

After the extension step, the system detects that the capacity constraint is violated. So, at least one of the undelivered requirements' customers' locations, X and Y, must be inserted between Locations B and C. We assume that the distance from Location B to X is shorter than from Location B to Y. So, Location X is the 1st in terms of distance. When considering about the capacity usage, the primary capacity constraint, weight, is considered. Before arriving at Location C, the vehicle already carries 8000 kg. of materials (5000 kg. belongs to Location X). Thus, Location X is also the 1st in terms of capacity usage. As a result, Location X will be inserted to the extended route, and there will be only 1 undelivered requirement left (Requirement Number 82). The route after insertion are shown in Figure 26.

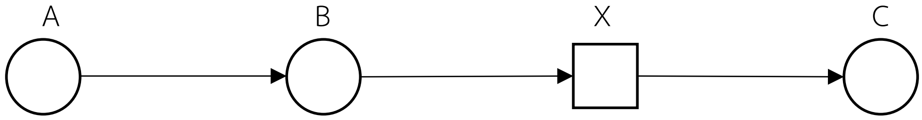


*Figure 26 the extended route after insertion of Example 9*

The second decision in Figure 23 is the consideration of the customers' locations. If the recently added requirement has the same customer's location as one of the undelivered materials transportation requirement, there will be no insertion. Otherwise, the third decision must be considered.

The third decision in Figure 23 is the consideration of nearby customers' locations. The nearby locations are defined in Definition 5.

Definition 5: A location is considered to be a nearby location when the distances between the last location of a modified route and the location and between a location and the supplier's location of the recently added requirement are less than the distance between the last location of that modified route and the supplier's location of the recently added requirement.

We are going to use the information from Example 8 (Table 30 and Figure 25) to explain the nearby location situation. We would like to know whether Location X is a nearby location or not?

Location X will be the nearby location when the distance between Locations B and X and the distance between Locations X and C are less than the distance between Location B and C.

If there is a nearby location, the nearby location will be inserted to an extended route at the insertion position (See Figure 24).

After a nearby location has been inserted, another undelivered materials transportation requirement's customer's location will be considered. But this time, there is a change in nearby location definition. "The last location of a modified route" in Definition 5 is changed to "the recently added customer's location".

Continuing from the above explanation, we assume Location X has already been considered as nearby location, and inserted to the extended route between Locations B and C. Next, Location Y will be considered. Location Y will be the nearby location when the distance between Location X and Y and the distance between Location Y and C are less than the distance between Location X and C.

The nearby location consideration will be repeated until there is no nearby location. If there is no nearby location from the beginning, there will be no insertion.

In Example 7, we assume every extended route after insertion consideration are shown in Table 31.

*Table 31 the extended routes after insertion consideration of Example 7*

| Extended Route Number | Visited locations arrangement after modification | | | Recently added Requirement Number | Extend from Obtained Route Number |
|---|---|---|---|---|---|
| 1 | 3 | 3 | | 2 | 1 |
| 2 | 3 | 4 | | 3 | |
| 3 | 3 | 2 | 5 | 4 | |
| 4 | 3 | 5 | | 5 | |
| 5 | 3 | 3 | | 1 | 2 |
| 6 | 3 | 4 | | 3 | |
| 7 | 3 | 5 | | 4 | |
| 8 | 3 | 1 | 5 | 5 | |
| 9 | 4 | 3 | | 1 | 3 |
| 10 | 4 | 3 | | 2 | |
| 11 | 4 | 5 | | 4 | |
| 12 | 4 | 5 | | 5 | |
| 13 | 5 | 1 | 3 | 1 | 4 |
| 14 | 5 | 3 | | 2 | |
| 15 | 5 | 4 | | 3 | |
| 16 | 5 | 5 | | 5 | |
| 17 | 5 | 3 | | 1 | 5 |
| 18 | 5 | 2 | 3 | 2 | |
| 19 | 5 | 4 | | 3 | |
| 20 | 5 | 5 | | 4 | |

As shown in Table 31, the number of visited locations of each extended route can be different depending on the insertion's factors.

*Complete the extended routes*

To complete an extended route, the second part of the route must be created. In this step, the recently added requirement is now included in the undelivered materials transportation requirements. Each route is considered individually. The undelivered materials transportation requirements' customers' locations will be added to an extended route. The nearest customer's location (measure from the last location of an extended route) will be added and positioned after the last location of the extended route. The completing step repeats until there is no undelivered materials transportation requirements' customers' locations left.

Using the information from Example 9 (Table 30), we assume the extended route after insertion consideration is shown in Figure 27.

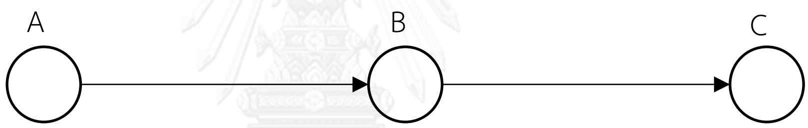


*Figure 27 an example's the extended route after insertion consideration*

There are 3 undelivered requirements, Requirement Numbers 81, 82, and 83. We assume Location X is the nearest location measuring from Location C, while Location Y is the nearest location measuring from Location X. As a result, Location X will be added to the extended route first. Location Y will be added afterwards, and Location Z will be added as shown in Figure 28.

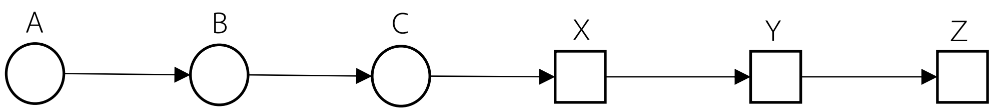


*Figure 28 an example of the complete extended route*

In Example 7, every completed extended route are shown in Table 32.

*Table 32 completed extended routes of Example 7*

| Complete Extended Route Number | Visited locations arrangement after modification | | | | Extend from Obtained Route Number |
|---|---|---|---|---|---|
| 1 | 3 | 3 | 1 | 2 | 1 |
| 2 | 3 | 4 | 2 | 1 | |
| 3 | 3 | 2 | 5 | 1 | |
| 4 | 3 | 5 | 2 | | |
| 5 | 3 | 3 | 1 | 2 | 2 |
| 6 | 3 | 4 | 1 | | |
| 7 | 3 | 5 | 1 | | |
| 8 | 3 | 1 | 5 | 2 | |
| 9 | 4 | 3 | 1 | 2 | 3 |
| 10 | 4 | 3 | 1 | | |
| 11 | 4 | 5 | 1 | | |
| 12 | 4 | 5 | 2 | 1 | |
| 13 | 5 | 1 | 3 | 2 | 4 |
| 14 | 5 | 3 | 1 | | |
| 15 | 5 | 4 | 1 | | |
| 16 | 5 | 5 | 1 | | |
| 17 | 5 | 3 | 1 | | 5 |
| 18 | 5 | 2 | 3 | 2 | |
| 19 | 5 | 4 | 2 | 1 | |
| 20 | 5 | 5 | 2 | 1 | |

**The route screening process (I)**

This process aims to eliminate some of the complete extended routes created from the layer extended process. The routes eliminated from this process are the routes that violate one of the time constraints or has positive reduced cost (See Definition 2 and Example 3 in 2.1.1). This process consists of 3 steps listed as follows.

1. Calculate a reduced cost of each complete extended route.
2. Calculate the arrival time of every location in each route.

3. Eliminate routes that violate the time constraints or have positive reduced cost.

*Calculate a reduced cost for each complete extended route*

In this research, the reduced cost of each route can be determined by using equation *(3.2.4)*. The reduced cost of a completed extended route is equal to the difference between distance cost and the summation of a dual variable of each materials transportation requirement including in that route. Note that, each route must have only 1 reduced cost.

$$R_s = C_s - \sum_{i \in s} \pi_i a_{is} \qquad (3.2.4)$$

s is a complete extended route

n is the total amount of requirements in a complete extended route r

$R_s$ is the reduced cost of route s

$C_s$ is the distance cost of route s

$\pi_i$ is the dual variable of materials transportation requirement number i

$a_{is}$ is the parameter indicating whether materials transportation requirement number i including in route s or not

$$a_{ir} = \begin{cases} 1 & \text{if requirement number i is in route s} \\ 0 & \text{otherwise} \end{cases}$$

In Example 7, if we want to calculate the reduced cost of Complete Extended Route Number 1 (See Table 32). The reduced cost calculation is shown in equation *(3.2.5)*.

$$\text{Reduced cost} = \text{Distance cost} - (d_1 + d_2) \qquad (3.2.5)$$

Complete Extended Route Number 1 contains Requirement Numbers 1 and 2, so that the obtained dual variable of those requirements from the initial process are used to calculate the reduced cost.

*Calculate the arrival time of every location in each route*

This step checks the arrival time of each location using the time between locations and loading/unloading time. The loading/unloading time must be added in every visited location.

*Eliminate routes that violate the time constraints or have positive reduced cost*

This step aims to eliminate routes that do not tended to reduce the transportation cost and the routes that violate one of time constraints. In this research, the routes that has positive reduced cost will increase the transportation cost, according to reduced cost definition (See Definition 2).

In Example 7, we assume that Complete Extended Route Numbers 1, 2, 3, 10, 12, 19, and 20 have been eliminated in this process. The routes that have not been eliminated is shown in Table 33.

*Table 33 the routes left after eliminate by the route screening process (I) of Example 7*

| Complete Extended Route Number | Visited locations arrangement after modification | | | | Extend from Obtained Route Number |
|---|---|---|---|---|---|
| 4 | 3 | 5 | 2 | | 1 |
| 5 | 3 | 3 | 1 | 2 | 2 |
| 6 | 3 | 4 | 1 | | |
| 7 | 3 | 5 | 1 | | |
| 8 | 3 | 1 | 5 | 2 | |
| 9 | 4 | 3 | 1 | 2 | 3 |
| 11 | 4 | 5 | 1 | | |
| 13 | 5 | 1 | 3 | 2 | 4 |
| 14 | 5 | 3 | 1 | | |
| 15 | 5 | 4 | 1 | | |
| 16 | 5 | 5 | 1 | | |
| 17 | 5 | 3 | 1 | | 5 |
| 18 | 5 | 2 | 3 | 2 | |
| 20 | 5 | 5 | 2 | 1 | |

**Is there any route left?**

If there is any route left after the route screening process (I), the route screening process (II) will be execute. Otherwise, the dual variable obtaining process will be performed.



In Example 7, there is 14 routes left as shown in Table 33, so the route screening process (II) will be the next process.

**The route screening process (II)**

This process applies LSP concept by eliminating seemingly inefficient complete extended routes to prevent the system from creating to many routes. In this system, the objective is to minimise the transportation cost. Each route is assumed to have the same service cost, because, at this process, the provider still does not know with routes will be operated by which type of vehicles. So, the efficiency of a complete extended route is determined by the distance cost. We also emphasise the importance of vehicle's utilisation by adding another efficiency factor which is average vehicle utilisation of a route into the screening process. Thus, there are 2 efficiency indicator which are distance, and vehicle utilisation. This process consists of 2 steps listed as follows.

1. Group the complete extended routes by its recently added materials transportation requirement number.

2. Eliminate the complete extended routes that are seemingly inefficient.

*Group the complete extended routes by its recently added materials transportation requirement number*

This step will group the left complete extended routes from the previous process using its recently added materials transportation requirement number.

In Example 7, the left complete extended routes can be grouped as shown in Table 34.

*Table 34 grouped left complete extended route of Example 7*

| Complete Extended Route Number | Recently added Requirement Number |
|---|---|
| 5, 9, 13, 17 | 1 |
| 14, 18 | 2 |
| 6, 15 | 3 |
| 7, 11, 20 | 4 |
| 4, 8, 16 | 5 |

*Eliminate the complete extended routes that are seemingly inefficient*

From the two efficiency's indicators, there must be at most 2 routes left after elimination for each group. One of the routes must be the route that has the cheapest distance cost, in other words, the shortest route. The other route is the route that has highest average vehicle utilisation. If there is only 1 route in a group, that route will not be eliminated.

In Example 7, we assume that we have already eliminated some of the complete extended route from the previous process. The routes that have not been eliminated are shown in Table 35.

*Table 35 the complete extended routes after elimination from the screening process (II) of Example 7*

| Complete Extended Route Number | Recently added Requirement Number |
|---|---|
| 5, 13 | 1 |
| 14, 18 | 2 |
| 6, 15 | 3 |
| 11, 20 | 4 |
| 8, 16 | 5 |

The system will repeat back to the layered extended process iteratively, until there is no route left after the route screening process (I) has been executed. If there is no route left, the dual variables obtaining process will be executed. Note that, the obtained routes of the layered extend process executed after the route screening process are the complete extended routes that have not been eliminated.

**The dual variables obtaining process**

This process has a purpose to obtain new dual variables from the created routes. The created routes including the initial routes, and the routes that have not been eliminate from the last route screening process (I). There are 4 steps in this process listed as follows.

