TRANSPORT CAPACITY UTILISATION IMPROVEMENT FOR CONSUMER PRODUCT DISTRIBUTION

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กรองมาลย์ วิเชียรบรรเจิด : การปรับปรุงการใช้ประโยชน์ระวางบรรทุกสำหรับการกระจายสินค้าอุปโภคบริโภค (TRANSPORT CAPACITY UTILISATION IMPROVEMENT FOR CONSUMER PRODUCT DISTRIBUTION) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. มาโนช โลหเตปานนท์, หน้า.

ปัจจุบันเศรษฐกิจในประเทศไทยได้มีการเติบโต บริษัทต่างๆจึงได้มีการศึกษาและวางแผนการดำเนินงานในการพัฒนาองค์กรให้สามารถต่อสู้กับคู่แข่งได้อย่างมีชั้นเชิง และหนึ่งในกลยุทธ์คือการจัดจ้างองค์กรภายนอกที่มีความชำนาญเฉพาะทาง (Outsource) ให้ช่วยดำเนินการในกิจกรรมที่ไม่ได้เป็นกิจกรรมหลัก (Non-core activities) อาทิเช่น กระบวนการขนส่ง เพื่อลดค่าใช้จ่ายในการดำเนินกิจกรรมนั้นๆและทำให้องค์กรสามารถมุ่งเน้นในการสรรค์สร้างกิจกรรมหลัก (Core activities) โดยการใช้ทรัพยากรขององค์กรได้อย่างเต็มที่ ดังนั้นผู้รับจ้างขนส่งจากภายนอก (Third-party logistics provider) ซึ่งเป็นองค์กรที่มีความชำนาญเฉพาะทางด้านการขนส่งจึงถือกำเนิดขึ้น ในงานวิจัยฉบับนี้ได้ทำการศึกษาการดำเนินงานขององค์กรผู้รับจ้างขนส่งภายนอก องค์กรได้พบเจอกับปัญหาเกี่ยวกับการใช้ระวางบรรทุกอย่างไม่มีประสิทธิภาพเท่าที่ควร ซึ่งปัญหาเกิดขึ้นจากการที่องค์กรผู้ว่าจ้างใช้ระบบการจัดเส้นทางรถที่ไม่เหมาะสม ดังนั้นงานวิจัยฉบับนี้จึงมีวัตถุประสงค์เพื่อพัฒนาการทำงานของผู้รับจ้างขนส่งโดยการออกแบบระบบการจัดเส้นทางเดินรถให้กับผู้รับจ้างขนส่งโดยการประยุกต์หลักการจำลองอบเหนียว (Simulated annealing) เพื่อปรับปรุงการใช้ประโยชน์ระวางบรรทุกให้มีประสิทธิภาพมากยิ่งขึ้น

ระบบการจัดเส้นทางรถถูกประเมินในสามแง่มุมหลักซึ่งก็คือการใช้ประโยชน์ระวางบรรทุก, จำนวนระยะทางที่ใช้ในการจัดส่งสินค้า และค่าใช้จ่ายที่เกิดขึ้นจากการขนส่งสินค้า ผลจากการทดสอบระบบที่ได้นำเสนอในงานวิจัยฉบับนี้พบว่าระบบสามารถปรับปรุงการใช้ประโยชน์ระวางบรรทุก และสามารถลดจำนวนระยะทางพร้อมทั้งค่าใช้จ่ายที่เกิดขึ้นภายใต้ข้อจำกัดต่างๆของผู้ว่าจ้างได้อย่างมีประสิทธิภาพ

ภาควิชา	ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต	ลายมือชื่อนิสิต	....
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KRONGMAL WICHIANBANJERD: TRANSPORT CAPACITY UTILISATION IMPROVEMENT FOR CONSUMER PRODUCT DISTRIBUTION. ADVISOR: ASST. PROF. MANOJ LOHATEPANONT, Sc.D., pp.

Currently, Thailand’s economic is growing. Several companies study strategies that advice the firms to gain competitive advantages. One of widely used strategies, that aids the firms to reduce cost and utilises their resources to focus on the firms’ core competencies, is outsourcing non-core activities (e.g. a transportation process). A transportation process is one of the non-core activities that requires to be managed appropriately. Therefore, a third-party logistics (3PL) provider that has expertise in the logistics process has been established, and provides service in the logistics management. In this research, a 3PL company is considered as a case study company. A current issue is a capacity utilisation problem due to the improper collaboration of route planning system between the 3PL company and a client (i.e., a retail business). Therefore, this research is operated to improve the capacity utilisation by developing a heuristic algorithm. The proposed algorithm is based on the simulated annealing metaheuristic (SA) for vehicle routing problem (VRP).

The experiments evaluate the transportation plans in three main perspectives that are the capacity utilisation, the total travelled distance, and the total transportation cost. The results show that the proposed algorithm provides superior performances than the company’s transportation plan while the constraints of the company are satisfied.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	....
		Advisor's Signature	....
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1. introduction

1.1 Background of problem

ABC limited company (a fictitious business name) is a foreign logistics provider company that expands its business to operate in Thailand and becomes one of the major logistics service provider in the country. Since the ABC company, which is the case study company, serves many sectors of industries, it has much experience and comes to be famous in many types of clients. Major customers of ABC company are companies in both retailer and restaurant sectors. A job of the company is to provide vehicles with drivers that are used for transporting products from one place to others, already assigned by customers. A specific case that will be considered in this research is a collaboration between ABC limited company, which is considered as a third-party logistics provider (3PL), and a retailer business, which is a client of the 3PL. Nowadays, the number of both 3PL companies and retail stores arise continually in Thailand. Therefore, ABC company should operate with high performance to maintain a position in the 3PL sector and to success as a partner of the retail business.

In order to success in the competitive environment, (Chandra and Grabis 2007) stated that supply chain management should be applied to the business. Supply chain management (SCM) can be explained as efficient approaches to manage activities that occur during a process of satisfying demands. These activities come from three major tiers in a supply chain that are suppliers, manufacturers, and distributors. Furthermore, the supply chain requires different responsibilities from each element to finish desired outcomes. Actions from several tiers need to be planned, managed, controlled, and harmonised. Therefore, gathering these activities as a system and targeting a same goal all over the chain can be defined as SCM. Additionally, an integration of supply chain is an important issue in the supply chain management because each unit in the supply chain cannot compete competitors effectively as individual, especially in the competitive environment. While, considering each unit as part of the chain and strengthening the whole chain together will make the supply chain becoming the powerful opponent in a marketplace.

Since all activities from the supply chain combine as one system, an inefficient action that occurs from a single part can affect all over the chain. Hence, each unit in the supply chain must understand a role of oneself and functions of the system to perceive performance of a company and to find a root cause of a problem that can happen in the system. According to the responsibility of the 3PL company, which is studied in this research, this can be stated as that the 3PL firm is a part of a retail store chain and functions of this chain will be explained as followed.

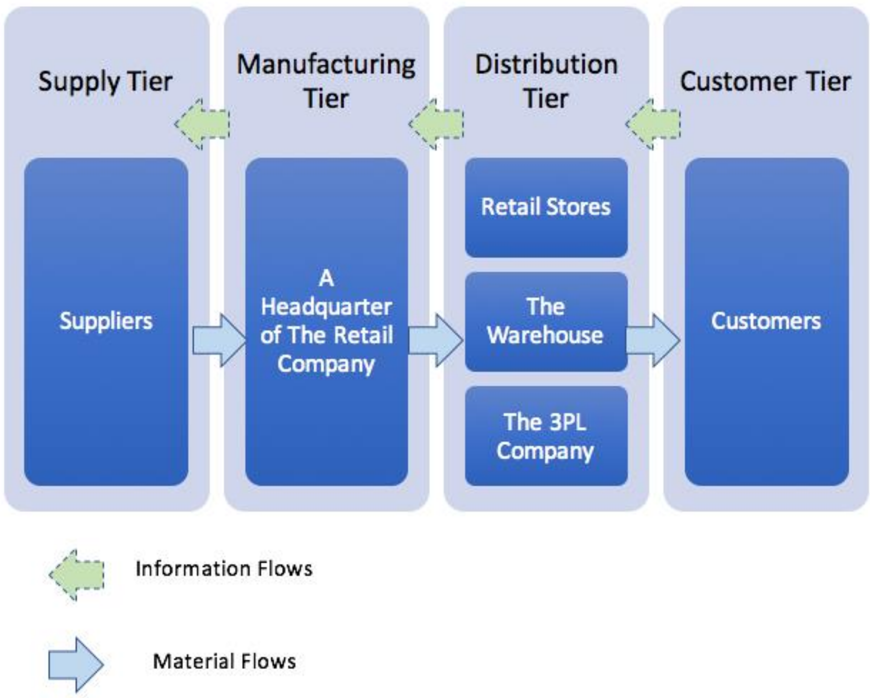


Figure 1: A retail store supply chain structure

Figure 1 (adapted from (Chandra and Grabis 2007) represents the retail store supply chain that is divided into four tiers that are a customer tier, a distribution tier, a manufacturing tier, and a supply tier. Some tier includes small subsets, which are called units, that work together in order to achieve a target of the tier. Even though each tier contains different functions, the whole system has a same target that is to be success as the chain in a competitive market. Apart from that characteristics of tiers can be categories into two point of views that are processes from a downstream tier to an upstream tier and vice versa. (Chandra and Grabis 2007) also states that flows from the downstream up to the upstream is information flows, while from the upstream down to the downstream is material flows. These collaborative flows will be explained as followed.

<u>Downstream to upstream</u>

- Customer tier

Customers purchase products at retail stores and selling items will be recorded in each store system.

- Distribution tier
  - Retail stores

Each retail store submits the number of requirement of products that needs to be fulfilled in a central system of the retail company.

  - The warehouse

Historical data of activities, which occur during picking products from a warehouse and receiving packages from suppliers and transferring them to the 3PL's fleets, are recorded. Then, this information will be transferred to the headquarter of the retail company.

  - The third-party logistics provider

The 3PL provides information that occurs during transportation and calculates expenses, which take place from transporting packages, to the headquarter of the retail company.

- Manufacturing tier
  - Data received from retail stores

All reordered items in the central system are gathered, these items will be checked with both the number of units in a stock, which are stored at the warehouse, and the number of units, which will be supplied from suppliers.

Moreover, the adjustment of demands will also be updated to suppliers in order to revise requirements in the next period.

- Data received from the warehouse

This data will be collected to index the performance of workers.

- Data received from the 3PL

The headquarter reviews the operational execution of the 3PL and will prepare the payment for the 3PL company.

- Supplier tier

Suppliers receive ordered requirements from the retail company.

<u>Upstream to downstream</u>

- Supplier tier

Suppliers ship packages at the warehouse as required by the headquarter.

- Manufacturing tier

After combining the total available units which are gathered from the stock and suppliers, these amounts of the items will be used for doing the transportation plan. Moreover, after finishing the plan, the plan will be transferred to the warehouse and the 3PL.

- Distribution tier

    - The warehouse

Products that are required to delivered in each day, which may be come from both picking items in the warehouse and supplying from suppliers. All items will be arranged and prepared for loading to vehicles of the 3PL.

    - The 3PL

Drivers of the 3PL will deliver packages according to the transportation plan.

    - Retail stores

Each retail store receives required items and allocate them to shelves.

- Customer tier

    Customers purchase products that are available at retail stores.

According to the study of the retail supply chain, this represent how all functions of each tier collaborates together. Furthermore, processes of the retail store company and the 3PL company are provided.

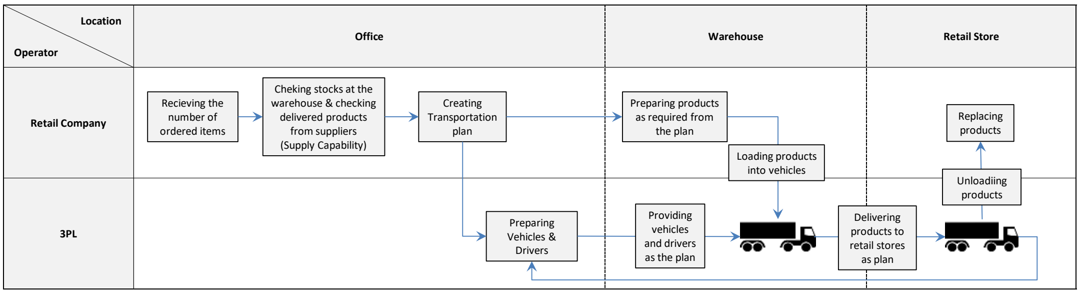


Figure 2: The company processes flow chart

Figure *2* represents collaborative processes between the retail company and the third party logistic provider in order to achieve the transportation plan and these schemes will be described as following.

1. Receiving the number of ordered items

    The headquarter of the retail company receives the number of products that each retail stores requires to replace from the central system of the retail company.

2. Checking the number of available products

    The headquarter of the retail company is responsible to check the number of products that is available in the warehouse and the number of products that will be delivered by suppliers in each day. Hence, the number of products that is able to fulfill requirements of retail stores is obtained.

3. Generating a transportation plan for delivering products

    After perceiving the total number of products that is available for replacing the requirements, then this data will be used to generate a transportation plan. A transport management system (TMS) department of the retail company is responsible for planning and scheduling routes that are required delivering products from the warehouse of the retail company to retail stores. A characteristic of a route planning system that the TMS department uses for generating a daily transportation plan is that to plan routes for the limited number of heterogenous vehicles to transport packages from the warehouse to retail store and each route starts and terminates at a warehouse. Information of each route informs the number of required drivers, a type of selected vehicle, a sequence of retail stores, a set of requirements of each retail store in term of volume (m^3). In addition, each route must satisfy three constraints that are a capacity constraint, a total time constraint, and an accessibility constraint. For the capacity constraint, each vehicle must not be loaded total requirements of retail stores of each trip at the warehouse greater than the maximum capacity of each type of vehicles. For the total time constraint, the total time of each trip is restricted by the total working hours of drivers. In addition, the total time of each route counts from that a vehicle leaves the warehouse until it returns to the warehouse and the total time constraint of each route depends on the number of drivers in a trip. For the accessibility constraints, an express retail store type allows only some types of vehicles to access that are four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo to deliver packages, since express retail stores have a limited space for unloading the packages. Moreover, an example of the daily transportation plan can be illustrated in Figure 3.

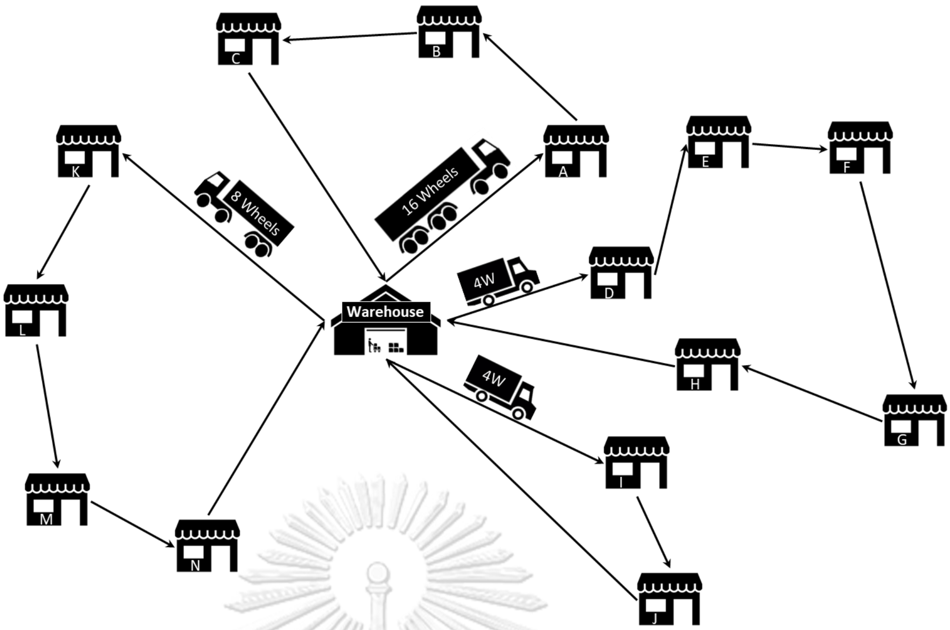


Figure 3: The daily transportation plan

4. Informing the transportation plan

After obtaining the transportation plan from the TMS department, the daily transportation plan will be transferred to two departments that are the headquarter of the 3PL company and the warehouse of the retail company.

- The headquarter of the 3PL company

Informative details of the exact transportation plan that inform to the 3PL company are that the number of required trucks and drivers, routes for every truck, and a set of total requirements in term of volume that will be delivered to each retail store. Then, the 3PL company arranges the number of vehicles and drivers that is required for transportation accordingly to the transportation plan. Next, drivers of the 3PL company that already base at the warehouse will be briefed routes that each of them is requested to deliver packages.

Apart from that the main job of the 3PL company is that to provide the daily number of vehicles that is already agreed with the client, which is the retail company. Even the daily number of required vehicles in the agreement is fixed and limited, the actual number of required vehicles varies in each day.

Since, the total number of requirements of retail stores that is required to replace varies from day to day. Additionally, in each day some retail stores required the replacements, while some of them do not want to. Therefore, the number of trips that requests vehicles for the transportation changes everyday. Aside from that not only the number of required vehicles is unstable but also the number of required drivers. Since, some trips require total travel times that exceed a working hour limit of one driver due to the labour relation act of Thailand. Then, the 3PL firm will assign two drivers in these trips in order to be abided by the labour relation act of Thailand. Hence, the way that the 3PL company operates to manage this issue is described as followed. To cope with these issues, a planning department of the 3PL company, which is responsible for preparing the number of vehicles and drivers, studies the trend of requirements from the forecasting data and the past data. For the forecasting data, the retail company sends six weeks ahead of forecast requirements of fleets to the 3PL company every week. This means that the forecast requirements are revised every week. Then, the 3PL company perceives a long-term forecasting and a medium-term forecasting that are six weeks ahead and one week ahead before obtaining an exact requirement, respectively. The planning department analyses the trend of the forecasting then adjusts the forecasting number of required vehicles for the following period. After that the planning department analyses the proportion number of drivers that is actual required compared with the number of required vehicles. Afterwards, the planning department will prepare spare vehicles and drivers in each day in order to provide the daily number of vehicles and drivers for operating transportation on each day.

- The warehouse of the retail company

Workers of the retail company at the warehouse receive the information that are the total number of every product that each retail store requires to fulfill, retail stores that will be delivered by the same vehicle, and a sequence of products of each retail store that will be placed in a container of each vehicle. Then, workers will prepare all requirements of products accordingly to the plan.

5. Operational processes that execute at the warehouse

After the 3PL company prepares vehicles and drivers to be ready for the transportation at the warehouse of the retail company and workers at the warehouse prepare products that are required for the replacement, processes at the warehouse will proceed as following.

5.1 Suppliers of the retail company unload products at the warehouse with the amounts that already inform to the headquarter.

5.2 If products that are supplied by suppliers are required delivering to retail stores in that day, these products will be sorted out and the remaining goods will be stored in the warehouse.

5.3 Workers pick products that are required delivering from the warehouse.

5.4 Both products that are supplied from suppliers and products that are picked from the warehouse will be classified into a requirement of each retail store branch.

5.5 A set of total product requirements of each retail store branch will be consolidated.

5.6 Requirements of several branches that will be delivered in a same route will be placed together at a reloading point of each vehicle. Additionally, at the same time, vehicles of the 3PL will be parked at assigned reloading points by drivers of the 3PL company.

5.7 Workers move products into containers of vehicles as the assigned sequence, since it will aid workers for unloading products at the retail store. For example, products of a retail store that will be firstly delivered will be placed lastly in a container.

5.8 After finishing the transferring products into vehicles, every vehicle will be sealed.

6. Drivers of the 3PL deliver packages at retail stores

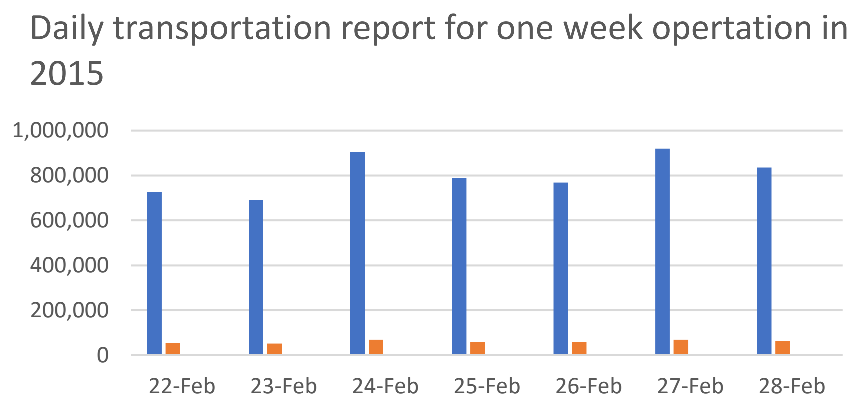
Drivers start to transport products from the warehouse to retail stores. After arriving at retail stores, packages will be unloaded. Then, workers at retail stores will fulfill products at shops.

7. Drivers of the 3PL drive back to the warehouse

After vehicles come back to the distribution center, each driver reports details of the trip to a supervisor and a condition of each vehicle is checked. Then, the supervisor will report the information of the transportation to the headquarter of the 3PL company.

1.2 Statement of problem

Since ABC company is a logistics company, then the main cost of the firm comes from the transportation. According to Figure 4, it represents that in each week this distribution center has a huge amount of total travel distance. Hence, if ABC company can well administrate routing plan by utilising every trip as much as possible, the expenses of the firm will be reduced significantly, e.g. attempting to have full truck load in every trip, grouping nearby customers in the same trip. Furthermore, ABC company conducts the business as a service company since it provides the service by distributing products of the client. Thus, a well-managed routing will lead to a high satisfactory level of the customer.



	22-Feb	23-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb
The total transportation cost (THB)	726,583.11	689,672.18	905,038.72	790,406.51	768,603.20	919,135.85	835,542.30
Total travelled distances (km)	55,544.20	52,573.20	68,505.59	59,713.00	59,153.56	69,716.02	62,893.45
Total requirements of retail stores (m3)	1,655.77	1,564.61	2,271.06	2,170.15	2,126.95	2,948.16	2,385.55
The number of trips (times)	589	670	603	568	493	588	597

Figure 4: Daily transportation report in 2015

Therefore, activities that are related to the transportation are analysed in order to identify the performance. After that a flaw of the operation that is non-utilised full truck load from the daily route plan, which is obtained from the retail company, is found. Figure 5 illustrates a percentage of the capacity utilisation and the data is collected from one week, with 782 trips, from each type of vehicles, which are four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo, 18-wheel trucks small, 18-wheel trucks, and ten-wheel trucks with trailers. Furthermore, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13 show the percentage of the capacity utilisation from one week operation of the different vehicle types that are four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo, 18-wheel trucks small, 18-wheel trucks, and ten-wheel trucks with trailers, respectively. These charts represent many unused capacities that can be considered as wastes. Due to the currently process between the 3PL company and the transportation plan, this can be summarised as that the 3PL is only responsible for transporting products. The 3PL firm receives the transportation plan, which is created by the retail company, and targets to transport products according to the plan successfully. Moreover, the 3PL firm does not involve in designing the transportation plan. So, this means that a root cause of the inefficient utilisation problem occurs from an improper model of the transportation plan is currently used. Drawbacks from this problem are that

1. The non-utilised full truck load leads to the high number of the requirement of vehicles. Then, an expense involves with the transportation are high and it consequently increases costs that occur in the supply chain.

2. The 3PL company is the company that provides vehicles with drivers for the transportation service while the firm does not have an algorithm for planning the route. Hence, this makes the firm losing opportunity to service clients that require a full-service transportation.

3. After the full truck load problem is considered, then interviews of planners who are responsible for planning routes of the retail company are conducted. Two processes of generating routes at the retail company are that, firstly, a planning route system of the retail company that is generated by a computer is used for pre-routing a transportation plan. Secondly, planners revise routes that have low capacity utilisation. A reason behind is that the currently used system is not proper to generate the transportation plan for the company, thus the system is unable to generate the complex solution.

In conclusion, if an effective transportation algorithm is created, these presently drawbacks should be discarded. Moreover, a high capacity utilisation might be trade-off with a farther length of a route, so that a model that will be developed in this research is evaluated by considering the total cost of the transportation.

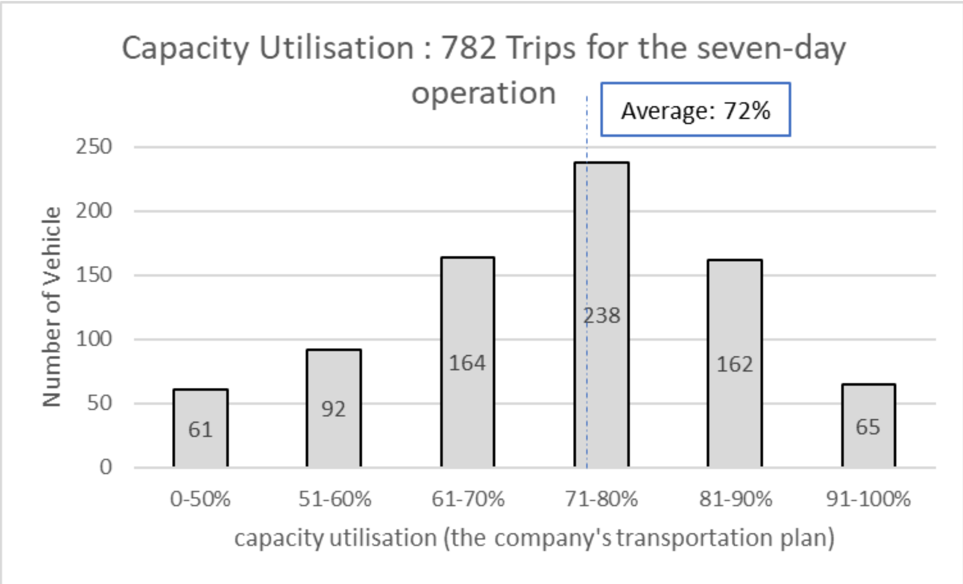


Figure 5: Capacity utilisation from one week, with 782 trips, of each type of trucks