1. Eliminate created routes that are in the tabu list.

2. Solve the set covering problem's relaxation model using a set of created routes.

3. Obtain new dual variables for each materials transportation requirement.

4. Update the tabu list

*Eliminate created routes that are in the tabu list*

This step checks each created route to acknowledge that whether it is included in the tabu list or not. If it is in the tabu list, that route will be eliminated from the set of created routes immediately.

*Solve the set covering problem's relaxation model using a set of created routes*

This step solves the set covering problem's relaxation model (See Model 3) by using every created routes that have not been eliminated.

*Obtain new dual variables for each materials transportation requirement*

After the set covering problem's relaxation model has been solved, the dual variables will be determined automatically by an optimiser. Each dual variable belongs to each materials transportation requirement, so the number of dual variables must be equal to the number of materials transportation requirements (which links to the number of constraints).

*Update the tabu list*

After the model has been solved, there will be some created routes that are not used in the solution. If there are too many number of unused routes, it could affect an optimiser computational time. Thus, these unused routes should be put into the tabu list.

**Does the system meet the stopping criteria?**

If the system still does not meet the stopping criteria, the system will repeat back to the layer extended process, and the set of created routes will be reset to consist of only the initial routes. Otherwise, the final solution identifying process will be executed, and the set of created routes will not be reset.

**The final solution identifying process**

This process is the last process of the system, and the output of the process will be the planned route for each vehicle. This process contains 3 steps listed as follows.

1. Solve the set covering problem's model using a set of created routes.
2. Cut and trim the solution
3. Calculate the system's actual cost

*Solve the set covering problem's model using a set of created routes*

This solving step aims to find the solution for the system by using the set of created routes (routes that are created and have not been eliminated along the processes). The model used in this step are quite similar to Model 3, but the constraint limited value of decision variable is different. In this step's model, the decision variables must be either 0 or 1. The model used in this step is Model 4.

Model 4

Let

U be the set of materials transportation requirements

S be the set of created routes

M be the average service cost of a contract and an outsourcing vehicle

$c_s$ be the distance cost of route s in set S

$x_s$ be the decision variable of a created route s in set S

$a_{rs}$ be the parameter indicating whether requirement r including in created route s or not

$$a_{rs} = \begin{cases} 1 & \text{if requirement r including in created route s} \\ 0 & \text{otherwise} \end{cases}$$

Objective:

To minimise $\sum_{s \in S} (c_s + M)x_s$ *(3.2.6)*

Subject to:

$\sum_{s \in S} a_{rs}x_s \geq 1$ for all r in U *(3.2.7)*

$x_s \in \{0, 1\}$ for all s in S *(3.2.8)*

As mentioned, equation *(3.2.8)* limits the value of $x_s$ to be either 0 or 1.

*Cut and trim the solution*

According to Model 4's equation *(3.2.7)*, a materials transportation requirement might be contained in more than 1 routes in the solution because the constraint *(3.2.7)* has a greater than or equal sign. As a result, the obtained solution from the previous step will be cut and trimmed. The cut and trim procedure is simple, if we find a materials transportation requirement that has been assigned to more than one route, we will maintain the assignment in the longest route (That requirement in other routes will be removed).

*Calculate the system's actual cost*

In the model objective function (See Model 4 equation *3.2.6*), we use the average service cost represented by M. To calculate the real cost, we must bring forward the solution, and check the number of routes in the solution.

If the number of routes are larger than the number of contract vehicles, the following function will be performed.

$$\text{Total Cost} = (C_f \times N) + (\sum_{k=1}^{P-N} C_o) + C_v \qquad (3.2.9)$$

$C_f$ is the service cost of a contract vehicle per day

N is the number of contract vehicles

$C_o$ is the service cost of an outsourcing vehicle per day

P is the number of route in the solution

$C_v$ is the distance cost of routes in the solution



If the number of routes is equal to the number of contract vehicles, the following function will be performed.

$$\text{Total Cost} = (C_f \times N) + C_v \qquad (3.2.10)$$

If the number of routes is less than the number of contract vehicles, the following function will be performed.

$$\text{Total Cost} = (C_f \times N) + C_v + (N - P) \times C_d \qquad (3.2.11)$$

$C_d$ is the guarantee cost per day per vehicle if a contract vehicle is not used in a particular day.

In conclusion, the detailed flow chart including every step of the system is shown in Figure 29.

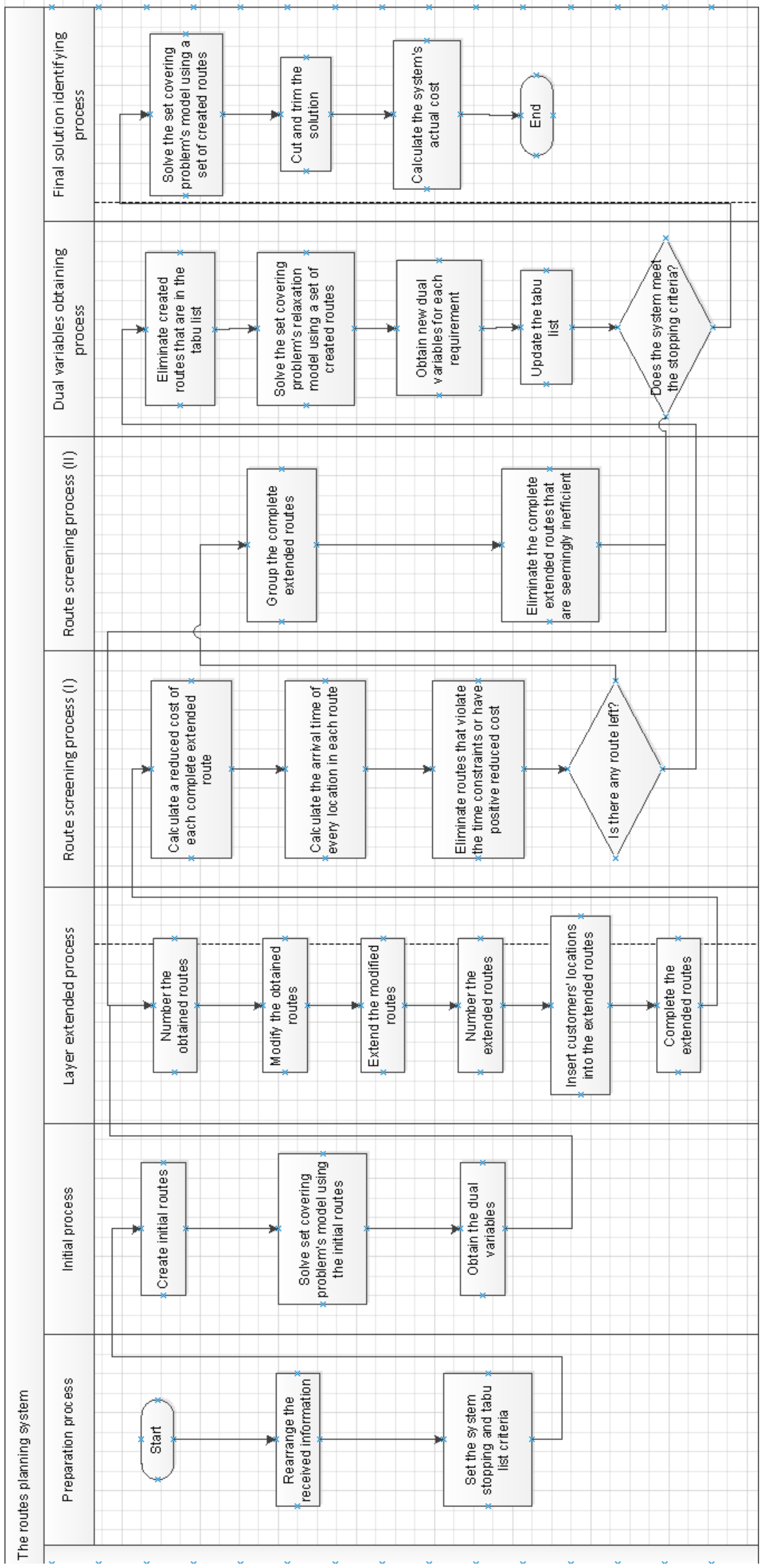


*Figure 29 the detailed flow chart of the routes planning system*

### 3.2.4. Example of the system

This sub-section gives an example to illustrate every process of the routes planning system as follows.

Example 10

In a particular day, there are 25 materials transportation requirements from 3 customers, Customer Numbers 1 2, 3 and 4. There are 4 contract vehicles, each of which can carry up to 6,000 kg, or 40 $m^3$. Driver's working hour per day is 12 hours (720 minutes), and the speed of each vehicle is 60 km/hr. The system start at 8 am and end at 8 pm. There are 3 delivery time windows which are 8.00 to 12.00, 12.00 to 16.00, and 16.00 to 20.00. The fixed cost of each contract vehicle is 2,250 baht a day, while the outsourcing vehicle is 2,700 baht. The transportation rate is 10 baht per kilometre. The location of each location is shown in X-Y coordination in Table 36, and the materials transportation requirements information is displayed in Table 37.

*Table 36 X-Y coordination of each location of Example 10*

| | Number | X | Y | | Number | X | Y |
|---|---|---|---|---|---|---|---|
| Customer | 1 | 68 | 21 | Supplier | 20 | 72 | 5 |
| | 2 | 35 | 37 | | 21 | 36 | 76 |
| | 3 | 21 | 48 | | 22 | 80 | 89 |
| Supplier | 4 | 80 | 103 | | 23 | 12 | 40 |
| | 5 | 114 | 107 | | 24 | 5 | 48 |
| | 6 | 12 | 33 | | 25 | 35 | 10 |
| | 7 | 9 | 88 | | 26 | 24 | 30 |
| | 8 | 91 | 111 | | 27 | 33 | 4 |
| | 9 | 29 | 11 | | 28 | 89 | 114 |
| | 10 | 24 | 72 | | 29 | 71 | 26 |
| | 11 | 111 | 84 | | 30 | 93 | 101 |
| | 12 | 93 | 81 | | 31 | 58 | 51 |
| | 13 | 43 | 4 | | 32 | 83 | 108 |
| | 14 | 10 | 62 | | 33 | 108 | 116 |
| | 15 | 71 | 48 | | 34 | 41 | 12 |
| | 16 | 93 | 98 | | 35 | 86 | 96 |
| | 17 | 99 | 104 | | 36 | 98 | 120 |
| | 18 | 97 | 96 | | 37 | 1 | 39 |
| | 19 | 64 | 47 | | 38 | 29 | 38 |

*Table 37 materials transportation requirements information of Example 10*

| Requirement Number | Supplier Number | Customer Number | Weight (kg.) | Volume ($m^3$) | Delivery time window |
|---|---|---|---|---|---|
| 1 | 4 | 2 | 363 | 0.05 | 16.00 – 20.00 |
| 2 | 8 | 2 | 300 | 0.04 | 16.00 – 20.00 |
| 3 | 37 | 1 | 994 | 0.13 | 8.00 - 12.00 |
| 4 | 19 | 2 | 749 | .0.10 | 12.00 – 16.00 |
| 5 | 19 | 3 | 660 | 0.08 | 16.00 – 20.00 |
| 6 | 19 | 1 | 450 | 0.06 | 16.00 – 20.00 |
| 7 | 12 | 2 | 660 | 0.08 | 8.00 - 12.00 |
| 8 | 38 | 2 | 410 | 0.05 | 12.00 – 16.00 |
| 9 | 28 | 1 | 1151 | 0.15 | 16.00 – 20.00 |
| 10 | 38 | 3 | 994 | 0.13 | 8.00 - 12.00 |
| 11 | 38 | 1 | 468 | 0.06 | 12.00 – 16.00 |
| 12 | 24 | 1 | 468 | 0.06 | 8.00 - 12.00 |
| 13 | 26 | 2 | 878 | 0.11 | 8.00 - 12.00 |
| 14 | 32 | 3 | 1188 | 0.15 | 16.00 – 20.00 |
| 15 | 35 | 1 | 664 | 0.08 | 16.00 – 20.00 |
| 16 | 15 | 1 | 655 | 0.08 | 16.00 – 20.00 |
| 17 | 31 | 1 | 1008 | 0.13 | 16.00 – 20.00 |
| 18 | 13 | 2 | 647 | 0.08 | 16.00 – 20.00 |
| 19 | 25 | 3 | 564 | 0.07 | 16.00 – 20.00 |
| 20 | 35 | 2 | 1026 | 0.13 | 16.00 – 20.00 |
| 21 | 5 | 1 | 624 | 0.08 | 12.00 – 16.00 |
| 22 | 77 | 1 | 983 | 0.12 | 16.00 – 20.00 |
| 23 | 32 | 1 | 1188 | 0.15 | 16.00 – 20.00 |
| 24 | 28 | 2 | 1184 | 0.15 | 16.00 – 20.00 |
| 25 | 17 | 1 | 733 | 0.09 | 8.00 - 12.00 |

The stopping criteria are set as follows.

- Stop when the objective value does not change for 10 iterations.

- Stop when there is no new route from the heuristic for 10 iterations.

- Stop when the heuristic has been performed for 50 iterations.

The tabu list criterion then created after the stopping criteria have been set as follows.

- The routes that are not chosen in the solution for 2 consecutive iterations will be tabooed.

Subsequently, the initial routes are constructed. In the example, there are 25 requirements, so there are 25 initial routes illustrating in Table 38.

*Table 38 the initial routes of Example 10*

| Initial Route Number | Visited locations arrangement | | Assigned Requirement Number |
|---|---|---|---|
| 1 | 4 | 2 | 1 |
| 2 | 8 | 2 | 2 |
| 3 | 37 | 1 | 3 |
| 4 | 19 | 2 | 4 |
| 5 | 19 | 3 | 5 |
| 6 | 19 | 1 | 6 |
| 7 | 12 | 2 | 7 |
| 8 | 38 | 2 | 8 |
| 9 | 28 | 1 | 9 |
| 10 | 38 | 3 | 10 |
| 11 | 38 | 1 | 11 |
| 12 | 24 | 1 | 12 |
| 13 | 26 | 2 | 13 |
| 14 | 32 | 3 | 14 |
| 15 | 35 | 1 | 15 |
| 16 | 15 | 1 | 16 |
| 17 | 31 | 1 | 17 |
| 18 | 13 | 2 | 18 |
| 19 | 25 | 3 | 19 |
| 20 | 35 | 2 | 20 |
| 21 | 5 | 1 | 21 |
| 22 | 7 | 1 | 22 |
| 23 | 32 | 1 | 23 |
| 24 | 28 | 2 | 24 |
| 25 | 17 | 1 | 25 |

After that, we solve the set covering problem's relaxation model (See Model 3) using those initial routes. In the substituted model, there are 25 constraints from the 25 requirements, and 25 decision variables from the 25 initial routes.

Once solved, the dual variable of each requirement is calculated as shown in Table 39.

*Table 39 dual variables of each requirement of Example 10*

| Requirement Number | Dual Variable |
|---|---|
| 1 | 2079.88 |
| 2 | 2092.80 |
| 3 | 2069.38 |
| 4 | 2030.68 |
| 5 | 2043.01 |
| 6 | 2026.31 |
| 7 | 2072.80 |
| 8 | 2006.08 |
| 9 | 2059.34 |
| 10 | 2012.81 |
| 11 | 2042.54 |
| 12 | 2068.54 |
| 13 | 2013.04 |
| 14 | 2086.28 |
| 15 | 2077.13 |
| 16 | 2027.17 |
| 17 | 2031.62 |
| 18 | 2033.96 |
| 19 | 2040.50 |
| 20 | 2077.99 |
| 21 | 2097.53 |
| 22 | 2070.84 |
| 23 | 2088.28 |
| 24 | 2094.05 |
| 25 | 2088.60 |

Next, we move on to the layer extended process. The illustration in Tables 40 to 44 shows the layered extended process of obtained route of Initial Route Number 1.

*Table 40 requirements information of Initial Route Number 1 of Example 10*

| Obtained Route Number | Assigned Requirement Number | Unassigned Requirement Number |
|---|---|---|
| 1 | 1 | 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 |

Then, the second part of Obtained Route Number 1 will be removed (displays in Table 41).

*Table 41 modified route of Obtained Route Number 1 of Example 10*

| Modified Route Number | Visited location arrangement | Assigned Requirement Number |
|---|---|---|
| 1 | 4 | 1 |



Every unassigned requirement's pickup location will be added to Modified Route Number 1 individually forming an extended route. Every extended route from Modified Route Number 1 is shown in Table 42.

*Table 42 extended routes created from Modified Route Number 1 of Example 10*

| Extended Route Number | Visited locations arrangement | | Assigned Requirement Number | Recently added Requirement Number |
|---|---|---|---|---|
| 1 | 4 | 8 | 1, 2 | 2 |
| 2 | 4 | 37 | 1, 3 | 3 |
| 3 | 4 | 19 | 1, 4 | 4 |
| 4 | 4 | 19 | 1, 5 | 5 |
| 5 | 4 | 19 | 1, 6 | 6 |
| 6 | 4 | 12 | 1, 7 | 7 |
| 7 | 4 | 38 | 1, 8 | 8 |
| 8 | 4 | 28 | 1, 9 | 9 |
| 9 | 4 | 38 | 1, 10 | 10 |
| 10 | 4 | 38 | 1, 11 | 11 |
| 11 | 4 | 24 | 1, 12 | 12 |
| 12 | 4 | 26 | 1, 13 | 13 |
| 13 | 4 | 32 | 1, 14 | 14 |
| 14 | 4 | 35 | 1, 15 | 15 |
| 15 | 4 | 15 | 1, 16 | 16 |
| 16 | 4 | 31 | 1, 17 | 17 |
| 17 | 4 | 13 | 1, 18 | 18 |
| 18 | 4 | 25 | 1, 19 | 19 |
| 19 | 4 | 35 | 1, 20 | 20 |
| 20 | 4 | 5 | 1, 21 | 21 |
| 21 | 4 | 7 | 1, 22 | 22 |
| 22 | 4 | 32 | 1, 23 | 23 |
| 23 | 4 | 28 | 1, 24 | 24 |
| 24 | 4 | 17 | 1, 25 | 25 |

Then, the insertion consideration is examined, and some customers' locations are added to the routes.

*Table 43 extended routes created after insertion consideration of Example 10*

| Extended Route Number | Visited locations arrangement | | | Assigned Requirement Number |
|---|---|---|---|---|
| 1 | 4 | 8 | | 1, 2 |
| 2 | 4 | 2 | 37 | 1, 3 |
| 3 | 4 | 19 | | 1, 4 |
| 4 | 4 | 19 | | 1, 5 |
| 5 | 4 | 19 | | 1, 6 |
| 6 | 4 | 12 | | 1, 7 |
| 7 | 4 | 38 | | 1, 8 |
| 8 | 4 | 28 | | 1, 9 |
| 9 | 4 | 2 | 38 | 1, 10 |
| 10 | 4 | 2 | 38 | 1, 11 |
| 11 | 4 | 2 | 24 | 1, 12 |
| 12 | 4 | 26 | | 1, 13 |
| 13 | 4 | 32 | | 1, 14 |
| 14 | 4 | 35 | | 1, 15 |
| 15 | 4 | 15 | | 1, 16 |
| 16 | 4 | 31 | | 1, 17 |
| 17 | 4 | 13 | | 1, 18 |
| 18 | 4 | 2 | 25 | 1, 19 |
| 19 | 4 | 35 | | 1, 20 |
| 20 | 4 | 5 | | 1, 21 |
| 21 | 4 | 7 | | 1, 22 |
| 22 | 4 | 32 | | 1, 23 |
| 23 | 4 | 28 | | 1, 24 |
| 24 | 4 | 17 | | 1, 25 |

The last step of the layered extended process is complete the extended routes. Thus, every complete extended route is shown in Table 44.

*Table 44 complete extended routes of <u>Example 10</u>*

| Complete Extended Route Number | Visited locations arrangement | | | | Assigned Requirement Number |
|---|---|---|---|---|---|
| 1 | 4 | 8 | 2 | | 1, 2 |
| 2 | 4 | 2 | 37 | 1 | 1, 3 |
| 3 | 4 | 19 | 2 | | 1, 4 |
| 4 | 4 | 19 | 2 | 3 | 1, 5 |
| 5 | 4 | 19 | 1 | 2 | 1, 6 |
| 6 | 4 | 12 | 2 | | 1, 7 |
| 7 | 4 | 38 | 2 | | 1, 8 |
| 8 | 4 | 28 | 2 | 1 | 1, 9 |
| 9 | 4 | 2 | 38 | 3 | 1, 10 |
| 10 | 4 | 2 | 38 | 1 | 1, 11 |
| 11 | 4 | 2 | 24 | 1 | 1, 12 |
| 12 | 4 | 26 | 2 | | 1, 13 |
| 13 | 4 | 32 | 2 | 3 | 1, 14 |
| 14 | 4 | 35 | 1 | 2 | 1, 15 |
| 15 | 4 | 15 | 1 | 2 | 1, 16 |
| 16 | 4 | 31 | 2 | 1 | 1, 17 |
| 17 | 4 | 13 | 2 | | 1, 18 |
| 18 | 4 | 2 | 25 | 3 | 1, 19 |
| 19 | 4 | 35 | 2 | | 1, 20 |
| 20 | 4 | 5 | 1 | 2 | 1, 21 |
| 21 | 4 | 7 | 1 | 2 | 1, 22 |
| 22 | 4 | 32 | 2 | 1 | 1, 23 |
| 23 | 4 | 28 | 2 | | 1, 24 |
| 24 | 4 | 17 | 1 | 1 | 1, 25 |

The process extends every initial route. As a result, the total number of complete extended route of initial routes of <u>Example 10</u> should be 24 X 25 = 600 routes.

Next, the reduced cost of each complete extended route will be determined using equation *(3.2.4)*. The reduced cost calculation of Complete Extended Route Number 1 will be used as an example.

The complete extended route has 2 assigned requirements which are Requirement Number 1 and 2. The dual variables of those requirements are 2079.88 and 2092.8 respectively (See Table 39), and the distance cost of the extended route which are calculated from distance and transportation rate is 196.4 baht. The reduced cost of this route will be 196.4 – 2079.88 – 2092.8 = -3976.28 baht. The routes that have positive reduced cost will be eliminated.

Subsequently, the time constraints of each complete extended route are considered by concerning the arrival time of each location and working hour. As a result, there are 14 routes after the elimination as shown in Table 45.

*Table 45 complete extended route that has not been eliminate after the route screening process (I)*

| Visited locations arrangement | | | | Assigned Requirement Number |
|---|---|---|---|---|
| 4 | 8 | 2 | | 3, 4 |
| 4 | 2 | 37 | 1 | 3, 10 |
| 4 | 19 | 2 | | 3, 15 |
| 4 | 19 | 2 | 3 | 3, 13 |
| 4 | 19 | 1 | 2 | 4, 21 |
| 4 | 12 | 2 | | 7, 10 |
| 4 | 38 | 2 | | 7, 11 |
| 4 | 28 | 2 | 1 | 10, 13 |
| 4 | 2 | 38 | 3 | 11, 21 |
| 4 | 2 | 38 | 1 | 12, 3 |
| 4 | 2 | 24 | 1 | 13, 3 |
| 4 | 26 | 2 | | 21, 11 |
| 4 | 32 | 2 | 3 | 25, 4 |
| 4 | 35 | 1 | 2 | 25, 8 |

Then, we group those complete extended route by the recently added requirement, and choose only 2 efficient routes in each group based on the distance and utilisation.

The route screening process (II) is executed, because there are still 14 routes left after the route screening process (I). Fortunately, for Example 10, there is no eliminated route in the route screening process (II).

Next, the system will execute the layer extended process again, and those 14 routes will be used as the obtained routes.

After several iterations, the dual variable obtaining process will be executed. The set covering problem's relaxation model will be solved using every created route from every iterations (including initial routes, but excluding routes that has been eliminated).

The new dual variable of each requirement will be identified afterwards, and if the stopping criteria still are not met, the layer extended process will be executed again using the initial routes as the obtained routes.

The final solution identifying process will be executed after one of the stopping criteria is met. For Example 10, the stopping criteria are met in iteration $20^{th}$. There are 64 created routes. We then solve the set covering problem's model (See Model 4) using those created routes. The obtained solution containing 5 routes are shown in Table 46.

*Table 46 solution routes after solving the set covering problem's model of* *<u>Example 10</u>*

| Solution Routes Number | Visited locations arrangement | | | | | | | | | | | | Assigned Requirement Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 37 | 24 | 19 | 1 | 2 | | | | | | | | 6, 15, 7 |
| 2 | 12 | 2 | 38 | 1 | 28 | 28 | 32 | 4 | 35 | 7 | 1 | 2 | 10, 14, 27, 12, 26, 4, 23, 25 |
| 3 | 38 | 26 | 2 | 3 | | | | | | | | | 13, 16 |
| 4 | 5 | 38 | 1 | 8 | 35 | 15 | 19 | 31 | 2 | 1 | | | 24, 14, 5, 18, 19, 9, 20 |
| 5 | 17 | 1 | 38 | 2 | 32 | 19 | 13 | 25 | 2 | 3 | | | 28, 11, 17, 8, 21, 22 |

According to <u>Table 46</u>, Requirement Number 14 are contained in 2 different routes. So, we need to remove that requirement from one of those 2 routes by using the cut and trim step. As a result, Requirement Number 14 is removed from Route Number 4. The solution routes after cut and trim step is shown in <u>Table 47</u>.