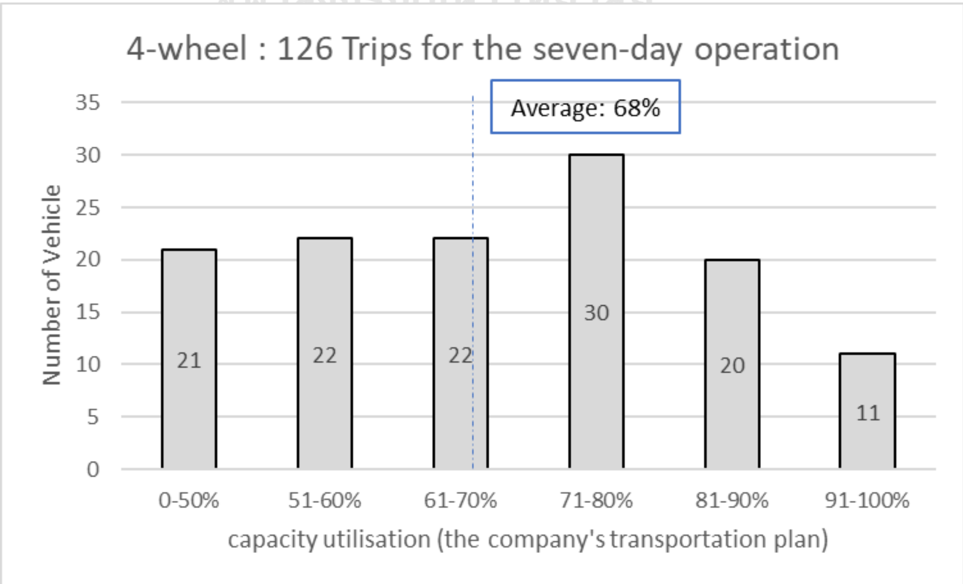


Figure 6: Capacity utilisation from one week, with 126 trips, of four-wheel trucks

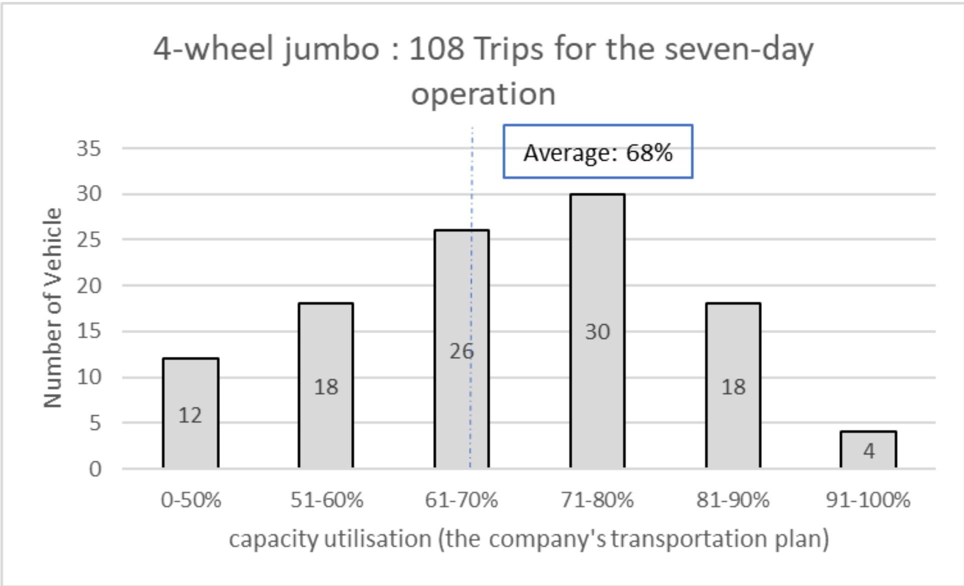


Figure 7: Capacity utilisation from one week, with 108 trips, of four-wheel trucks jumbo

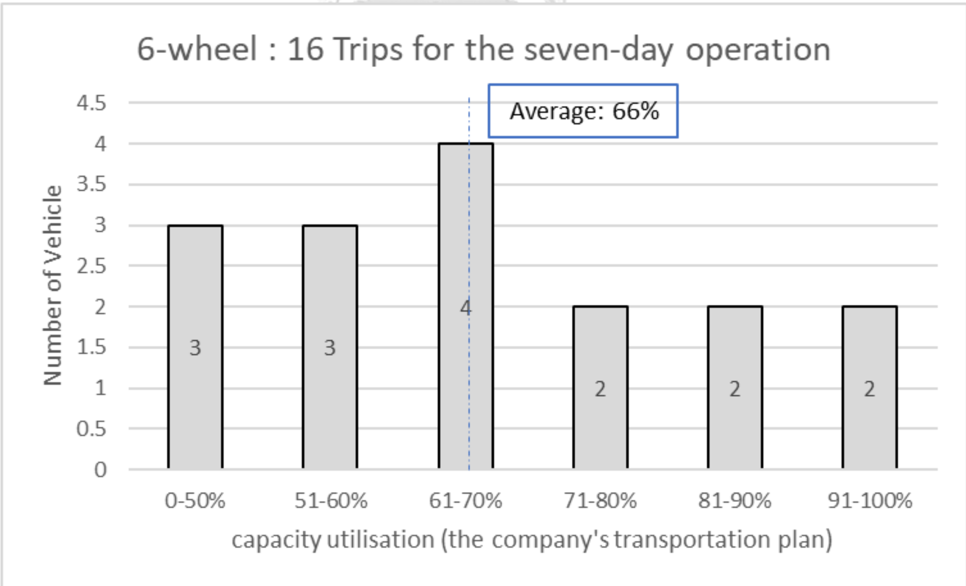


Figure 8: Capacity utilisation from one week, with 16 trips, of six-wheel trucks

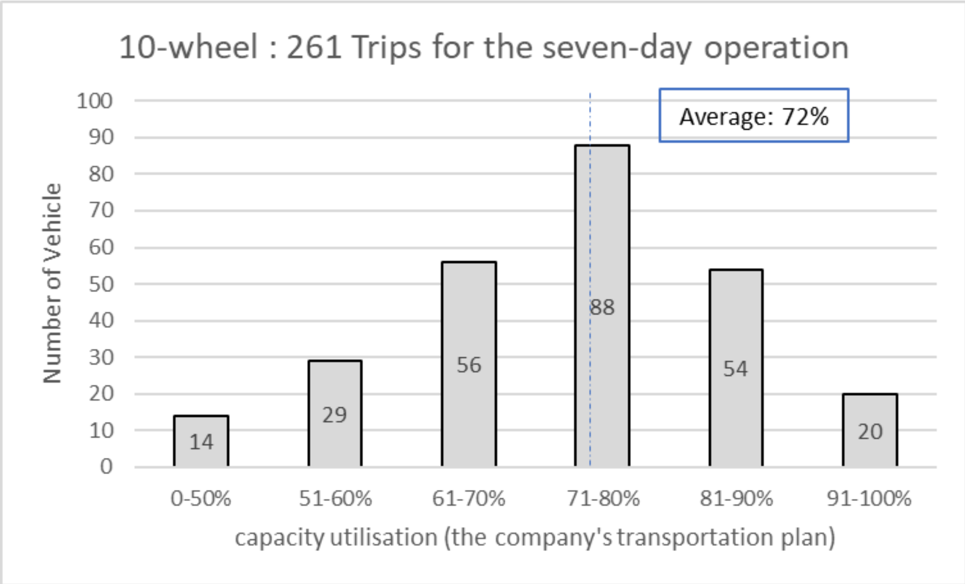


Figure 9: Capacity Utilisation from one week, with 261 trips, of ten-wheel trucks

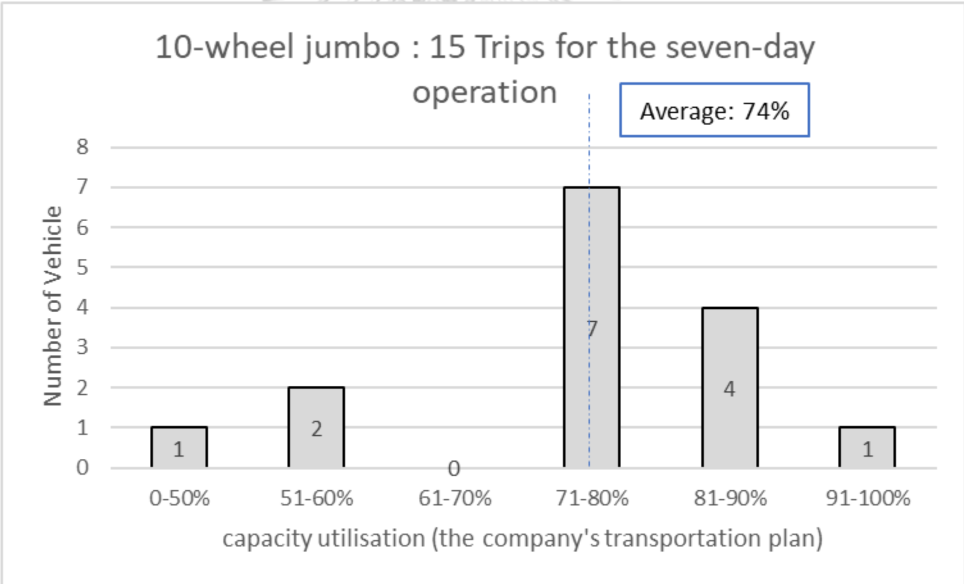


Figure 10: Capacity Utilisation from one week, with 15 trips, of ten-wheel trucks jumbo

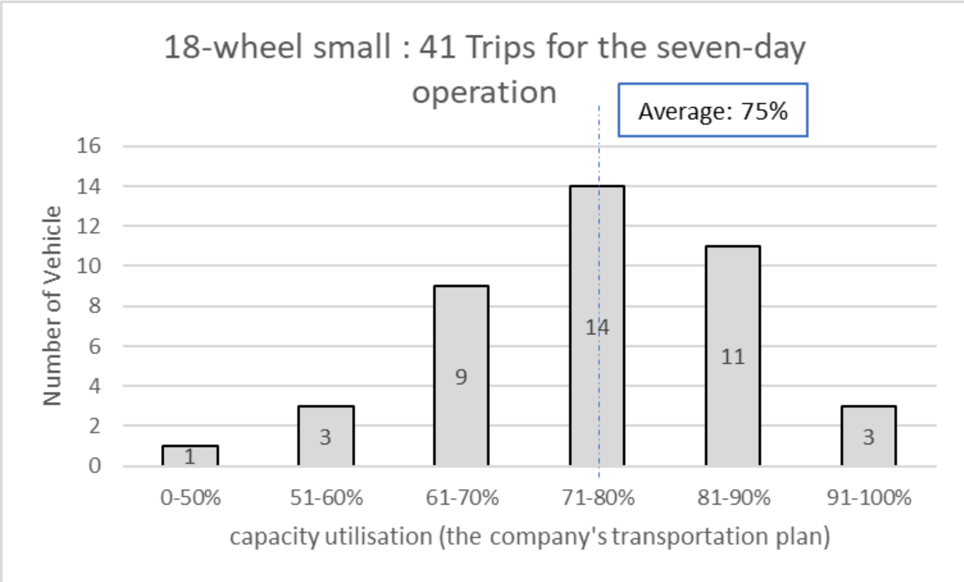


Figure 11: Capacity Utilisation from one week, with 41 trips, of 18-wheel small trucks

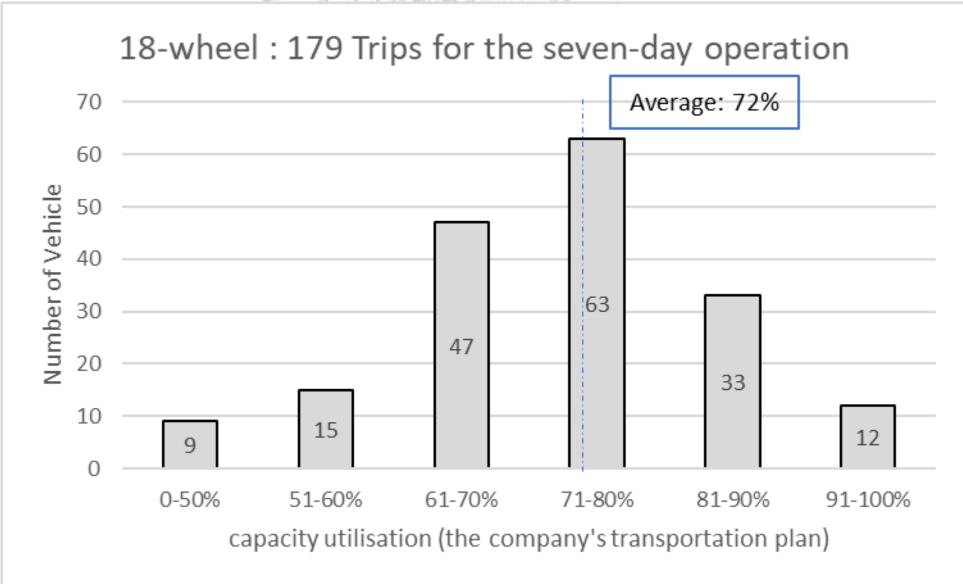


Figure 12: Capacity Utilisation from one week, with 179 trips, of 18-wheel trucks