*Table 47 solution routes after cut and trim step of* *<u>Example 10</u>*

| Solution Routes Number | Visited locations arrangement | | | | | | | | | | | | Assigned Requirement Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 37 | 24 | 19 | 1 | 2 | | | | | | | | 6, 15, 7 |
| 2 | 12 | 2 | 38 | 1 | 28 | 28 | 32 | 4 | 35 | 7 | 1 | 2 | 10, 14, 27, 12, 26, 4, 23, 25 |
| 3 | 38 | 26 | 2 | 3 | | | | | | | | | 13, 16 |
| 4 | 5 | 1 | 8 | 35 | 15 | 19 | 31 | 2 | 1 | | | | 24, 5, 18, 19, 9, 20 |
| 5 | 17 | 1 | 38 | 2 | 32 | 19 | 13 | 25 | 2 | 3 | | | 28, 11, 17, 8, 21, 22 |

Subsequently, we calculate the real actual of those solution by using the formula in the last step of the final solution identifying process. There are 5 routes in the solution, but the provider has only 4 contract vehicles. So, equation *(3.2.9)* will be used.

Lastly, the actual cost of system from the calculation is 24,777 baht.

In conclusion, both systems have already been explained thoroughly. The vehicle estimation system calculates the proper number of contract vehicles hired to use in the routes planning system by applying the expected value concept. The routes planning system designs the route sequence for each vehicles. The system applies the column generation algorithm and LSP heuristic concepts to construct route sequences. Both systems aim to minimise cost (in terms of vehicle service cost for the vehicle estimation system and transportation cost for the routes planning system). And, to measure our proposed systems, the next chapter will discuss about systems measurement, computational evaluation.

# Chapter 4

# Systems measurements

This chapter aims to measure the performance of our proposed systems. The measurement is the computational experiment which evaluates the performance of the proposed systems by varying several parameters. The computational experiment has an objective to determine the situations that our proposed systems are efficiently applicable. Several experiments are conducted for the computational experiment section. To obtain some realistic information, we conduct the interview with several experts in the transportation field in Thailand. The experiments will be discussed in the next section.

## 4.1. Computational Experiment

This section aims to determine the situations that our proposed systems operate efficiently in terms of transportation cost. We conduct several experiments, and compare our proposed system with the procedure that one of the interviewed experts suggested, called “the basic procedure” in this section.

The basic procedure is similar to one of the two phase heuristic, cluster-first-vehicle-second. The procedure starts with the materials transportation requirements clustering. The requirements are grouped base on its customer’s location, requirements which has the same customer’s location will be in the same group. Each group will be considered separately. The suggested routes planning procedure is greedy method. The requirement having the largest amount of capacity usage in terms of weight will be assigned to a route first, and the capacity constraint will be verified. Iteratively, the next largest will be added, and capacity and time constraints will be verified; if one of the constraints is violated, the recently added requirement will be removed, and the next largest requirement will be considered. The procedure will be finished when every requirement has been assigned to a route. The procedure flow chart are exhibited in Figure 30.

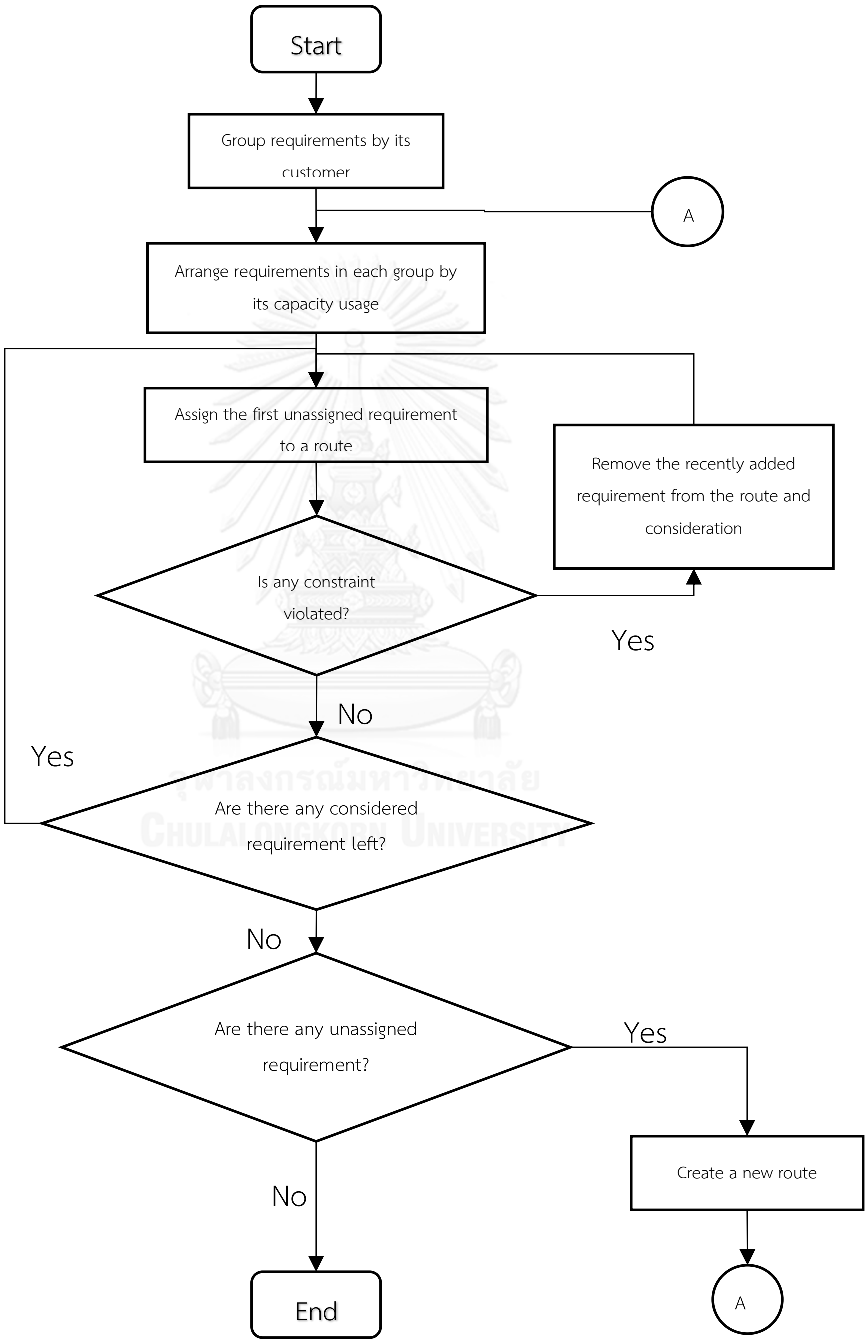


*Figure 30 the basic procedure flow chart suggest by an expert in the transportation field*

In this research, we conduct 5 experiments: distance experiment, time window experiment, customers' locations experiment, average number of requirements experiment, and supplier's location distribution experiment. In each experiment, we aim to explore how each factor affects the gap of performance between the transportation costs computed from our proposed systems as compared to the cost computed from the basic procedure suggested from one of the interviewed experts. Every experiments have been executed on Microsoft Visual Studio Express 2013 program, and CPLEX Studio IDE optimiser (32 bytes). The program and optimiser are operated on Lenovo Z5070, Intel Core i7 with 2 GHz and 4 GB memory.

The experiments assumptions are listed as follows.

1. The experiments is only measure the performance of the routes planning system by comparing the proposed system with the basic procedure. Figure 31 shows the experiment procedure. Both basic procedure and the routes planning system use the same vehicle estimation procedure, the proposed vehicle estimation system.

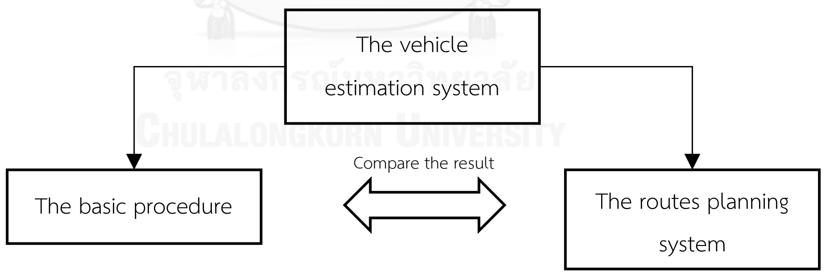


*Figure 31 the experiment procedure*



2. According to one of the interviewed experts, the outsourcing vehicles' service cost is usually 20% higher than the contract vehicles' service cost. As a result, we set the outsourcing vehicles' service cost to be 20% higher than the contract vehicles' service cost.

3. The yearly plans used in the vehicle estimation system are randomly generated, while the exact plans are generated based on the yearly plans with 50%

fluctuation. For example, if the yearly plan state that Customer A will place order from Supplier 1 with the estimated number of materials of 800 kg., in the exact plan, Customer A can require 400 – 1200 kg. of materials from Supplier 1 each time they places order.

4. In each particular experiment, we conduct 10 samples to reduce the bias of the vehicle estimation system. In each sample, the vehicle estimation system will be operated first using the new randomly generated yearly plans, then we will random a month that the routes planning system will be tested. And, the exact plans in a particular day will be generated based on the yearly plans. In other words, each sample will always use the new set of information to reduce the bias of the systems.

5. The utilisation in the experiment is the weighted utilisation calculated from equations *(4.1)*, *(4.2)*, and *(4.3)*.

$$\text{Utilisation of each journey} = \frac{\text{Capacity usage X Distance of journey}}{\text{Distance of route}} \quad (4.1)$$

$$\text{Utilisation of each route} = \frac{\sum \text{Utilisation of journeys}}{\text{Number of journeys in a route}} \quad (4.2)$$

$$\text{Utilisation of each route} = \frac{\sum \text{Utilisation of routes}}{\text{Number of generated routes}} \quad (4.3)$$

6. Uncertainties, e.g., traffic, road closure, driver ability, are not considered in the experiments.

### 4.1.1. Distance experiment

This experiment has the objective to determine the effect of the distance between locations to our systems. To adjust the distance between locations, we vary the limit of generated locations' coordinates. For example, in the first experiment we generate locations' coordinates within 60 kilometres area – the value of X and Y coordinates is between 0 and 60. We conduct experiment for 6 values of generating areas: 60, 90, 120, 180, 240, and 330 kilometres (as shown in Table 48). Each of the values consists of 10 samples. And, each location in each sample is generated uniformly and randomly (limited to the value of generating area). The other setup parameters in the experiment are listed and explained as follows.

1. The number of customers in the systems is 3.

2. The capacity constraint in term of weight limitation is 6,000 kg. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

3. The capacity constraint in term of volume limitation is 40 $m^3$. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

4. The working hour time constraint is limited to 12 hours. The working hour time constraint is set with respecting to the Labour Relation Act of Thailand.

5. The vehicle speed is fixed at 60 km/hr. The average speed is set from the speed limit of vehicles used for materials transportation of Thailand.

6. The outsourcing vehicle's service cost per day is 2,700 baht. The cost is set from the information from one of the interviewed experts company.

7. The contract vehicle's service cost per day is 2,250 baht. The cost is set from the information from one of the interviewed experts company.

8. The guarantee cost needed to pay for each unused contract vehicle per day is 1,000 baht. The cost is set from the information from one of the interviewed experts company.

9. There are 3 different arrival time windows which are 8.00 – 12.00, 12.00 – 16.00, and 16.00 – 20.00. The arrival time windows are informed by one of the $2^{nd}$ tier suppliers in an automobile supply chain.

10. Each materials transportation requirement has 5 – 30 % of capacity usage in terms of weight. This information is informed by one of the interviewed expert.

11. The average number of requirement of each customer in a particular day is 50. One of the interviewed expert exposes that in a particular day a customer

usually has 40 – 60 materials requirement, so we use 50 as the representative of the number of requirements.

12. The loading/unloading time at each location is 30 minutes. This information is informed by one of the interviewed expert.

*Table 48 distance experiment information*

| Distance Experiment Number | Generating area limitation |
|---|---|
| 1 | 60 X 60 kilometres |
| 2 | 90 X 90 kilometres |
| 3 | 120 X 120 kilometres |
| 4 | 180 X 180 kilometres |
| 5 | 240 X240 kilometre |
| 6 | 330 X 330 kilometre |



We compare the performance of our proposed systems with the basic procedure in terms of transportation cost. In addition, we also compare the average vehicles' utilisation to examine the relationship of the transportation cost and vehicles' utilisation. The transportation cost comparison is displayed in Figures 32.

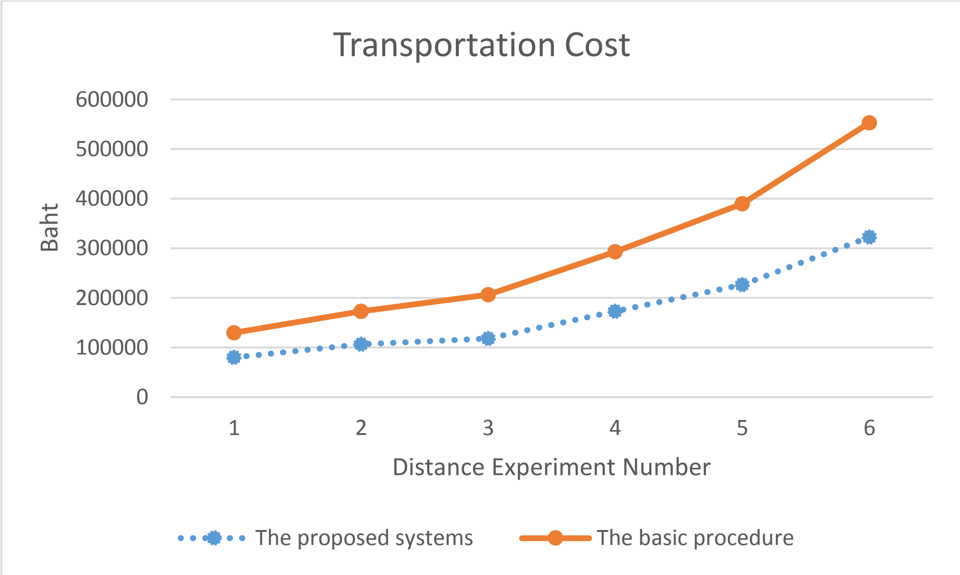


*Figure 32 the transportation cost comparison of the distance experiment*

We calculate the transportation cost reduction percentage using equation *(4.1.1)*, and we also calculate the vehicles' utilisation difference percentage using equation *(4.1.2)*. The percentage comparisons, for both transportation cost and vehicles' utilisation, are shown in Figure 33.

$$\text{Transportation cost reduction (\%)} = \frac{\text{The basic procedure cost-The proposed systems cost}}{\text{The basic procedure cost}} \qquad (4.1.1)$$

$$\text{Vehicles' utilisation difference (\%)} = \frac{\text{The proposed systems uti.-The basic procedure uti.}}{\text{The basic procedure uti.}} \qquad (4.1.2)$$

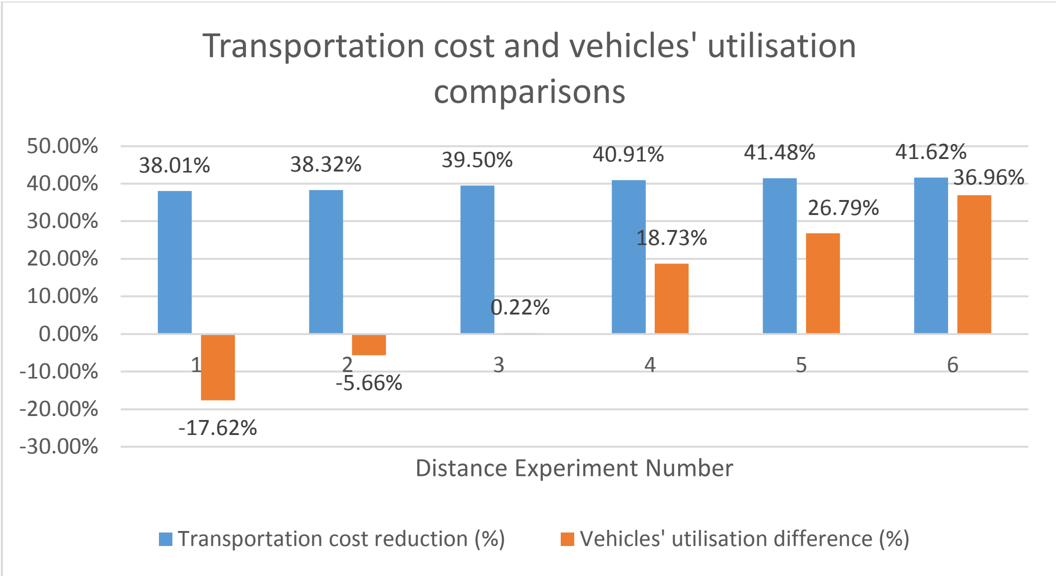


*Figure 33 the transportation cost and vehicles' utilization comparisons of the distance experiment*

According to Figure 32, the proposed systems perform better than the basic procedure in terms of the transportation cost in every distance experiment. In Distance Experiment Number 1, the average transportation cost of every sample set from the proposed systems is less than 100,000 baht, while the suggest procedure's average transportation cost is 129,930 baht. Both methods' transportation cost is increased as the generating area limitation is larger. The increasing of the transportation cost mostly because of the distance cost; when the distance between locations is increased, the distance cost will be increased. The service cost also affects the increasing of the transportation cost, but in a smaller amount. The longer distance between locations means the lower number of locations that a vehicles can visit in a day because of the working hour time constraint. When considering about the increasing rate, our proposed systems have lower rate than the basic procedure (can be implied by the gap between the lines in Figure 32).

As shown in Figure 33, the transportation cost reduction percentage is in positive area means the proposed systems' transportation cost is lower than the basic procedure's transportation cost. The transportation cost reduction percentage is increased when the generating area limitation is enlarged. Thus, we can imply that our proposed systems are appropriate for the setup where distances between locations are lengthy. For the vehicles' utilisation difference, the bar graphs in the negative area indicate that the average vehicles' utilisation of the proposed systems is lower than the suggest procedure. According to Figure 33, in the first 2 experiments our proposed systems have lower vehicles' utilisation than the basic procedure, -17.62 and -5.66 percent. The reason behind this is because there is the nearby locations consideration which encourages vehicles to visit nearby customers' location before pickup new materials transportation requirement. Thus, our proposed systems' utilisation is not as high as the basic procedure that aims to collect materials until a vehicle is full. The vehicles' utilisation of our proposed systems is improved as the generating area limitation is enlarged, and outperforms the basic procedure in Distance Experiment Numbers 4, 5, and 6.

In conclusion, our proposed systems outperform the basic procedure in terms of transportation cost in every distance experiment. The different between the transportation cost generated from our systems and the basic procedure is increased as the generating area limitation is enlarged. In contrast, the proposed systems' vehicles' utilisation is lower than the basic method in 2 out of 6 experiments. Our proposed systems' vehicles' utilisation is improved in the same trend as the transportation cost, better when the generating area limitation is large. From the contrast, we can imply that the high vehicles' utilisation (in average) does not lead to the low transportation cost.

#### 4.1.2. Time window experiment

This experiment has the objective to determine the effect of the length of the arrival time window to our systems. The length of the arrival time window means the allowable time interval that a particular requirement is required to be arrived within. We conduct experiment for 5 length of arrival time window: 12, 6, 4, 3, 2 hours (as shown in Table 49). Each of the lengths consists of 10 samples. The other setup parameters in the experiment are listed and explained as follows.

1. The number of customers in the systems is 3.

2. The capacity constraint in term of weight limitation is 6,000 kg. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

3. The capacity constraint in term of volume limitation is 40 $m^3$. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

4. The working hour time constraint is limited to 12 hours. The working hour time constraint is set with respecting to the Labour Relation Act of Thailand.

5. The vehicle speed is fixed at 60 km/hr. The average speed is set from the speed limit of vehicles used for materials transportation of Thailand.

6. The outsourcing vehicle's service cost per day is 2,700 baht. The cost is set from the information from one of the interviewed experts company.

7. The contract vehicle's service cost per day is 2,250 baht. The cost is set from the information from one of the interviewed experts company.

8. The guarantee cost needed to pay for each unused contract vehicle per day is 1,000 baht. The cost is set from the information from one of the interviewed experts company.

9. The generating area limitation is 120 kilometres. From the distance between most industrial estates around Bangkok.

10. Each materials transportation requirement has 5 – 30 % of capacity usage in terms of weight. This information is informed by one of the interviewed expert.

11. The average number of requirement of each customer in a particular day is 50. One of the interviewed expert exposes that in a particular day a customer usually has 40 – 60 materials requirement, so we use 50 as the representative of the number of requirements.

12. The loading/unloading time at each location is 30 minutes. This information is informed by one of the interviewed expert.

*Table 49 time window experiment information*

| Time Window Experiment Number | Arrival time window | Length of each arrival time window |
|---|---|---|
| 1 | 8.00 – 20.00 | 12 hours |
| 2 | 8.00 – 14.00, 14.00 – 20.00 | 6 hours |
| 3 | 8.00 – 12.00, 12.00 – 16.00, 16.00 – 20.00 | 4 hours |
| 4 | 8.00 – 11.00, 11.00 – 14.00,…, 17.00 – 20.00 | 3 hours |
| 5 | 8.00 – 10.00, 10.00 – 12.00,…, 18.00 – 20.00 | 2 hours |

We compare the performance of our proposed systems with the basic procedure in terms of transportation cost. The transportation cost comparison is displayed in Figures 34. In addition, we also calculate the transportation cost reduction percentage of our proposed systems to the basic procedure as shown in Figure 35.

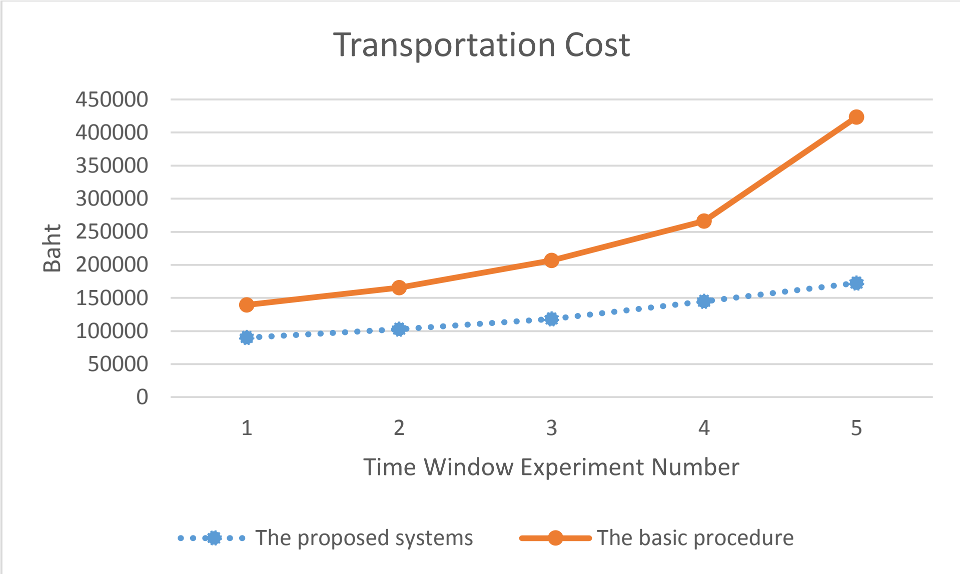


*Figure 34 the transportation cost comparison of the time window experiment*

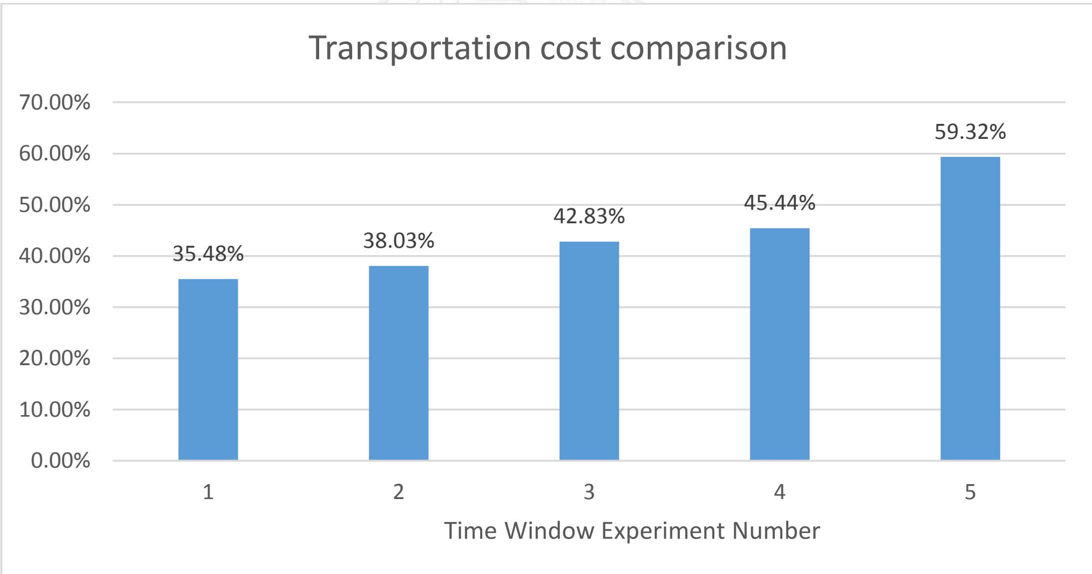


*Figure 35 the transportation cost comparison of the time window experiment*

According to Figure 34, our proposed systems outperform the suggest procedure in every experiment. Both methods' transportation costs are increased as the length of time window is shortened. The transportation cost of the basic procedure is increased rapidly in Time Window Experiment Numbers 4 and 5 which have strict arrival time window, 3 and 2 hours. Similarly, out proposed systems' transportation cost is increased as arrival time window is shortened, but in a smaller rate than the basic procedure, can be implied by the gap between two lines in Figure 34. We investigate the reasons behind this successful outperformance, and find out that the clustering process the key indicator of the increasing transportation cost of the basic procedure. The clustering process reduces the search space of the method. So, with the narrower search space and a strict arrival time window, the basic procedure cannot find any efficient route.