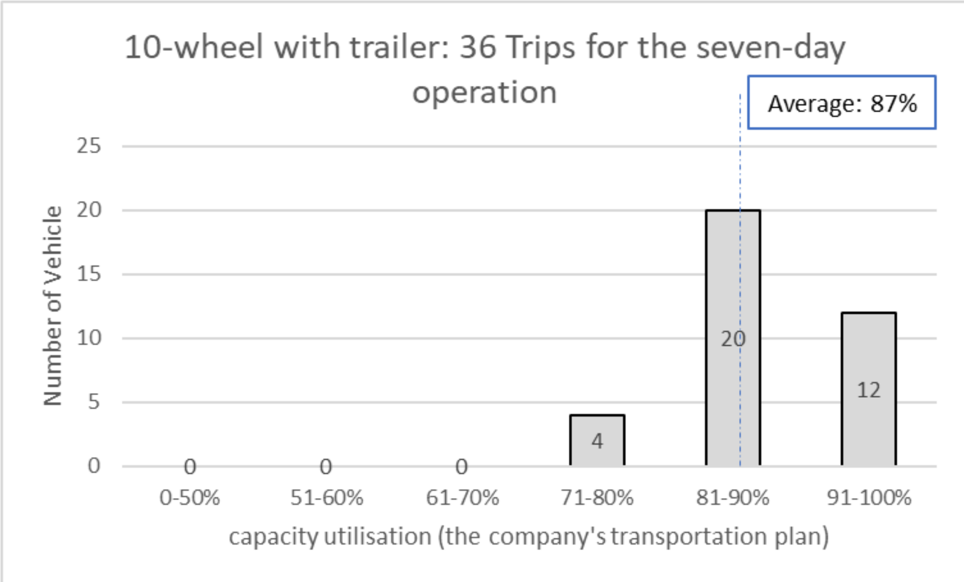


Figure 13: Capacity Utilisation from one week, with 36 trips, of ten-wheel trucks with trailers

1.3 Assumption

1. Vehicles that are used for transportation in this research are heterogeneous fleets. Eight types of fleets that comprise of four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo, 18-wheel trucks small, 18-wheel trucks, and ten-wheel trucks with trailers are considered. The limited number of each type of vehicles is 33 units, 19 units, 4 units, 41 units, 5 units, 9 units, 40 units, and 7 units, respectively. In addition, these quantities of vehicles are summarised in *Table 3* and they will be available constantly in everyday of working routine.
2. The maximum capacity of four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo, 18-wheel trucks small, 18-wheel trucks, and ten-wheel trucks with trailers are 4.8 m^3, 9 m^3, 19 m^3, 25 m^3, 37 m^3, 41 m^3, 44 m^3, and 55 m^3, respectively. These maximum capacities are considered as a capacity constraint in this research.
3. Retail stores that are considered in this research comprise of 947 stores. Every store can be supplied products by any types of vehicles, excepting an express store type that cannot be supplied packages by 10-wheel trucks with trailers,

18-wheel small trucks and 18-wheel trucks. Additionally, this will be defined as an accessibility constraint in this research.

4. Each type of fleets contains different travelled distance cost and service cost and they are exemplified in chapter 3.
5. Distances that are considered between locations are displacements and a calculation of the displacement in the route planning system is mentioned in chapter 3.
6. Only one warehouse is considered.
7. Every vehicle begins and finishes at the warehouse.
8. Vehicles drive with a constant speed which is 60km/hr.
9. Travelled time is related to travelled distanced by a linear relationship.
10. There is no limitation of combining packages of any retail stores in the same route.
11. Each route can require either one driver or two drivers depend on the total required time to service a route.
12. Total working hours of one driver per route and two drivers per route are limited with 10 hours and 36 hours, respectively and these can be considered as a total time constraint.
13. The number of drivers is unlimited.
14. An unloading duration of every retail store is the same that is equal to 60 minutes.
15. A capacity constraint is restricted by a volume of each vehicle (m^3).
16. An order of each retail store that is specified by the client is considered in terms of volume (m^3).
17. An order of each retail store (m^3) that is specified by the client cannot be split.
18. The total volume of an order of each retail store (m^3) that is specified by the client is not greater than the capacity of the biggest vehicle in the system.
19. A retail store can require more than one order per day, if the total volume of the order (m^3) is greater than the maximum capacity of the largest vehicle.
20. The volume of an order of each express retail store cannot be greater than the maximum capacity of the accessible largest-sized vehicle.

21. Unforeseen situations and uncontrollable factors during the transportation are not considered in this research, for example, traffic, accident, disaster.

1.4 Objective of research

To improve capacity utilisation for consumer product distribution by developing a heuristic algorithm.

1.5 Scope of study

The study concentrates on minimising total travelling cost by optimising total traveling distance and capacity utilisation in following issues.

1. This research only studies about generating a transportation plan. Decisions that are required from the transportation plan are a route for every vehicle and the number of drivers per vehicle.
2. One warehouse and retail stores that are supplied products by this warehouse are considered.
3. There is only one provider of the transportation in a system, which is the ABC third-party logistics provider.
4. The parameters that are used in the heuristic algorithm will be adapted in order to conform with the problem of ABC company.
5. The parameters that are studied in this case are the amount of delivered products in each day in terms of volume, the various types of fleets, the accessibility constraint of the retailers, the total time constraint of each route, and the capacity constrain of each vehicle.
6. The proposed algorithm uses a heuristic solution method that will provide an acceptable solution with reasonable time. Therefore, there is no guarantee that an optimal solution will be acquired.
7. Paths in a considered system can be classified into two types that are paths between the warehouse and retail stores, paths between retail stores and retail stores.

1.6 Decision variables

In order to plan a route for each vehicle, three decision variables that are considered in the route are a sequence of retail stores, a type of vehicles, and the number of required drivers.

1.7 Inputs

1. Locations of the warehouse and retail stores
2. Demands of each retail store in terms of volume (m^3)
3. Several types of vehicles
4. The limited number of each type of vehicles
5. Capacities of vehicles in each type in terms of volume
6. Variable costs of each type of vehicle with a baht/km unit
7. Semi-fixed costs of each type of vehicle
8. A constant speed of vehicles
9. Distances between every point in a system
10. Travel time between every point in a system
11. The limitation of working hours of one driver per route and two drivers per route

1.8 Constraints

2. The limited number of each type of vehicles
3. A capacity constraint of vehicles in terms of volume
4. An accessibility constraint for express retail stores
5. A total time constraint in terms of working hours of one-driver route and two-driver route

1.9 Expected results

1. Generating a heuristic solution method for planning routes effectively.

1.10 Expected benefits

- For a point of view of the ABC third-party logistics provider
    1. The total cost of transportation could be reduced
    2. The total required volume of vehicles might be reduced.
    3. The capacity utilisation of vehicles could be increased.
- For a point of view of the client, which is a retail company
    1. The client could spend their resources on their core activities.
    2. The transportation cost of the client could be reduced.

1.11 Research methodology

Research process	Methodology	Expected outcomes
1. **Collect general information of the 3PL and the client**	Managers and workers from the 3PL and the client company are interviewed about their roles in the supply chain.	▪ Understanding the retail supply chain ▪ Understanding the collaboration in the supply chain
2. **Analyse the supply chain**	Daily processes of the 3PL and the client are observed. Then managers and workers from these companies are interviewed about daily processes in order to find any dilemmas.	▪ Understanding work processes of the 3PL and the client company ▪ Finding an area that could be improved

3. **Collect data from the data base of the 3PL company**	Data from the data base of the 3PL company that is related to the area that could be improved is collected.	▪ Obtaining supportive data of an area that could be improved
4. **Define the problem**	Analyse the collected data	▪ Statement of problem
5. **Define the scope of the problem**	Identifying the problem area that will be studied in this research	▪ Research's objective ▪ Research's assumption
6. **Understand the problem and the approach of solving**	Reviewing literatures that are relevant to the problem and studying the way of solving the problem	▪ Obtain the scheme of problem solving
7. **Finding an approach for solving the problem**	Analysing several proposed methods from other researchers and finding the most fit approach from a heuristic scheme.	▪ Obtain candidate models for solving the problem
8. **Adjusting selected methods**	Steps and parameters of selected methods are studied and adjusted to suit with the problem of this research	▪ Obtain an appropriate approach for solving the problem

9. Generate a heuristic model	Generate a heuristic model for solving the problem	▪ Obtain a heuristic solving method
10. Evaluate a proposed heuristic method	A plan that is generated by the proposed method is compared with a plan that is currently used by the company.	▪ Approval the proposed method
11. Conclude the research	Concluding all approaches of this research from the beginning until getting the results, then generating a research report	▪ Research report

Table 1: Research methodology

2. Literature reviews and related theories

2.1 Literature reviews

Since this research desires to acquire a method for generating a transportation plan that suits with several conditions, which occur in the studied company. Therefore, literatures from other researchers that suggest solution approaches of the related problem of this research will be studied.

2.1.1 Travelling salesman problem (TSP)

This study starts with a method that is used for finding the shortest path in a studied system. This method is called the travelling salesman problem (TSP) (Laporte 1992). The problem is to find the shortest path for servicing every customer in a system by only one vehicle and each customer must be visited only once. Although, the shortest distance consideration is an issue that should be considered, the TSP does not concern other realistic issues in a transportation problem. For example, there are several customers in a considered system and each customer requires demands. Then, only one vehicle in the system might not have enough capacities to serve all the requirements, so that a next studied issue is the vehicle routing problem (VRP) that considers a practical viewpoint of the transportation. In addition, a system of the TSP is to find the shortest path of a considered problem and it is illustrated in Figure 14.

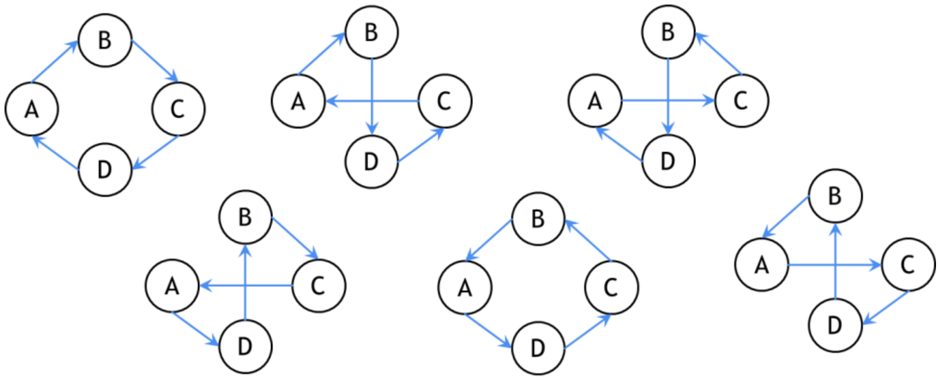


Figure 14: An example of the travelling salesman problem

2.1.2 Vehicle routing problem (VRP)

The VRP is an approach for designing routes in a system that requires vehicles to deliver products to customers or to collect packages from customers. Vehicles start and end at either one depot or several depots and several constraints that are relevant to each type of a considered problem will be concerned (Laporte 1992). According to this statement, the VRP conforms with a problem of this research, so that details of the VRP are examined. A scheme of finding a solution of the VRP begins with considering a problem as a graph that comprises of nodes and arcs. Nodes represent a depot and customers, while arcs represent paths that link among combinations of a depot and customers. Moreover, these paths are considered as a cost of a route planning system, if they are selected to include in the solution. The number of required vehicles is also considered, since it expresses one kind of costs in the system. Finally, the method will choose routes based on an objective of the system, for example, the cheapest total fixed cost, the cheapest total variable cost. Apart from that some conditions that attach to each problem might alter some function of the route planning system. Examples of general constraints that many researchers study about in the VRP are that

1. Capacity constraint: each route that assign a vehicle to deliver or collect products must not exceed a capacity of each vehicle. This problem is called the capacitated vehicle routing problem (CVRP) (Baldacci and Mingozzi 2009). In addition, this variant of the VRP is most widely used and studied and a system of the CVRP is illustrated in Figure 15.
2. Total time restriction: each route is restricted by total duration or total distance that is already defined before starting to solve a problem (Osman 1993).
3. Time windows: customers indicate durations that packages can be delivered or collected and this constraint refers to the vehicle routing problem with time windows (VRPTW).
4. Multi-depot: there are more than one depot in a system. This becomes another variant in the VRP that is the multi-depot vehicle routing problem.

5. Heterogeneous fleets: In a general variant of the VRP, e.g. the CVRP, a homogenous fleet of vehicles are assigned to transport products. While a system that consists of several types of vehicles is categorised as another variant of the VRP and it is the heterogeneous vehicle routing problem (HVRP). Furthermore, this variant is analogous with the problem of this research, thus the HVRP will be further described.
6. The open vehicle routing problem: vehicles are not required to return to a depot after delivering packages and this problem is categorised as the open vehicle routing problem (Li, Leung et al. 2012).

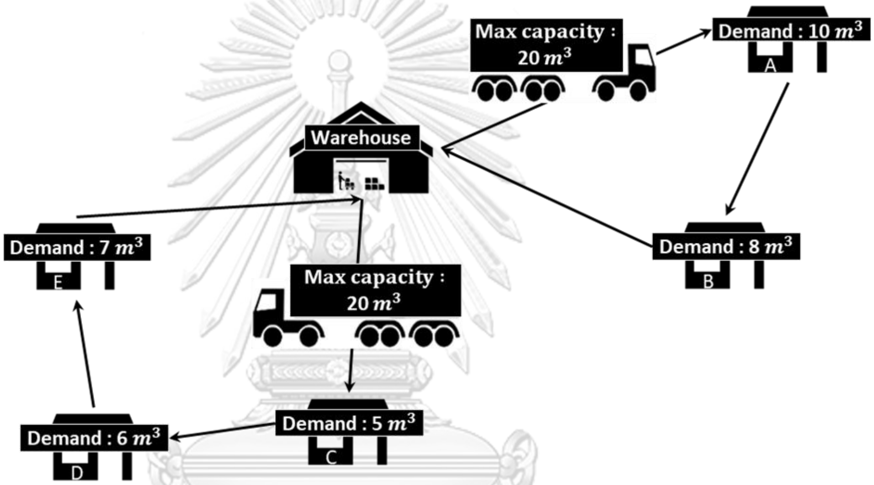


Figure 15: An example of the capacitated vehicle routing problem

The study of the TSP states that the TSP is NP-hard problem (Laporte 1992) and the TSP is one of the simplest variants of the VRP. This statement can be explained as that the TSP is the VRP system that considers only one vehicle with an unlimited capacity to service all customers in the system (Cordeau, Laporte et al. 2007). Therefore, the VRP that requires to solve more complicated systems than the TSP is also considered as NP-hard problem or a hard-combinatorial optimisation problem. Apart from that two methods of solving the VRP problem that are an exact method and a heuristic method will be explained as followed.