The transportation cost reduction calculated from equation *(4.1.1)* is shown in Figure 35. The proposed systems perform better in every experiment. As explained, the length of arrival time window impacts the basic procedure significantly. In Time Window Experiment Number 5, the proposed systems' transportations cost is lower than the basic procedure for almost 60%, while in Time Window Experiment Number 5 is 35% which is quite high in terms of transportation cost reduction.

In conclusion, we observe that our proposed systems are appropriate for the system that has strict arrival time window constraint. Our system can explore more feasible solution than the basic procedure leading to the more efficient routes creation.

### 4.1.3. Customers' locations experiment

This experiment has the objective to determine the effect of the customers' location to our systems. We divide the generating area into 4 small areas, namely, the innermost, the 2$^{nd}$ inner, the 2 outer, and the outermost. Every small area's corner is displayed in Figure 36. In every experiment, we have 3 customers. Thus, we conduct an experiment by locating customers' location in 3 of the 4 corners of a particular small area. For example, when we conduct an experiment for small area D (See Figure 36), the customers' locations are 3 out of 4 corners of the generating area. The detail of each small area is shown in Figure 36. Area A is at the middle of the generating area and consist of only 4 locations: (60, 60), (60, 61), (61, 60), and (61, 61). The detail of each experiment is shown in Table 50. Each of the small area experiment consists of 10 samples. The other setup parameters in the experiment are listed and explained as follows.

1. The number of customers in the systems is 3.

2. The capacity constraint in term of weight limitation is 6,000 kg. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

3. The capacity constraint in term of volume limitation is 40 $m^3$. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

4. The working hour time constraint is limited to 12 hours. The working hour time constraint is set with respecting to the Labour Relation Act of Thailand.

5. The vehicle speed is fixed at 60 km/hr. The average speed is set from the speed limit of vehicles used for materials transportation of Thailand.

6. The outsourcing vehicle's service cost per day is 2,700 baht. The cost is set from the information from one of the interviewed experts company.

7. The contract vehicle's service cost per day is 2,250 baht. The cost is set from the information from one of the interviewed experts company.

8. The guarantee cost needed to pay for each unused contract vehicle per day is 1,000 baht. The cost is set from the information from one of the interviewed experts company.

9. There are 3 different arrival time windows which are 8.00 – 12.00, 12.00 – 16.00, and 16.00 – 20.00. The arrival time windows are informed by one of the 2$^{nd}$ tier suppliers in an automobile supply chain.

10. Each materials transportation requirement has 5 – 30 % of capacity usage in terms of weight. This information is informed by one of the interviewed expert.

11. The average number of requirement of each customer in a particular day is 50. One of the interviewed expert exposes that in a particular day a customer usually has 40 – 60 materials requirement, so we use 50 as the representative of the number of requirements.

12. The loading/unloading time at each location is 30 minutes. This information is informed by one of the interviewed expert.

13. The generating area limitation is 120 X 120 kilometres. From the distance between most industrial estates around Bangkok.

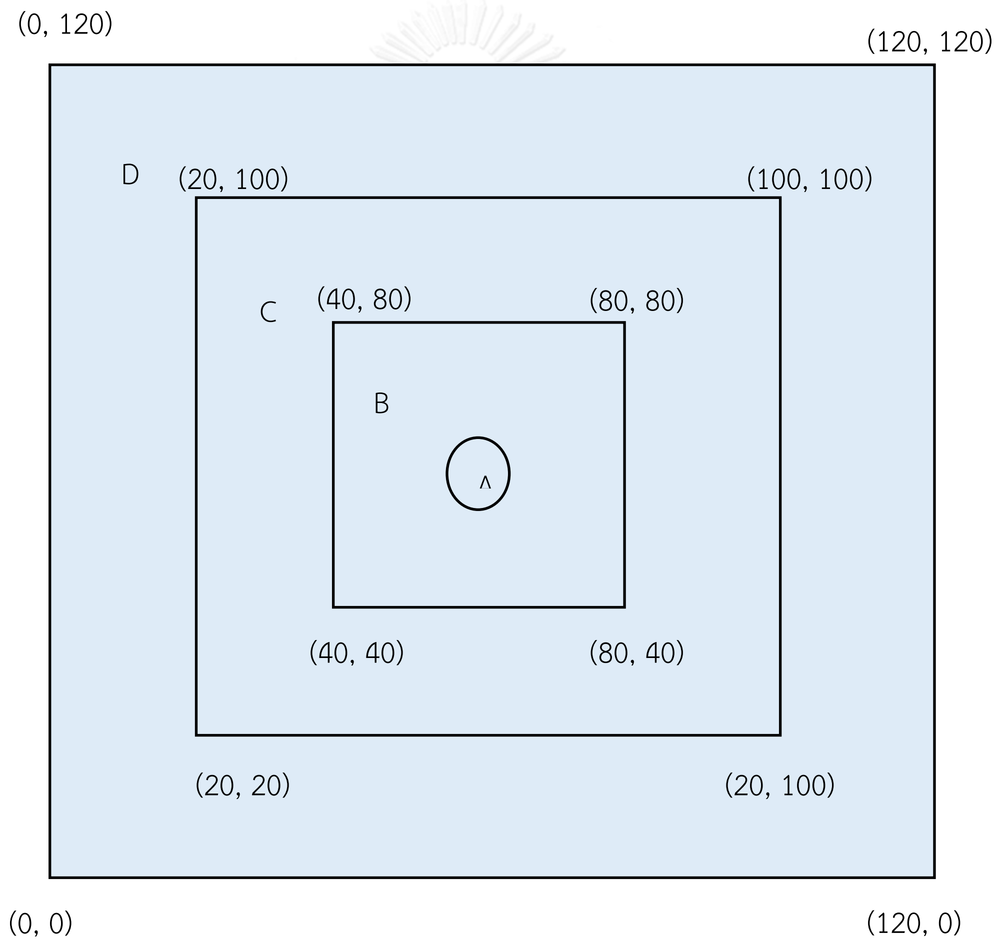


*Figure 36 generating area information*

*Table 50 customers' locations experiment information*

| Customers' Location Experiment Number | Customer locate at the corners of Small Area |
|---|---|
| 1 | A |
| 2 | B |
| 3 | C |
| 4 | D |

We compare the performance of our proposed systems with the basic procedure in terms of transportation cost. The transportation cost comparison is displayed in Figures 37. In addition, we also calculate the transportation cost reduction percentage of our proposed systems to the basic procedure as shown in Figure 38.

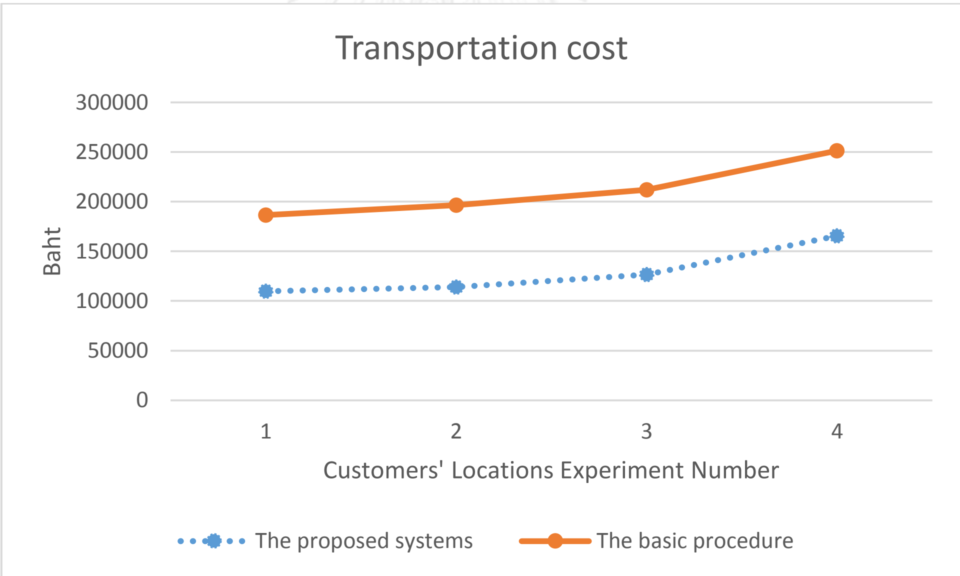


*Figure 37 the transportation cost comparison of the customers' locations experiment*

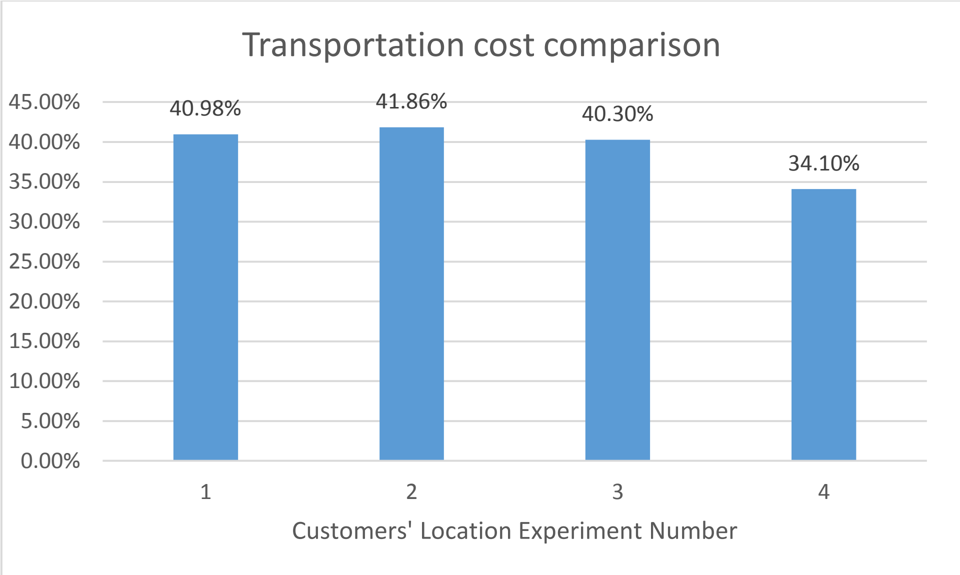


*Figure 38 transportation cost comparison of the customers' locations experiment*

According to Figure 37, our proposed systems outperform the basic procedure in every experiment. The transportation cost of both methods is increased as the customers' locations located farther from the middle of the generating area (the average transportation cost of Customers' Locations Experiment Number 1 is only 148,000 baht while in Experiment Number 4 is 208,000 baht).

From Figure 38, the average transportation cost reduction for the first 3 experiments is around 41%, while the last experiment is only 34%. We try to investigate the root causes behind this incident. And, we recognise that in our routes planning system, there is a nearby customers' locations consideration in the layer extended process. The consideration encourage a vehicle to visit customers' locations that are considered as nearby locations even though the vehicle is still not full. In Customers' Location Experiment Number 4, every customers' locations are located at the outer most corner of the generating area, so the customers' locations are hardly to be considered as the nearby locations. As a result, our proposed systems cannot perform efficiently in that experiment.

In conclusion, we acknowledge that our proposed systems are appropriate for the system that customers is not located at the outermost area. The proposed systems encourage vehicles to visit the nearby customers' locations, instead of trying to full up the vehicles. That encouragement affect the transportation cost significantly.

#### 4.1.4. Average number of requirements experiment

This experiment has the objective to determine the effect of the average number of requirements of each customer to our systems. The average number of requirements means the average number of materials transportation requirement that has been placed from customers in a particular day. We conduct experiment for 6 values of average number of requirements: 16, 35, 52, 60, 70, and 102 requirements for each customer (as shown in Table 51). Each of the average number of requirement consists of 10 samples. The other setup parameters in the experiment are listed and explained as follows.

1. The number of customers in the systems is 3.

2. The capacity constraint in term of weight limitation is 6,000 kg. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

3. The capacity constraint in term of volume limitation is 40 $m^3$. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

4. The working hour time constraint is limited to 12 hours. The working hour time constraint is set with respecting to the Labour Relation Act of Thailand.

5. The vehicle speed is fixed at 60 km/hr. The average speed is set from the speed limit of vehicles used for materials transportation of Thailand.

6. The outsourcing vehicle's service cost per day is 2,700 baht. The cost is set from the information from one of the interviewed experts company.

7. The contract vehicle's service cost per day is 2,250 baht. The cost is set from the information from one of the interviewed experts company.

8. The guarantee cost needed to pay for each unused contract vehicle per day is 1,000 baht. The cost is set from the information from one of the interviewed experts company.

9. The generating area limitation is 120 kilometres. From the distance between most industrial estates around Bangkok.

10. Each materials transportation requirement has 5 – 30 % of capacity usage in terms of weight. This information is informed by one of the interviewed expert.

11. There are 3 different arrival time windows which are 8.00 – 12.00, 12.00 – 16.00, and 16.00 – 20.00. The arrival time windows are informed by one of the 2nd tier suppliers in an automobile supply chain.

12. The loading/unloading time at each location is 30 minutes. This information is informed by one of the interviewed expert.

*Table 51 average number of requirements experiment information*

| Number of Requirements Experiment Number | Average Number of Requirement of each Customer |
|---|---|
| 1 | 16 |
| 2 | 35 |
| 3 | 52 |
| 4 | 60 |
| 5 | 70 |
| 6 | 102 |

We compare the performance of our proposed systems with the basic procedure in terms of transportation cost. The transportation cost comparison is displayed in Figures 39. In addition, we also calculate the transportation cost reduction percentage of our proposed systems to the basic procedure as shown in Figure 40.

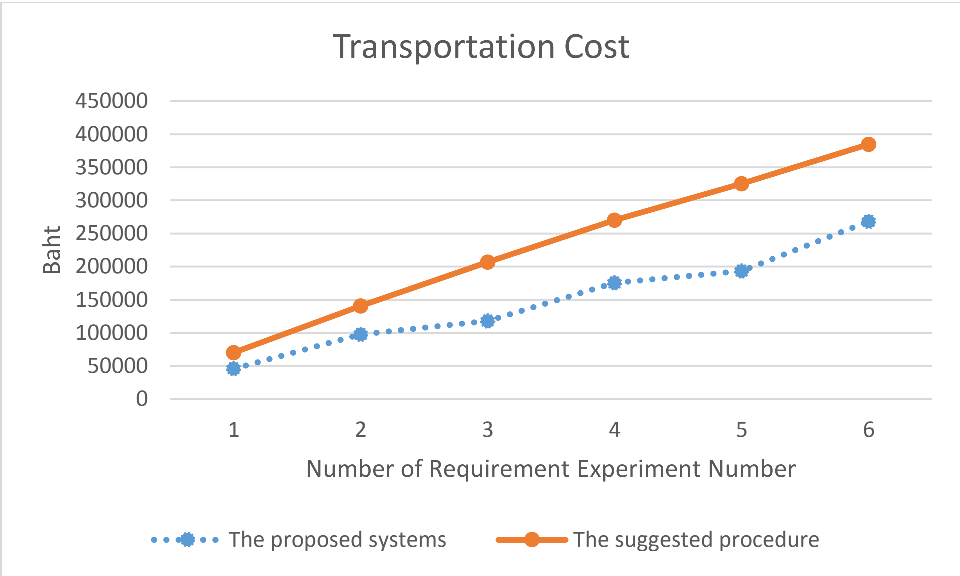


*Figure 39 the transportation cost comparison of the number of requirement experiment*

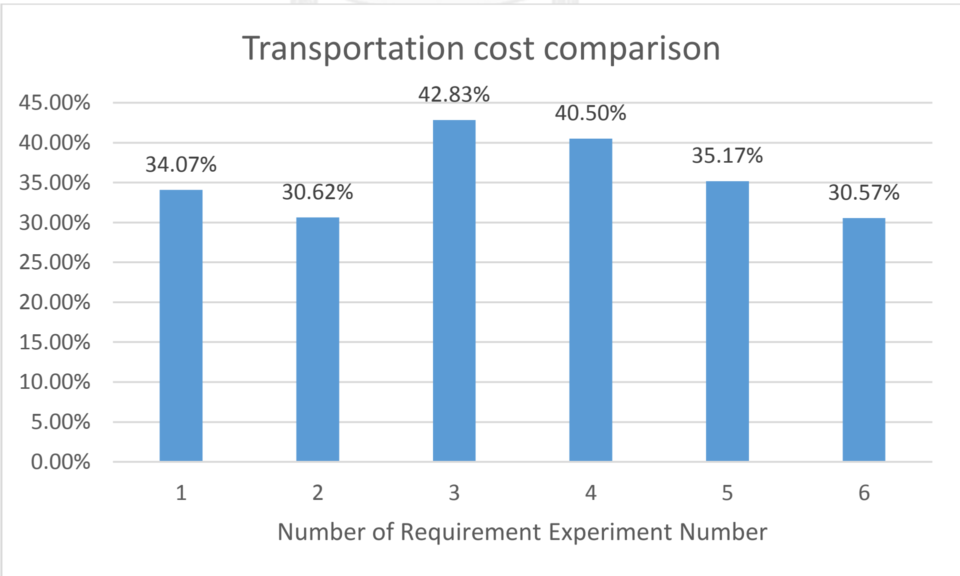


*Figure 40 transportation cost comparison of average number of requirements experiment*

According to Figure 39, the transportation cost is increased when the average number of requirements of each customer is risen. The basic procedure's transportation is increased linearly as displayed in Figure 40. In contrast, the transportation cost of our proposed system is increased without any pattern. The increasing transportation cost mostly come from the service cost, because the system require more vehicles to satisfy larger number of materials transportation requirement. Fortunately, our proposed systems outperform the basic procedure in every experiment.

Refer to Figure 40, the number of requirements of each customer does not affect the cost reduction. As shown in Figure 40, the cost reduction percentage is started from 34% in the first experiment and decreased to 30%, then increased to 43%. The proposed systems perform efficiently in Experiment Numbers 3 and 4, with more than 40% of the transportation cost reduction percentage. Meanwhile, the lowest transportation cost reduction percentage is from Experiment Number 6 which has the largest number of requirements in each customer.

In conclusion, the number of requirements of each customer does not affect the transportation cost significantly. However, our proposed systems still perform better than the basic procedure in every experiment.



#### 4.1.5. Suppliers' locations distribution experiment

This experiment has the objective to determine the effect of the suppliers' location distribution to our systems. We separate suppliers' location distribution into 2 types which are random and uniform, and grouped (as shown in Figures 40 and 41). Each of the distributions experiment consists of 10 samples, Sample Numbers 1 to 10. The other setup parameters in the experiment are listed and explained as follows.

1. The number of customers in the systems is 3.

2. The capacity constraint in term of weight limitation is 6,000 kg. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

3. The capacity constraint in term of volume limitation is 40 $m^3$. The capacity constraint is set with respecting to the Land Traffic Act of Thailand.

4. The working hour time constraint is limited to 12 hours. The working hour time constraint is set with respecting to the Labour Relation Act of Thailand.

5. The vehicle speed is fixed at 60 km/hr. The average speed is set from the speed limit of vehicles used for materials transportation of Thailand.

6. The outsourcing vehicle's service cost per day is 2,700 baht. The cost is set from the information from one of the interviewed experts company.

7. The contract vehicle's service cost per day is 2,250 baht. The cost is set from the information from one of the interviewed experts company.

8. The guarantee cost needed to pay for each unused contract vehicle per day is 1,000 baht. The cost is set from the information from one of the interviewed experts company.

9. There are 3 different arrival time windows which are 8.00 – 12.00, 12.00 – 16.00, and 16.00 – 20.00. The arrival time windows are informed by one of the 2nd tier suppliers in an automobile supply chain.

10. Each materials transportation requirement has 5 – 30 % of capacity usage in terms of weight. This information is informed by one of the interviewed expert.

11. The average number of requirement of each customer in a particular day is 50. One of the interviewed expert exposes that in a particular day a customer usually has 40 – 60 materials requirement, so we use 50 as the representative of the number of requirements.

12. The loading/unloading time at each location is 30 minutes. This information is informed by one of the interviewed expert.

13. The generating area limitation is 120 X 120 kilometres. From the distance between most industrial estates around Bangkok.

There are 2 types of distribution in the experiments listed as follows.

1. Randomly and uniformly generated suppliers' locations

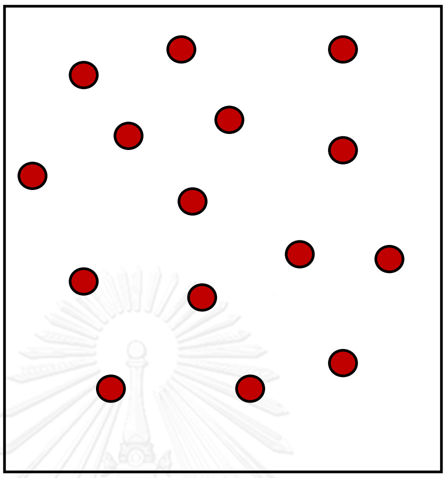

*Figure 41 the randomly and uniformly generated suppliers' location*

2. Grouped suppliers' locations

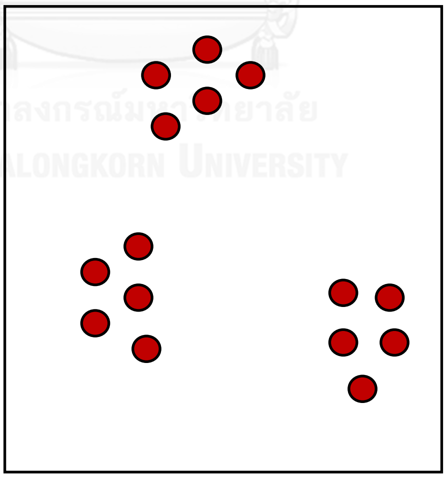

*Figure 42 the group suppliers' location*

We compare the performance of our proposed systems with those 2 distributions by using the transportation cost reduction. For example, the first bar, indicating with 0.39 in Sample Number 1, shows the transportation cost of our proposed systems is 39% lower than the basic procedure in the random and uniform suppliers' location. The second bar, indicating with 0.34 in Sample 1, shows the transportation cost of our proposed systems is 34% lower than the basic procedure in the grouped suppliers' location. In addition, we also compare the average vehicles' utilisation to examine the relationship of the transportation cost and vehicles' utilisation. The transportation cost reduction percentage comparison is displayed in Figures 43.

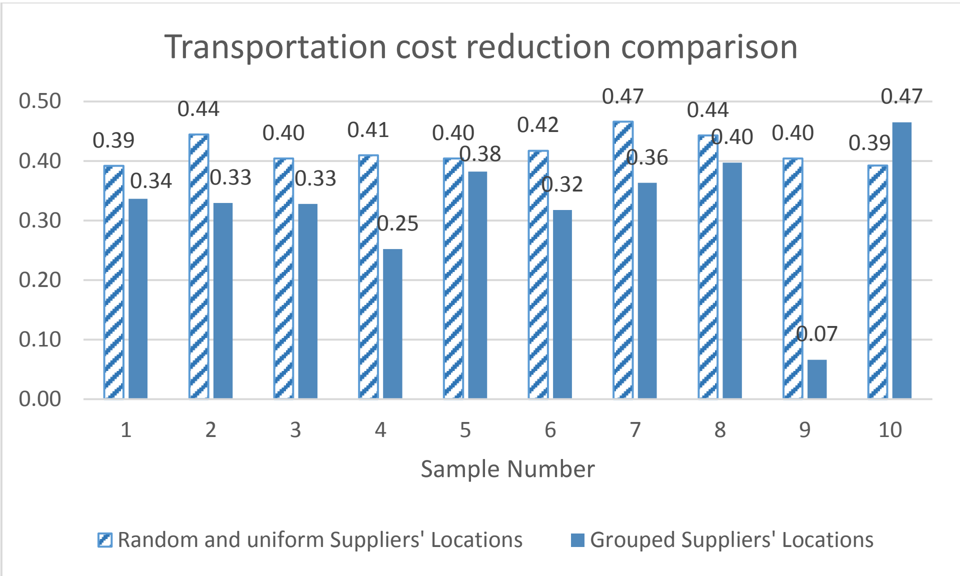


*Figure 43 transportation cost comparison of the suppliers' locations distribution experiment*

The comparison in terms of the vehicles' utilisation between the two suppliers' locations distribution is shown in Figure 44.

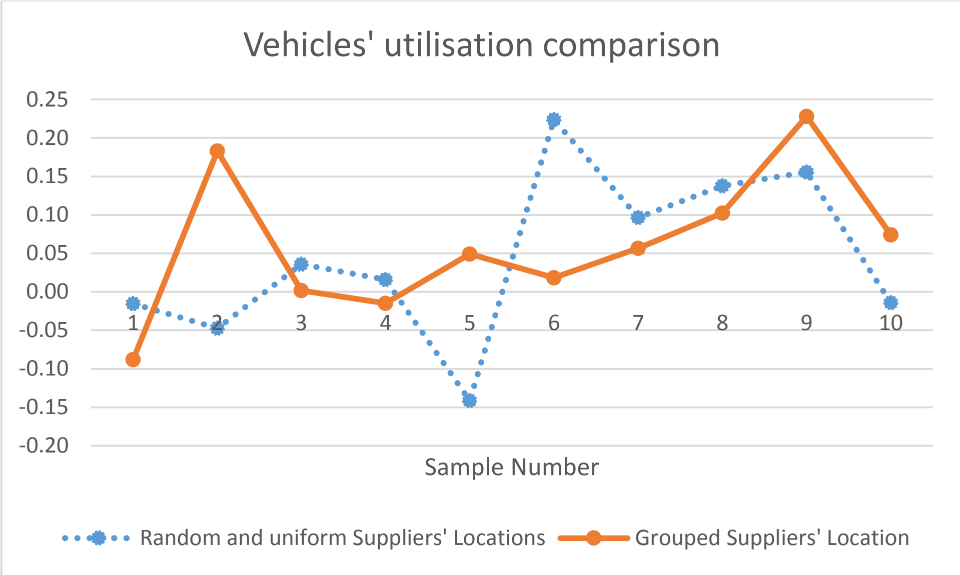


*Figure 44 vehicles' utilisation comparison of the suppliers' locations distribution experiment*

According to Figure 43, our proposed systems outperform the basic procedure in every sample and every suppliers' distribution (every bar is in the positive area). The transportation cost reduction is around 25 to 50%, except Sample Number 9 grouped distribution. Most of the random and uniform suppliers' locations distribution perform better than the grouped distribution, 9 out of 10 samples. However, the grouped suppliers' location distribution performs better in Sample Number 10. We find that the transportation cost is depended on how we grouped the suppliers' locations. For example, if the grouped suppliers' locations are the supplier locations of the requirements from the same customer, it will perform surprisingly well. Otherwise, the grouped distribution will be outperformed by the other distribution.