VRP exact method

The exact method is a solving scheme that provides the optimal solution for a problem. Nevertheless, it can be applied with only small-size problems. (Cordeau, Laporte et al. 2007) states that the VRP problem is a very complicated problem, even the simplest variant of the VRP, which is the CVRP, is hard to be solved a 100-nodes problem optimally. Furthermore, for the HVRP, which is a considered variant in this research, (Penna, Subramanian et al. 2013) stated that according to the best of knowledge of these researchers the exact method can be used for solving the HVRP with up to 100 nodes by (Baldacci and Mingozzi 2009). Therefore, the deep detail of the exact method is not explored since it is not suit with this research's problem.

VRP heuristic method

The heuristic method is classified into two categories that are classical heuristics and metaheuristics (Laporte 2007).

Classical heuristics are comprised of two steps for resolving the VRP that are a constructive heuristic phase and an improvement heuristic phase. Firstly, the constructive heuristic method is a method for initially generating a feasible route plan of a considered problem. In other words, the constructive heuristic process initially assigns that which vehicles should transport packages for which customers until every customer is already served without violating constraints of a problem. Examples of interesting constructive heuristics from (Clarke and Wright 1964), (Gillett and Miller 1974), (Fisher and Jaikumar 1981) are described. A widely used method of constructive heuristics is the (Clarke and Wright 1964) savings algorithm. The savings algorithm begins with assigning one vehicle to serve one customer, which becomes one route, then each route tries to combine together. During the process of the combining route, routes that could be combined with other routes without violating constraints and provide the cheapest cost of combining are proceeded. After that the combining route process repeats until no more route is feasible to merge. The sweep algorithm of (Gillett and Miller 1974) starts with a center point of a considered area of customers. Next, two rays are originated from the center point that are a fixed ray, which is used for indexing a starting line, and a moving ray, which is used for sweeping customers into routes.

Then, the moving ray will sweep off from the fixed ray in order to sweep customers into each vehicle until every customer is assigned to vehicles. The last example, which is the cluster first route second algorithm of (Fisher and Jaikumar 1981) is quite different from the first two instances since the algorithm is divided into two functions during generating a route plan. The cluster phase, customers are grouped into routes and these routes also abide by capacity constraints. Then, a sequence of retail stores in each route is arranged by using the TSP algorithm in order to find the shortest path in the routing phase.

Secondly, the improvement heuristic method is used for improving an initial solution that is obtained from the constructive heuristic method. Several approaches of the improving heuristics are introduced by many researchers and a major characteristic of the improving heuristics is to perturb the initial solution in order to obtain other Neighbour solution. Since, a solution space of the VRP is large and it is impossible to find every combination of a solution. So that a purpose of perturbing the initial solution is to find other desirable solutions in the solution space and these new solutions are called neighbourhoods. Moreover, two categories of improving heuristic methods that are widely used during generating the route plan are intra-route heuristics and inter-route heuristics. On one hand, for intra-route heuristics, an alteration process only occurs within each route, for example, reinsertion approach. On the other hand, inter-route heuristics, the change occurs between routes, for example, shifting one customer from one route to another route (Penna, Subramanian et al. 2013). At each iteration of improvement heuristics, a neighbourhood that provides better result than a current solution will be accepted, so that at the end of the improvement process a locally optimal solution will be obtained.

Procedures of the metaheuristic method contains both the constructive heuristic method and the improvement heuristic method that previously described but the metaheuristic procedures add on a logic to accept worse neighbourhoods during the improvement process. Accepting the worse Neighbour solution is a crucial characteristic of the metaheuristics, since it makes the algorithm escaping from the locally optimal solution and more Neighbour solutions in the solution space are explored. Examples of metaheuristics are that tabu search, simulated annealing, and genetic algorithm.

2.1.3 Heterogeneous vehicle routing problem (HVRP)

Since many researchers study about the VRP, some of them try to relate real life situations of the transportation with the VRP. Hence, abundant variants of the VRP occur. The HVRP is one of variants of the VRP that gets attention from researchers because various types of vehicles in the transportation come from many reasons, for example, firstly, a company buys several types of vehicles for the flexibility in servicing customers. Secondly, after a company using fleets for a while, some functions of vehicles might be modified. Thirdly, even a company purchases a new set of fleets that are the same model of existing fleets, the new lot and the old lot might have different fuel consumption rate.

(Koç, Bektaş et al. 2016) states that the HVRP is studied to generate a route plan for heterogeneous fleets. The planning system considers two factors that are the number of each type of vehicles that is required to service customers and a route for each selected vehicle. The HVRP is divided into two major categories that are the fleet size and mix vehicle routing problem (FSM), which considers the unlimited number of vehicles, and the heterogeneous fixed fleet vehicle routing problem (HF), which the number of vehicles in a system is limited. The FSM is firstly proposed by (Golden, Assad et al. 1984) and most researchers apply it to a case that a company wants to buy new fleets. While, researchers study the HF, which is introduced by (Taillard 1999) for optimising the usage of existing fleets. Apart from that both FSM and HF consist of other subsets that are classified by cost consideration and time window constrained consideration (Koç, Bektaş et al. 2016).

For cost consideration, expenses of the transportation comprise of a variable cost, which is a travelling cost from one place to others, and a fixed cost, which is the cost of using vehicles. Additionally, both costs in the HVRP depend of the type of vehicles. In summary of cost consideration, the FSM is divided into three categories, while the HF is separated into two types as following (Baldacci, Battarra et al. 2008)

- Fleet Size and Mix VRP with Fixed Costs and Vehicle Dependent Routing Costs (FSMFD)
- Fleet Size and Mix VRP with Vehicle Dependent Routing Costs (FSMD)
- Fleet Size and Mix VRP with Fixed Costs (FSMF)
- Heterogeneous VRP with Fixed Costs and Vehicle Dependent Routing Costs (HVRPFD)
- Heterogeneous VRP with Vehicle Dependent Routing Costs (HVRPD)

For time window constrained consideration, several researchers attach the time window constraint to the HVRP. Therefore, (Koç, Bektaş et al. 2016) classified the HVRP into two categories that are the HVRP that includes the time window constraint and the HVRP without the time window constraint.

Apart from variants of these two considerations, there are other variants that are studied under the HVRP and some instances will be described as following. For the first example, the multi-depot HVRP that in a considered system contains several depots is introduced by (Salhi and Sari 1997). Secondly, nowadays, a polluted emission issue is concerned and a transport company is a business that emits a lot of pollution to atmosphere. Hence (Kwon, Choi et al. 2013) introduces a model that copes with the HVPR and considers polluted emissions concurrently. Thirdly, the HVRP with backhauls is proposed by (Belmecheri, Prins et al. 2013) The model clusters customers into 2 types of purposes that are linehauls and backhauls. Customers that require packages from a depot are classified as linehauls, while clients that need vehicles to pick up products and ship them to a depot are categorised as backhauls. Lastly, the open HVRP is introduced by (Li, Leung et al. 2012). Researchers combine the open VRP with the HF. The system can be described as that heterogeneous vehicles are used for serving customers and after servicing fleets are not required going back to a depot.

Furthermore, (Koç, Bektaş et al. 2016) also concludes all studies of the HVRP as followed. For the number of published literatures of the major variants of the HVRP that are the FSM and the HF is represented with 60 references and 32 references, respectively. Additionally, there are others 11 references that come from researchers who research both FSM and HF. Almost of solution methods are constructive heuristics for all variants. Additionally, none of exact algorithms is especially researched for the HF variant excepting some of published literatures that study both FSM and HF and provide exact algorithms for both variants.

2.1.4 Case study

Since the vehicle routing problem and the variants are applied to solve several cases of the transportation, some of them are studied and summarised in this following section. These case studies will provide the function of solution methods, so that the collaboration of constructive heuristics, improvement heuristics and metaheuristics will also provide. Furthermore, examples of the solution approach of the VRP from five literatures that are (Chiang and Russell 1996), (Jiang, Ng et al. 2014), (Penna, Subramanian et al. 2013), (Gheysens, Golden et al. 1984), (Brandão 2009) are described as following.

- The first case study

(Chiang and Russell 1996) studies about a transportation plan for the VRPTW. Details of a considered system are that

1. Vehicles begin and finish at a depot.
2. Customers will be serviced by either delivering packages or picking packages.
3. Total transported demands of each route must not exceed a maximum capacity of each vehicle.
4. A time window constraint is a hard constraint. The hard constraint means that if a vehicle arrives at a customer's location before time window, it needs to wait until the allowable time. While arriving after time window, a vehicle does not allow to service a customer.
5. An objective function is multiple criteria, since it requires to minimise several factors that are total travel time, total travel distance, and the number of required vehicles.

(Chiang and Russell 1996) uses "a parallel construction procedure with a simulated annealing improvement heuristic" as a solution method. The method begins with the parallel construction method and this step is the constructive heuristic. The author adapts the insertion heuristic of (Solomon 1987) by changing from the sequential construction into the parallel construction. Next, the improvement method, the authors apply two improvement heuristics that are "*k*-node interchange mechanism of (Christofides and Beasley 1984)", which is named as N1 in this literature, and "λ-interchange mechanism of (Osman 1993)", which is mentioned as N2. A purpose of using two neighbourhood schemes is that the author wants to compare the performance of these Neighbour solution schemes. Furthermore, simulated annealing (SA) is also applied for accepting Neighbour solutions in order to escape from a locally optimum solution that obtains from the classical improvement heuristics. Apart from that SA is a memoryless heuristic, thus there is a chance that the algorithm will accept a same solution that is already found from a previous iteration. Therefore, the author brings a tabu list for holding a set of moves that already occur during the improvement process for the designated number of iterations. A tabu list will be cooperated with the N2 neighbourhood scheme, so this mentions in the literature as N2-tabu neighbourhoods.

The author verifies the proposed algorithms by testing on 56 test problems of (Solomon 1987) and on large-scale problems, which comprise of 249-node problem and 417-node problem. Results from testing on 56 test problems of Solomon represent that the N1 neighbourhood algorithm provides the best result with the smallest requirement of fleets and this is followed by the N2-tabu neighbourhood and the N2, respectively. Results from testing on 249-node problem show that the N1 is scarcely better than the N2 and the N2-tabu neighbourhood. In addition, the N2-tabu neighbourhood provides better schedule time and less traveled distances than the N2. Results from examining on 417-node problem, both N2 and N2-tabu neighbourhood generate drastically better results than the N1. While the N2-tabu neighbourhood does not enhance results of the N2. Lastly, SA with three Neighbour methods that are the N1, the N2 and the N2-tabu neighbourhood are compared with other three algorithms from other researchers. These comparisons find that SA requires the least number of vehicles.

- The second case study

(Jiang, Ng et al. 2014) studies the vehicle routing problem with a heterogeneous fleet and time windows (VRPHETW). Additionally, the number of fleets in a considered system is limited. A solution method that the author decides to use is “a two-phase tabu search algorithm” and this method is divided into two phases. For the first phase, it begins with a sorting procedure that is acquired for constructing routes. The sorting procedure sequences both customers and vehicles. For sorting customers, “the greatest distance rule” is applied. This rule means that a customer that locates farthest from the depot will be firstly selected to service. For ordering vehicles, “the greatest capacity rule” is chosen and this can be explained as that the largest-sized vehicle will be firstly used for transportation. After the sorting, the tabu search is applied and Neighbour solutions are generated from several types of moves. The tabu list will store customers that already move for the indicated number of iterations. Furthermore, a

Neighbour solution will be accepted when a customer is not in the tabu list or the move of the Neighbour solution passes the aspiration criterion. For the second phase, the tabu search is applied with post-processing moves. Moves in this phase tries to transfer customers that are already assigned to be serviced by large vehicles from the first phase to be served by smaller vehicles instead. So that the fixed cost will be reduced. The author verifies the proposed method by testing with several test cases. Results show that the proposed method is an effective model for solving the VRPHETW.

- The third case study

(Penna, Subramanian et al. 2013) proposes a model for solving several variants of the HVRP and a considered transportation system wants to utilise various types of fleets. Additionally, several types of fleets contain different capacities and costs. The author proposes “an iterated local search (ILS) metaheuristics which uses a variable neighbourhood descent procedure, with a random neighbourhood ordering (RVND)” as a solution method. An approach of this algorithm that is used for escaping from the locally optimal solution is that to proceed a local search process repeatedly on the locally optimal solution. This approach is different from other methods as that after obtaining the locally optimal solution, others will go back to the starting process. The author states that to do local search on the local optimum will narrow down the searching space for reaching the nearly global optimum.