Refer to Figure 44, the vehicles' utilisation is not affected by the suppliers' locations distribution. The random and uniform suppliers' location distribution has higher vehicles' utilisation in 6 out of 10 samples, and reach negative area in Sample Number 5. The negative area indicates that the vehicles' utilisation of that sample is lower than the basic procedure. Thus, we can conclude that the vehicles' utilisation has no relationship with the transportation cost. Because, in Sample Number 5, the transportation cost of random and uniform suppliers' locations distribution is still 40% lower than the suggest procedure, according to Figure 43, although the vehicles' utilisation is lower.

In conclusion, the purposed systems perform better than the basic procedure in every sample, especially in the random and uniform suppliers' locations distribution. In contrast, some of the samples reveal that our purposed systems' vehicles' utilisations are lower than the basic procedure, because of the nearby locations consideration.

## 4.2. Experiments Conclusion

After those 5 experiments have been conduct, we conclude that our purposed systems outperform the suggest procedure in every experiments in terms of transportation cost. We also conclude that there is no relationship between vehicles' utilisation and the transportation cost, since some of experiments show that our purposed systems have lower vehicles' utilisation than the suggest procedure but still have lower transportation cost.

According to the distance experiment, the transportation cost is increased as the distances between locations are enlarged. The increasing of transportation cost is mostly caused by the increasing of distance cost due to the increasing of the distances. Moreover, the service cost also affect the increasing of transportation cost in farther distances between locations, because the number of visited locations is decreased as the distances between locations are increased,. The experiment shows no relationship between vehicles' utilisation and the transportation cost. Lastly, our purposed systems are favourable in the systems that have farther distances between locations.

From the time windows experiment, the transportation cost is increased as the time windows become tighter. The basic procedure performs poorly in the strict situations, 2 or 3 hours arrival time windows, while our purposed systems operate efficiently. We realise that the size of search space affect the transportation cost significantly. The method having larger search space might tend to find more efficient solution. As a result, our purposed systems are more preferable than the basic procedure in the situation that the arrival time windows are tight.

In the customers' locations experiment, we recognise that our nearby locations consideration affect the transportation cost significantly, because when we locate customers' location at the outermost corner, the purposed systems perform inefficiently (locating the customers' locations at the outermost corner means it will hardly be considered as nearby locations). As a result, our purposed systems will operate efficiently when the customers' locations are not located at the outermost of the considered area.

Refer to the average number of requirements experiment, the number of requirements from each customer does not affect the transportation cost. However, the transportation cost is increased when the number of requirements of each customer increased.

Lastly, the suppliers' locations distribution experiment indicate that our purposed systems outperform the basic procedure in every sample, especially in the random and uniform suppliers' location distribution. However, the vehicles' utilisation of the purposed systems are lower than the basic procedure in some samples. The contrast emphasises that there is no relationship between the vehicles' utilisation and the transportation cost.

Overall, the average transportation cost reduction percentage from 200 samples is 40.51%, and the average utilisation reduction percentage is 10.07%. The proposed systems emphasise the prioritisation of the transportation cost over vehicles' utilisation, and also encourage vehicles to visit nearby locations instead of trying to full up the vehicles. As a result, we conclude the situations that our purposed systems will become more favourable in the following list.

1. The farther distances between locations.

2. The tighter arrival time windows.

3. Customers' locations are not located at the outermost of the considered area.

4. The random and uniform suppliers' location distribution.

## 4.3. Experiments Limitations

1. It can be interesting to consider the comparison between the proposed systems and the academic best practice procedure in the literatures.

2. In the experiments, we focus on some key parameters or factors that seem to affect our systems significantly. Other factors can also be explored in the future work of this research.

4. The ratio of contract and outsourcing vehicles' service cost is set at 20%. To extend our experiment, the effects of this ratio on our proposed systems' performance can be explored.

# Chapter 5

# Conclusion and Discussion

## 5.1. Conclusion

Thailand's economics is growing, and Thai's government focuses intensively to expand the industrial sections. One of the largest industrial in Thailand is the automobile industry. Many international automobile companies, e.g., Toyota, Honda, are using Thailand as the primary cars manufacturer base. Thus, two of the major export products of Thailand is cars and auto parts. Nowadays, many automobile companies are starting to keep their intention on their supply chain rather than their sales and marketing. The competition is shifted from between big international assemblers to between their supply chain management. There are many stakeholders in the automobile supply chain, from the big international assembler companies to the small local SMEs producing very small parts such as nuts and bolts. Many strategies are developed to gain competitive advantages. One of the most useful strategies is using third party logistics to provide non-core activities, i.e., activities that do not add value to companies' products. Materials transportation is the most popular activities for using third party logistics services, because the transportation is one of the most expensive non-core activities of many companies. For some big assemblers, they have a lot of powers and can control their flows of materials. Thus, they are able to operate the transportation system by themselves. The most famous assemblers' transportation system is the milk run using by Toyota. Unfortunately, for small auto part manufacturers in the automobile supply chain, they do not have much power to control their flow of materials. As a result, some of them end up in high inventory or transportation cost. Recently, the trend in using a third party transportation provider is growing significantly, but there is only few providers available in Thailand (Most of the materials transportation services are only in a freelance vehicle form, employer companies need to plan the transportation schedules by themselves; a freelance vehicle is only driven using the given transportation schedules). Usually, the providers consider each of their customers separately. The individual consideration has several drawbacks. As a result, this research provides a logistic management systems to a third party transportation provider.

The systems are designed for a third party transportation provider which has auto part manufacturers as the customers. Thus, there are 3 stakeholders in this research, namely, a provider, customers, and suppliers (customers' suppliers). The provide provides the materials transportation service, pick up materials from customers' suppliers and deliver to customers. The provider receives 2 types of plan from their customers: the yearly plan given at the beginning of a particular year, and the exact plan given at the beginning of a particular day. The yearly plan informs about the predicted materials requirements of each customer, while the other plan notifies about the actual materials transportation requirements in a particular day of each customer. Also, we aim to design the systems for the SME provider that does not have their own vehicles. Thus, there are 2 types of vehicles in this research which are contract vehicles and outsourcing vehicles. The contract vehicles are hired yearly, while the outsourcing vehicles are hired daily. The provider makes contract with the contract vehicles at the beginning of a particular year, so the number of contract vehicles are needed to be determined beforehand. In contrast, the outsourcing vehicles are hired when the number of contract vehicles is not sufficient in a particular day. The transportation cost in the systems consists of 2 costs, service cost (fixed cost) and distance cost (variable cost). The service cost is calculated from the number of vehicles, while the distance cost is identified by the travelled distance. The service cost of outsourcing vehicle is more expensive than the outsourcing vehicle, but the distance cost is calculated at the same rate. In addition, if a contract vehicles is not used in a particular day, the provider need to pay that vehicle the guarantee cost. As a result, this research are separated into 2 systems, the vehicle estimation system to determine the number of needed contract vehicles, and the routes planning system to design the efficient routes in terms of distance cost.

The objective of this research is to develop an efficient heuristic for a third party transportation provider for a large scale network of suppliers and factories.

For the vehicle estimation system, we aim to minimise vehicle service cost of the system by estimating the proper number of contract vehicles from given customers' yearly plan. The output of this system is the number of contract vehicles that are going to be used in a particular year. Most of the system's inputs are from the given customers' yearly plan. The constraints of this system are capacity constraints in terms of weight and volume, and time constraint in terms of vehicles' working hour.

The routes planning system aims to minimise the transportation cost in a particular day by designing efficient routes for serving customers' materials transportation requirements. The output of this system is the planned route for each vehicle in a particular day. The system's inputs come from the given customers' exact plans. The constraints of the system are capacity constraints in terms of weight and volume, time constraints in terms of vehicles' working hour and deliveries time window.

We have reviewed several literatures to find the appropriate tools and methods for operating the research's systems. The vehicle estimation system can be comparable as the fleet sizing problem, while the routes planning system can be considered as the vehicle routing problem. Several fleet sizing literatures focused on the car rental industry. And, most of the fleet sizing literatures concentrate on short term estimation, they determined the number of fleets using in an upcoming day. But our vehicle estimation system has a purpose to identify the number of contract vehicles using in an upcoming year (long term estimation). The vehicle routing problem is comparable to our routes planning system. There are many types of vehicle routing problem, and the system can be considered as the open vehicle routing problem with pickup and delivery. Several methods were proposed to solve this problem --- exact methods, heuristic methods, and metaheuristic methods. We found that there is only few literatures that considered the open variant in the pickup and delivery vehicle routing problem, and most of them has the route sequencing restriction constraint, vehicles must pick up materials, until full, before delivery. As a result, we adjusted some concepts and ideas of the reviewed literatures, and applied them to this research in order to operate our systems effectively.

For the vehicle estimation system, we use the concept of expected cost to estimate the number of contract vehicles. The designed vehicle estimation system consists of 3 core processes: the preparation process, the vehicle estimation process, and the final number of contract vehicles calculation process. The preparation process rearranges the inputs from the given yearly plans into the proper form. The vehicle estimation process estimates the number of needed contract vehicles for each supplier. This process contains to sub-process which are monthly and yearly vehicle estimation sub-process. In the vehicle estimation process, each supplier is considered individually. The monthly representatives of a particular supplier are determined, then the most efficient number in terms of vehicles service cost is selected to be the yearly representative of that particular supplier. After each supplier has their own yearly representative, the final number of contract vehicles calculation process will be operated. The outcome of the last process is the number of needed contract vehicles in a particular year.

For the routes planning system, we use the concepts of the column generation algorithm, and LSP heuristic to create a travelling route for each vehicle. The designed routes planning system consist of 7 core processes: the preparation process, the initial process, the layer extended process, the route screening process (I), the route screening process (II), the dual variables obtaining process, and the final solution identifying process. The first process aims to rearrange the received exact plans, and the initial process targets to create initial columns for obtaining the primary dual variables. After the dual variables have been generated by using the initial columns in the set covering problem's model, the layer extended process is execute for lengthen the obtained routes. Subsequently, the extended routes will be screened by the route screening process (I), and routes that have positive reduced cost or violate time constraints will be eliminated. If there are any route left, the route screening process (II) will be operated. Otherwise, the dual variables obtaining process will be executed. After the route screening process (II) had been performed, the layer extended process will be repeated until the dual variables obtaining process have been done. Then, after the new dual variables are obtained from the dual variables obtaining process, the stopping criteria are considered. If the stopping criteria are met, the final solution identifying process will be complete, otherwise the layer extended process will be repeated again. The outcome of this system is the planned routes for each vehicle with specific visited locations arrangement.

Lastly, we measure our proposed systems computationally.. We conduct 5 experiments: distance, time window, customers' locations, average number of requirement, and suppliers' locations distribution experiments. In each experiment, we compare the efficiency of our proposed systems with the basic procedure from one of the interview experts in transportation field. Our proposed systems outperform the suggest procedure in every experiments' sample, especially in the sample having lengthy distance between locations, tight deliveries' time window, customers' locations situated at the middle area of the delivery area, and random and uniform suppliers' locations distribution. We also recognise that the vehicles' utilisation has no effect to the transportation cost in our systems. The average transportation cost percentage reduction of our proposed systems with the basic procedure is 40.51%.

## 5.2. Discussion

In this research, there are some limitations in the systems due to time and resources. Also, there are some perspectives that could be extended for the work in the future. As a result this section will discuss about the research limitations and future work opportunities.

### 5.2.1. Research Limitations

1. In the vehicle estimation system, the predicted value of a material requirement is used for calculating the number of contract vehicles. In case of high demand fluctuation, the predicted value may not well represent the situation and alternative method should be considered.

2. The total transportation cost in the routes planning system consists of both contract vehicles cost and outsourcing vehicles cost. To better evaluate system's performance, it is interesting to distinguish sources of cost (service cost, distance cost, and guarantee cost) so that we can evaluate whether the number of contract vehicles is appropriate or the routes planning decision is appropriate.

3. The size of the systems (number of requirements, and number of locations) is limited to the computer's memory. Too large problem might not be able to solve.

### 5.2.2. Future Works

1. In the routes planning system, the journey from/ to the vehicles owner locations could be considered to make the systems become more realistic.

2. The ratio of service cost of outsourcing vehicles and contract vehicles might affect the cost unexpectedly. Thus, some more works could be extended to determine the consequences after the ratio has been adjusted.

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