Furthermore, the solution method comprises of three procedures that are generating initial solution, doing local search, and perturbing solution. Firstly, to construct an initial solution, the process begins with filling a seed customer to each route randomly. After that both insertion criteria and insertion strategy that are used for assigning unrouted customers to vehicles are chosen randomly. This process will repeat until every customer is assigned to routes. Secondly, the local search procedure, “the variable neighbourhood descent procedure, with a random neighbourhood ordering (RVND)” is applied. Several classical improvement heuristics from both inter-route heuristics and intra-route heuristics are considered. This begins with the inter-route heuristics. Several schemes of inter-route heuristic are introduced, while only one method will be selected randomly to utilise at a time. If the selected inter-route heuristic can generate a better result than a currently solution, the intra-route heuristics will start. Otherwise, other inter-route heuristics will be selected at random and this process will be repeated until a solution of the inter-route heuristic is better than the current solution. Next, steps of the intra-route heuristics are the same as the inter-route heuristics and at the end the locally optimal solution will be obtained. Lastly, the local search scheme will be applied to perturb the locally optimal solution. In conclusion, the author tests the proposed method with 52 well-known benchmark instances that contain customers up to 100 nodes. The results show that the ILS-RVND method improves four instances and it provides similar results for almost of the remaining instances.

- The fourth case study

(Gheysens, Golden et al. 1984) proposes the cluster first route second approch for solving the fleet size and mix vehicle routing problem (FSMVRP). At a beginning process of the proposed method, the researcher applies the lower bound procedure in order to find the quantity of mix types of vehicles, since this type of problem dose not limit the number of vehicles at the beginning stage. After obtaining the proper number of vehicles in each type, seed customers that are the first assinged customer in each route are considered. Furthermore, an approch for finding seed customers is that, for the first seed customer, it will be a customer that locates farthest from a depot. For the next seed customer, it will be a customer that locates farthest from a depot and other seed customers that are assigned previously. Then, this process will repeat until the number of seed customers is equal to the number of vehicles that is obtained from the lower bound process. After that a sorting process is applied to seed customers and vehicles, for seed customers, they are sorted by the farthest distance from the depot. For example, the first ordered seed customer is a customer locates farthest from the depot and the second ordered seed customer is a customer locates second farthest from the depot. Whereas, vehicles are arranged by the largest capacity, for example, the first ordered vehicle is the largest-capacity vehicle and the seconded ordered vehicle is the second largest-capacity vehicle. After that the researcher matches the first ordered seed customer with the first ordered vehicle and this matching process will repeat until every vehicle contains a seed customer. Then, remaining unrouted customers will be assigned to these vehicles by considering the cheapest cost of inserting them into routes. After that, customers in each route are rearranged in order to find the shortest path of the route by apply the TSP sloving approach.

- The fifth case study

(Brandão 2009) proposes the tabu search algorithm to solve the fleet size and mix vehicle routing problem (FSMVRP). The proposed method begins with route construction processes. The author proposes three approachs for constructing an initial solution, while an approach is applied to the proposed method for generating the initail solution at a time. The first approach of the route construction is the neartest neighbour process. The nearest neighbour process begins with finding the smallest-sized vehicle that can service at least one unrouted customer. After finding unrouted customers can be routed by this vehicle, the first customer in the route will be the farthest customer from a depot. Next, if this vehicle has remaining capacities, other unrouted customers will be inserted in the route due to a nearest neighbour criteria and without violating any constraints. The nearest Neighbour criteria is to find an unrouted customer that locates nearest to the customers that are previously assigned to the route. In addition, the nearest unrouted customer can be placed before or after its nearest neighbour that depends on which position provides the best cost to the route. This route will be inserted by nearest customers until no more unrouted nearest customers can be inserted in the the route. Then, a new route starts by repeating all processes through all customers are routed. The second approach of the construcing process is the nearest neighbour plus insert. Procedures of generating the initial solution of this method are almost similar to the nearest neighbour scheme, while two different points are applied that are the δ-neighbourhood and the insertion phase. Since the beginning process through assigning the first customer to the selected vehicle, processes of the nearest neighbour plus insert are the same as those of the nearest neighbour. After that the δ-neighbourhood of each customer in the route is applied to admissible next customer into the route until no remaining admissible customer. Next, the insertion phase is applied to insert unrouted customers in the route by considering the cheapest cost of the insertion and without violating constraints of the problem. The insertion phase proceeds until no more unrouted customer can be insert in this vehicle. Moreover, if unrouted customers remain, the whole process will repeat until every customer will be assigned to vehicles. The last construction heuristic is the giant tour that generates one giant route to service all customers. Moreover, the construction of this giant tour could be interpreted as finding a solution for the TSP. After obtaining the tour, a patitioning process starts from choosing a customer that locates the most adjacent to a depot. Then, the smallest-sized vehicle that can serve demands of this customer is selected. Next, other customers in the giant tour will be removed from the tour and inserted in the selected vehicle instead until no more customer from the tour can be inserted in this vehicle. Furthermore, a sequence of these customers remains the same as that they are already assigned from the giant tour. The patitioning process repeats until no more customer remains in the giant tour.

The next process of the proposed method is to apply the tabu search algorithm. Three schemes of generating neighbour solutions are used during the local search process that are the single insertion, the double insertion and the swap. Furthermore, processes of these neighbour structures are briefly described as following. The single insertion is to transfer a customer from a current route to another route, whereas the double insertion is to transfer two customers from a current route to another route. For the swap, the process is to exchange a customer from a route with another customer from another route. Furthermore, a tabu list and a tabu tenure are applied to the local search process in order to avoid a repeated solution that is already found from a previous iteration. The tabu list is used for recording an original route that a customer locates before moving to another route. This customer does not allow to be back to the original route for the number of iterations that is equal to the value of the tabu tenure. Moves of customers that are generated by neighbourhood structures will be admissible only if they comply with one of these following criterias. Firstly, “a move is not currently in the tabu list" (Brandão 2009). Secondly, “if a move is tabu and infeasible, while an obtained solution from this move provides the cheaper cost than the best infeasible solution, which is previously found” (Brandão 2009). Thirdly, “if a move is tabu and feasible, while an obtained solution from this move provides the cheaper cost than the best feasible solution, which is found before” (Brandão 2009).

2.2 Related theories

This section provides related theories that will be applied to the proposed method in this research.

2.2.1 Constructive heuristics of (Jiang, Ng et al. 2014)

According to the study of (Jiang, Ng et al. 2014), the researcher finds that the quality of an initial solution of the vehicle routing problem with a heterogeneous fleet and time windows (VRPHETW) could be affected by an arrangement of customers and vehicles. Additionally, the VRPHETW solving method is to plan routes for several types of vehicles to service customers that have different demands, locations and required service durations. Therefore, the author sorts both customers and vehicles as the following ways.

Sorting of customers

A customer that will be serviced in a next sequence is the customer that satisfies following rules. Furthermore, one or several rules could be applied based on a type of considered problem.

- Earliest ready time rule: A customer allows to be served with the earliest time.
- Tightest window rule: A customer allows to be served with the shortest service duration.
- Greatest distance: A customer locates farthest from a depot.

- Greatest demand: A customer requires the greatest demand.

Sorting of vehicles

A vehicle that will be requested servicing in a next sequence is the vehicle that satisfies these following rules. Whereas, one or several rules could be used based on a considered problem.

- Greatest capacity rule: A vehicle has the greatest capacity.
- Smallest capacity rule: A vehicle has the smallest capacity.
- Greedy insertion rule: This rule applies the greedy insertion heuristic to select the next used vehicle. A process of the greedy insertion heuristic is to find that which type of vehicles could provide the best solution among the others, if only one type of vehicles is used. Then, a sequence of used vehicles will be sorted based on the quality of solutions, which is obtained from the greedy insertion heuristic.

2.2.2 Initial solution of (Solomon 1987)

The most successful insertion heuristic of (Solomon 1987) that is used for constructing an initial solution is called I1 (Bräysy and Gendreau 2005). The process of this insertion heuristic begins with defining a seed customer, which is the first customer of a route. The seed customer could be either an unrouted customer that locates farthest from the depot or an unrouted customer that has the earliest starting service time. Next, remaining unrouted customers will be inserted in the route by considering the best insertion criteria that is indicated by a user, for example, the cost of the insertion. If the route is full and unrouted customers remain, the whole process that starts from selecting the seed customer will repeat until all customers are assigned to vehicles.

2.2.3 Constructive heuristics of (Penna, Subramanian et al. 2013)

A constructive method that (Penna, Subramanian et al. 2013) applies for generating an initial solution is to insert customers into routes by considering insertion criteria and insertion strategies. Steps of this algorithm will be explained as followed.

1. Defining a set of customers (*k*) that are not assigned to any routes yet and this set is indicated as candidate list (*CL*).

$$CL = \{1,2,3,\dots,k\}$$

2. Defining a set of routes (*S*)

$$S = \{S^1, S^2, \dots S^v\}$$

   S^1 means a route that is assigned for vehicle number 1 and $\boldsymbol{v}$ is the total number of vehicles in a system. In addition, at this stage every route is empty.

3. Each route will be inserted by one customer that is randomly selected from the candidate list. Hence, at this step, remaining customers in the candidate list are equal to $\boldsymbol{k - v}$.

4. In order to insert remaining unrouted customers into routes, insertion criteria and insertion strategies are analysed. This step begins with considering two insertion criteria and selects one of them with random. After that one of two insertion strategies is also chosen randomly.

   4.1. Insertion criteria

   A function of insertion criteria is to provide a choice for an algorithm to either considering costs or considering distances that increase from inserting remaining unrouted customers in routes. In addition, the modified cheapest feasible insertion criterion (MCFIC) represents as the increased cost consideration, while the nearest feasible insertion criterion (NFIC) represent as the increased distance consideration. These two criteria are formularised as following.

   - MCFIC

$$g(k) = \left(c_{ik}^u + c_{kj}^u - c_{ij}^u\right) - \gamma(c_{0k}^u + c_{k0}^u)$$

Equation 1: The modified cheapest feasible insertion criterion calculation

The first correspond of Equation 1 indicates the increased cost that occurs after inserting an unrouted customer *k* between routed customers that are a customer *i* and a customer *j* by using a vehicle type *u*. While the second correspond represents the travelled cost of a vehicle *u* from a depot to the customer *k* and back. The author states that the second correspond aids the model to avoid late considering customers that locate far from the depot.

- NFIC

$$g(k) = c_{ik}^{u}$$

Equation 2: The nearest feasible insertion criterion calculation

Equation 2 calculates the cost that occurs from travelling distances between an unrouted customer *k* and a customer *i* that is already assigned to a route by using vehicle *u*.

After one of these criteria is chosen randomly, the cost $g(k)$ of every remaining unrouted customer (k) is calculated. Then, the least-cost of $g(k)$ is selected and an unrouted customer *k* that gives the least cost is assigned to a route.

4.2. Insertion strategies

Two considered insertion strategies are the sequential insertion strategy (SIS) and the parallel insertion strategy (PIS).

- SIS

  For the SIS, only one route will be considered for an insertion at each iteration. The processes of the SIS consideration in each iteration are that

  1. If there are remaining customers in the candidate list and at least one customer can be assigned to routes without breaking any constraints, the next step will proceed.
  2. One route in a system will be chosen at random, then the costs of insertion $g(k)$ of each remaining customer are calculated.
  3. The remaining customer that provides the least cost of insertion will be inserted in a selected route. Then, this customer will be

deleted from the candidate list and the number of customers in the chosen route is updated.

4. Step 1 to step 3 are repeated until no customer remains in the candidate list.

- PIS

  For the PIS, all routes are analysed simultaneously at each iteration and steps of the PIS in each iteration are that

1. If there are remaining customers in the candidate list and at least one customer can be assigned to routes without breaking any constraints, the next step will proceed.
2. The costs of insertion $g(k)$ of each remaining customer in every route are calculated.
3. A customer and a route that are associated with the least cost of insertion are picked. Then, the chosen customer is erased from the candidate list and the number of customers in the selected route is updated.
4. Step 1 to step 3 are repeated until no customer remains in the candidate list.

2.2.4 Neighbourhood Solution

Inter-route neighbourhood structure

The meaning of inter-route neighbourhood structure is to obtain a neighbour solution of a current solution by selecting more than one route, then these routes will be perturbed by several operations.

λ-Interchange generation mechanism (Osman 1993)

This mechanism represents the way to alter a solution *S* into a neighbour solution (*S'*) of the solution *S*. For the vehicle routing problem (VRP), the solution *S* can be represented as $S = \{R_1, R_p, R_q, \ldots, R_v\}$ and R_p is a group of customers that is assigned to be serviced by a route *p*. An approach of alternating starts with two routes are selected. Then customers that are served by these two routes are chosen with a size of less than or equal to λ and these customers are alternated between these routes. Moreover, a shift process that is one type of the λ-Interchange generation mechanism is illustrated in Example 1 as following.

Example 1

1. Obtaining the solution *S*

$$S = \{R_1, R_p, R_q, \ldots, R_v\}$$

2. Selecting two routes of the solution *S*

$$R_p = \{1,2,3,4\} \text{ and } R_q = \{5,6,7\}$$

Route *p* composes of customer1, customer2, customer3, and customer4, while route *q* comprises of customer5, customer6, and customer7.

3. Indicating a value for λ

For the shifting process, a value of λ is equal to one and it can be illustrated by (1,0) or (0,1) operators. These operators mean that one customer of one route is picked, whereas the other route is not.

4. Selecting a customer from R_p or R_q with the size that is indicated in the step 3. For example, customer4 from R_p is picked.
5. Altering the selected customer between R_p and R_q

Due to the step4, customer4 from R_p is selected, then it will be removed from R_p. Next it will be shifted to any position of R_q depending an objective of a problem and during the shift (0,1) process every constraint of the problem must be satisfied. Then, two new routes are obtained and these can be represented as followed.

$$R'_p = \{1,2,3\} \text{ and } R'_q = \{4,5,6,7\}$$

6. Obtaining the neighbourhood solution (*S'*) of the solution *S*

$$S' = \{R_1, R'_p, R'_q, \ldots, R_v\}$$

Intra-route neighbourhood structure

The meaning of the intra-route neighbourhood structure is to obtain a Neighbour solution (S') of a solution S by varying one or more customers within a route. Furthermore, a reinsertion process that is one of intra-route neighbourhood schemes is illustrated as following.

1. Obtain solution *S*

$$S = \{R_1, R_p, R_q, \dots, R_v\}$$

2. Selecting a route of the solution *S*

$$R_p = \{1,2,3,4\}$$

Route *p* composes of customer1, customer2, customer3, and customer4.

3. One customer from R_p is selected. This customer is removed from the current sequence of the route, and then it is reinserted back to the route in the other position without violating any constraints. For example, customer4 from R_p is picked and a current position of customer4 is the fourth sequence. Then, customer4 is removed and it is reinserted in the first position of the route. Therefore, a new route is obtained, which is R'_p.

$$R'_p = \{4,1,2,3\}$$

4. Obtaining the neighbourhood solution (S') of the solution S

$$S' = \{R_1, R'_p, R_q, \dots, R_v\}$$

2.2.5 Simulated Annealing

The simulated annealing, (Lin, Vincent et al. 2009) state that this method is to find the nearest promising solution rather than looking for the best. Most search algorithm techniques look for a next-best possible solution based on an existing initial solution, so that these will lead to be trapped in a local optimum. However, the simulated algorithm is able to accept a worse solution and this ability aids a user to avoid the local optimal solution, which can be illustrated by *Figure 16*.

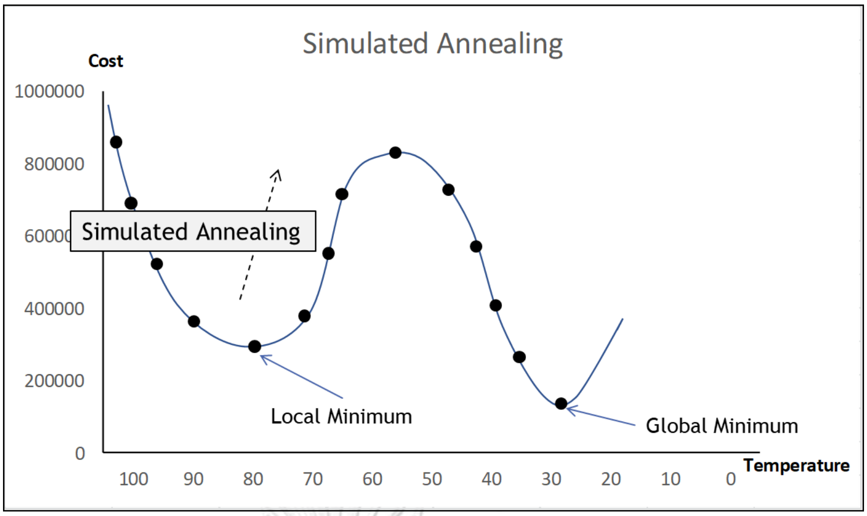


Figure 16: The process of the simulated annealing

As suggested by (Tavakkoli-Moghaddam, Safaei et al. 2006), the simulated annealing is applied to the vehicle routing problem with the independent route length (VRPIRL). Two procedures are operated in order to generate an initial solution by using a nearest neighbour based heuristic (NNBH) and to improve the initial solution by using the simulated annealing algorithm. After that the model is verified by testing it with 18 problems. A result of the model represents acceptable performance with a reasonable computational time. Furthermore, (Lin, Vincent et al. 2009) apply the simulated annealing algorithm to solve a truck and trailer routing problem (TTRP), which is a variant of the vehicle routing problem. Procedures in this literature start with generating a feasible initial solution. Next, neighbour solutions of the initial solution are created by implementing insertion, swap, and change of service vehicle type. After that the simulated annealing is applied for accepting the neighbour solutions. A result illustrates that the proposed algorithm provides best solutions among other TTRP benchmark problems.

In order to apply the SA metaheuristic method to a problem, two major factors are required to define. These two factors are classified into problem specific choices and generic choices (Eglese 1990). For problem specific choices, four parameters are identified that are a set of required solutions from the solving method, an initial solution approach, a neighbour solution scheme, and an objective function of a studied problem. These decisions are related to a selected problem that is required to solve, thus these could be varied, depended on a configuration of problem. On the other hand, for generic choices, parameters in this category are related to the SA algorithm and they are required to be defined before applying the algorithm to the problem. These parameters are an initial temperature, a cooling ratio, epoch length, and a frozen system. Furthermore, an example of the SA metaheuristic approach is illustrated below.

Tool review

An example of procedures of the SA metaheuristic algorithm that can be applied for solving the VRP problem is demonstrated by Example 2 as followed. As stated by (Chiang and Russell 1996), there are four steps that are used for operating the simulated annealing algorithm and they are illustrated in Figure 17.

Example 2

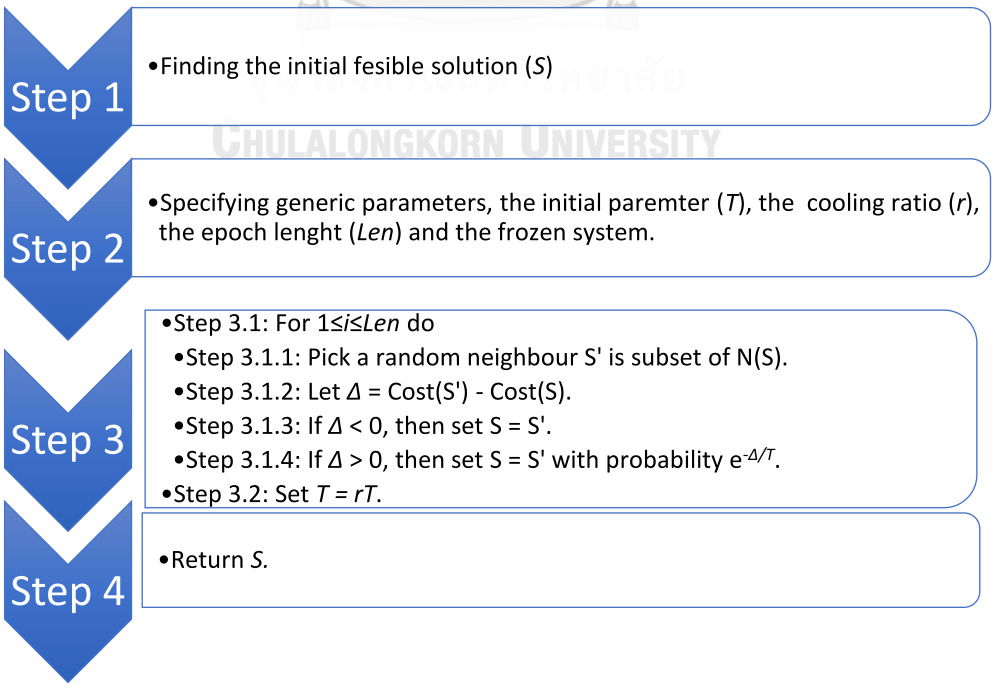


Figure 17: Simulated annealing procedures

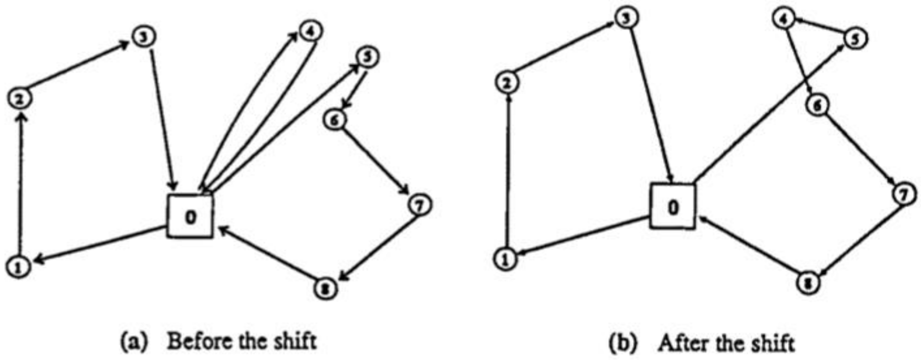


Figure 18: A shift (0,1) process (Osman 1993)

In the first step, an initial solution for heterogeneous vehicle routing problem is required. This initial solution must be a feasible solution that satisfied constraints of the problem, which are a capacity constraint and an accessibility constraint.

In the second step, generic parameters that are used in the algorithm are generated. They comprise of three main parameters and one optional parameter that are randomly generated. Moreover, these values are recorded each iteration for finding the proper figures that provide the best solution of the problem. For the three main parameters, firstly, an initial temperature is introduced (T_0). It should start with an acceptable range of a worse solution that may be accepted in the solution with probability P_0. Secondly, a cooling ratio (r), (Chiang and Russell 1996) suggest that typical values for r lie between 0.85 and 0.95. Furthermore, the higher value of r will lengthen duration of the system. Thirdly, an epoch length (*Len*) is a maximum number of iterations that use for running the system. Therefore, it should be a large enough number in order to guarantee that the nearest optimal solution can be obtained. For the optional generic parameter, it is a frozen system. The frozen is used for optimizing a running time. According to (Chiang and Russell 1996), there are two suggested frozen system. On one hand, the first frozen system is TIME. TIME is a specific number for stopping the iteration when no improvement has been found for the consecutive number of iterations. On the other hand, MINPERCENT is the second frozen system that focuses on an acceptance of a neighbour solution. If neighbour solutions are not acceptable for consecutive MINPERCENT times, the algorithm will stop.

The third step, after specifying all required parameters, the simulated annealing algorithm proceeds. For step 3.1, it means that if a current iteration (*i*) is less than the maximum number of iterations (*Len*), the algorithm will start. In case that the SA algorithm starts, steps from step 3.1.1 to step 3.1.4 will proceed. For step 3.1.1, a neighbour solution of the current solution (*S*) is selected randomly. The neighbour solution can be generated from several methods, for example, the λ-interchange mechanism. In addition, a (0,1) shift process, which is one of other operations of the λ-interchange process, is illustrated by Figure 18 (Osman 1993). After that a value of a different cost between the neighbour solution and the current solution (Δ) is calculated by using step 3.1.2. Then, there are two choices for the Δ value. If the neighbour solution is better than the current solution (negative Δ value), the current solution will be replaced by the neighbour solution as represented in step 3.1.3. On the other hand, step 3.1.4 represents a case that the neighbour solution is worse than the current solution. Then, this solution may be accepted with probability $e^{-\Delta/T}$. Furthermore, the probability $e^{-\Delta/T}$ can be investigated as that if the temperature in the system is still high and a range of the worse solution is small, a chance of an acceptance of this neighbour solution is high. Next, after finishing this iteration, the temperature is updated by following step 3.2.

Finally, the last step is return *S*. The simulated annealing algorithm suggests a solution of this iteration and information that is informed in the solution is a route for each required vehicle in a transportation plan. Then, the third step to the fourth step are repeated until *i* is equal to *Len*.

2.2.6 Post processing

The post-processing is suggested by (Jiang, Ng et al. 2014), since the author wants to improve a solution after obtaining it from the proposed model. A propose of the post-processing is to utilise small-size vehicles instead of large-size vehicles in terms of capacity to reduce the fixed cost. Since at the beginning of the process, the researcher applies the sorting process by selecting the greatest capacity rule for the vehicle, thus the large-size vehicles are firstly used for servicing customers in the routing plan. Then, the author suggests two procedures for transferring customers from the large-size vehicles into the smaller-size vehicles that are a multi-transfer process and a split process.

- Multi-transfer

A route is selected and then some part of the route is considered. The part of the route will be chosen from any starting point until the last customer of the selected route. Then, this chosen part is shifted to a smaller empty vehicle. In addition, the whole selected route also could be transferred to the smaller empty vehicle, if the smaller empty vehicle has enough capacity for servicing all customers in the route. Aside from that the sequence of customers of the selected part that is transferred to the smaller vehicle remains unchanged.

- Split

A route is selected then the route is split into two sections. A separate position of the selected route could be any position of the route. After that these two separate routes will be put into two smaller empty vehicles. Moreover, the sequence of customer that is already assigned before splitting is still the same.

3. Methodology

3.1 Data collection

3.1.1 Collecting past data from the 3PL company

According to the problem of this research, collecting real data from a data base of the 3PL company for studying the performance of the firm is necessary. The collected information is relevant to two sources that are the actual information that the retail company is used for generating the exact transportation plan and the actual information that the 3PL performs for operating daily transportation accordingly to the transportation plan. Moreover, this information will be applied to this research during generating the proposed method and computing the experiment in the next chapter for measuring the performance of the proposed method. Therefore, the performance between the exact transportation plan of the proposed method and the exact transportation plan of the company can be examined. Furthermore, in order to insist that the collected data is enough for evaluating the operation, the data of the real transport operation for seven days is collected from the company's data base. Details of the collected data are illustrated in a following section.

- Daily transportation plan

This data provides all requirements that the client requires the 3PL company to deliver packages to retail stores. Details that are informed in the transportation plan are listed as following and illustrated in *Table 2*.

- A sequence of retail stores that are required to be serviced in each route
- A type of vehicle in each route
- The number of total requirements of each retail store in a cubic meter unit (m^3)
- Names and numbers of retail stores
- The number of required drivers in each trip
- The delivery date

- The number of trips

Delivery date	Trip number	Store number	Store name	The total number of requirements (m^3)	Vehicle type	The number of drivers
22-Feb	1	276	A	1.5	4-wheel	1
		723	B	2.3		
		176	C	1		
22-Feb	2	783	E	3.5	4-wheel jumbo	1
		254	F	2.1		
		376	G	1.5		
		485	H	1.8		

Table 2: An example of the transportation plan

- Vehicle details

There are eight types of vehicles in this studied problem that are 4-wheel vehicles, 4-wheel jumbo vehicles, 6-wheel vehicles, 10-wheel vehicles, 10-wheel jumbo vehicles, 18-wheel small vehicles, 18-wheel vehicles, and 10-wheel with trailer vehicles. In addition, the limited number of vehicles in each type and their capacities are illustrated in Table 3.

Type of vehicles	Number of vehicles (unit)	Capacity (m^3)
4-wheel	33	4.8
4-wheel jumbo	19	9
6-wheel	4	19
10-wheel	41	25
10-wheel jumbo	5	37
18-wheel small	9	41
18-wheel	40	44
10-wheel with trailer	7	55

Table 3: The limited number of every type of vehicles and the maximum capacity of every type of vehicles

- The unloading time

According to the interview of an expert of the transportation of the company, the expert informs that the range of unloading time at each retail store is approximately 30-60 minutes. Hence, during the experiment in this research, the unloading time is set to be 60 minutes that is the maximum time of the actual situation. In addition, a reason behind is that to avoid an unfinished transportation plan of each route since each route is restricted by the total time constraint.

- The company transportation process

From the chapter 1, work processes between the 3PL company and the client are illustrated. Therefore, it could be concluded as that the client company copes with the transportation plan process. Whereas the job of the 3PL company is to provide the daily number of vehicles that are already agreed with the client and the number of drivers that are required in each day. In addition, this research desires to generate the route planning system for the 3PL company. Then, the currently route planning process is observed.

1. Receiving requirements from every retail stores

In each day retail stores that require a replacement of products will submit the requirements to the headquarter of the retail company.

2. Summing up the total requirements of each retail store

Products that each retail store requests to fulfill will be summed up in terms of volume (m^3). Then, daily required demands of each retail stores will be considered as a set of total requirements of each retail store. Since a container of each vehicle that is used for transporting products is a square shape and to consider requirements of each retail store in terms of volume will aid a planner to arrange a route for each vehicle easily. In addition, if a set of requirements of a retail store is greater than the maximum capacity of the largest-size vehicles in a system, the set of requirements of this retail store will be separated into more than one set.

3. Generating a daily transportation plan

A planner of the retail company inputs several input data that are locations of the warehouse and retail stores, sets of total requirements of every retail store in terms of volume (m^3), the limited number of vehicles in each type, a type of each retail store, the maximum capacity of vehicles in each type in terms of volume, costs of each type of vehicles in terms of travelled cost and service cost, and the limited total time of one-driver per trip and two-driver per trip into a route planning system of the company. Then, a daily transportation plan that satisfies constraints of the system is obtained. The daily transportation plan informs a route for each selected vehicle and information of each route is a type of a selected vehicle, the number of required drivers, a sequence of retail stores, a set of requirements of each retail store.

4. Revising the routing plan

After generating the routing plan by a computer, a planner revises generated routes that have low capacity utilisation by exchanging or transferring stores between routes.

5. Informing the transportation plan to the warehouse and the 3PL company

After obtaining the transportation plan, it will not only be informed to the warehouse in order to rearrange required products for loading into vehicles but also be notified to the 3PL company in order to provide the number of required vehicles and drivers.

- Distances in the transportation plan

A distance that is used for generating the transportation plan is the specified displacement between locations that is calculated in a specific way by the retail company and a calculation of this specified displacement is described as following. Locations of the warehouse and retail stores are real coordinates, which are latitudes and longitudes on the geographic map, for example, a location of a retail store *a* is 13.718774^{0}N, 100.568045^{0}E, where 13.718774^{0}N is the latitude and 100.568045^{0}E is the longitude. Moreover, a general displacement between two locations can be calculated by using Euclidean distance and it is represented in Equation 3.

$$Displacement = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

Equation 3: Euclidean distance calculation

Where; x_1: the latitude of the location 1

x_2: the latitude of the location 2

y_1: the longitude of the location 1

y_2: the longitude of the location 2

Furthermore, a route planner of the company introduces two multipliers that are a converted factor and a proportionate distance factor to multiply the general displacement. The converted factor is used for converting the change of 1° in latitude and longitude to the change of kilometer in surface distance and a value of the converted factor is 111. After that the planner takes a sample of displacements between locations in a kilometer unit to compare with real distances between the same locations, then a result finds the different proportion between the displacement and the real distance. This proportion is used as the proportionate distance factor and it equals to 1.269. In summary, the distance, which is the specified displacement, can be calculated by Equation 4 and Example 3 illustrates the procedure of calculating the distance that is thoroughly used in this research.

$$Distance\ (km) = Displacement \times The\ converted\ factor \times the\ proportionate\ distance\ factor$$

Equation 4: the calculation of distances in the computational experiment

Example 3

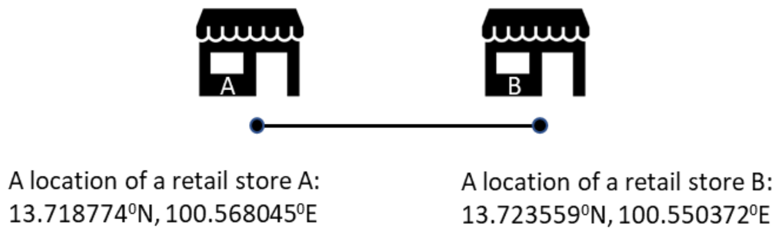


Figure 19: An example of the distance calculation

From Figure 19, it represents that a location of a retail store A is 13.718774^{0}N, 100.568045^{0}E and a location of a retail store B is 13.723559^{0}N, 100.550372^{0}E.

1. Calculating the general displacement

   The general displacement is calculated by using Equation 3 and it equals to 0.018309.

$$Displacement = \sqrt{(13.718774 - 13.723559)^2 + (100.568045 - 100.550372)^2}$$

2. Calculating the distance

   After obtaining the general displacement, the distance that is used in this research is calculated by using Equation 4, then the distance is equal to 2.579032 km.

$$Distance\ (km) = 0.018309 \times 111 \times 1.269$$

- Transportation cost calculation

In each day, the 3PL company operates to transport packages to retail stores, consequently expenses of the transportation occur. The 3PL company divides these expenses into two categories for each trip that are a travelled distance cost and a service cost. In addition, the total transportation cost can be formularised as Equation 5.

$$The\ total\ transportation\ cost = the\ travelled\ distance\ cost\ +\ the\ service\ cost$$

Equation 5: The total transportation cost calculation

- The travelled distance cost

For the travelled distance cost, an average fuel cost during vehicles are utilised per kilometer (km) are considered, thus total travelled distances in each trip are calculated in terms of the displacement that is previously described. The travelled distance cost depends on travelled distances in a trip, so that it is a variable cost. Furthermore, not only travelled distances of a trip are considered but also a type of a selected vehicle in the trip, since a different type of vehicles requires the different cost. Then, a manager of the 3PL firm suggests the multiplier cost of each type of vehicles and a measured unit is THB/km. Moreover, the multiplier cost of every type of vehicles in the considered system is shown in Table 4 and the travelled distance cost can be formularised by Equation 6.

Type of vehicles	The multiplier cost of a selected vehicle in a trip (THB/km)
4-wheel	6.63
4-wheel jumbo	7.29
6-wheel	7.65
10-wheel	10.20
10-wheel jumbo	10.71
18-wheel small	12.12
18-wheel	12.24
10-wheel with trailer	14.28

Table 4: The multiplier cost of a selected vehicle in a trip

$$\begin{aligned} &\textit{The travelled distancecost of a trip}(THB) \\ &\qquad = \textit{total travelled distances of a trip}(km) \\ &\qquad \times \textit{the multiplier cost of a selected vehicle in a trip}(THB/km) \end{aligned}$$

Equation 6: The travelled cost of a trip calculation

- The service cost

Aside from the travelled distance cost, the 3PL company must pay the service cost to drivers who transport packages from the warehouse to retail stores accordingly to the transportation plan. The total service cost in each trip composes of two expenses. Firstly, a semi-fixed cost considers an expense from the farthest retail store of a trip, which locates farthest from the warehouse in terms of the displacement compared with other retail stores in the same trip. A characteristic of the semi-fixed cost (DRURY 2013) is that the cost is constant for a specific range of an activity, which is the displacement in this case. While the considered activity reaches another specified range, the cost will change accordingly to another specified range. An example of the characteristic of the semi-fixed cost is represented in Figure 20 and

Figure 21. The Figure 20 represents the semi-fixed cost graph from (DRURY 2013), while the Figure 21 shows the graph of the cost of the longest retail store in a trip for four-wheel vehicles that is indicated by the 3PL company. These two graphs illustrate the same characteristic, so that the cost of the farthest retail store in each trip is considered as the semi-fixed cost. Apart from that the semi-fixed cost of the farthest retail store in this research varies from a type of a selected vehicle and the number of drivers in a trip. Therefore, every semi-fixed cost of each specified range of the displacement from all types of vehicles is summarised in Table 5.

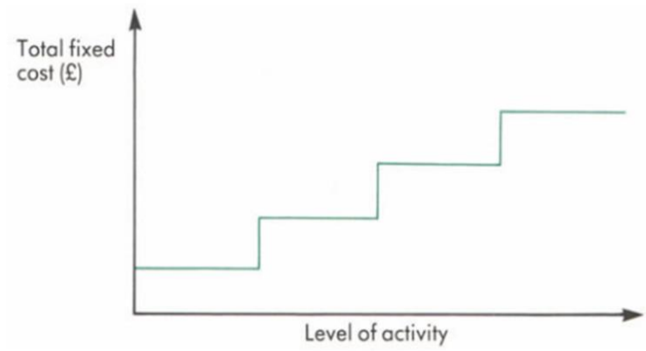


Figure 20: The semi-fixed cost graph (DRURY 2013)

Figure 21: The cost of the longest retail store in a trip for 4-wheel vehicles

Displacement (X) between the warehouse and the longest retail store in a trip (km.)			The semi-fixed cost of the farthest retail store in a trip (THB)							
			Types of vehicles							
			18-wheel small & 18-wheel & 10-wheel with trailer		6-wheel & 10-wheel & 10-wheel jumbo		4-wheel jumbo		4-wheel	
			The number of drivers per trip		The number of drivers per trip		The number of drivers per trip		The number of drivers per trip	
			1 driver	2 drivers	1 driver	2 drivers	1 driver	2 drivers	1 driver	2 drivers
0	< X <	75	200	280	120	160	120	160	110	146.67
75	≤ X <	150	250	280	160	213.33	130	173.33	110	146.67
150	≤ X <	200	350	480	280	380	190	253.33	150	200
200	≤ X <	275	400	600	280	380	255	340	210	280
275	≤ X <	300	450	600	300	400	285	380	255	340
300	≤ X <	325	480	640	330	440	315	420	300	400
325	≤ X <	400	520	700	360	500	345	460	300	400
400	≤ X <	450	590	800	420	560	405	540	375	500
450	≤ X <	500	670	900	480	640	450	600	420	560
500	≤ X <	550	712.5	950	525	700	495	660	450	600
550	≤ X <	600	825	1100	600	800	555	740	495	660
600	≤ X <	650	900	1200	675	900	615	820	540	720
650	≤ X <	700	1012.5	1350	720	960	645	860	570	760
700	≤ X <	750	1125	1500	795	1060	705	940	615	820
750	≤ X <	850	1237.5	1650	885	1180	795	1060	690	920
850	≤ X <	900	1350	1800	975	1300	855	1140	735	980
900	≤ X <	925	1350	1800	975	1300	885	1180	780	1040
925	≤ X <	1000	1425	1900	1005	1340	900	1200	780	1040
1000	≤ X		1500	2000	1125	1500	990	1320	855	1140

Table 5: The semi-fixed cost of the farthest retail store in a trip

Secondly, the service cost of retail stores in a trip excepting the farthest retail store of the trip is charged by 75 THB/retail store/driver. Additionally, the service cost of other retail stores will be high or low depended on the number of retail stores in a trip, thus it is a variable cost. The service cost of other retail stores is formularised as Equation 7. Moreover, an example of the total transportation cost calculation is illustrated in Example 4.

$$\begin{gathered} \textit{The service cost of other retail stores, excepting the farthest store in a trip } (THB) \\ = (\textit{the total number of retail stores in a trip} - 1) \\ \times \textit{the number of drivers in a trip} \times 75\ (THB) \end{gathered}$$

Equation 7: The service cost of other retail stores, excepting the farthest store in a trip

Example 4

$$R_1^{4-wheel} = \{a, b, c\}\ with\ one\ driver$$

This means that route 1 is serviced by a 4-wheel vehicle and a driver of this vehicle delivers packages for a retail store a, a retail store b, and a retail store c, sequentially.

1. Calculating distances between the warehouse and customers in a route and this example is illustrated by Figure 22.

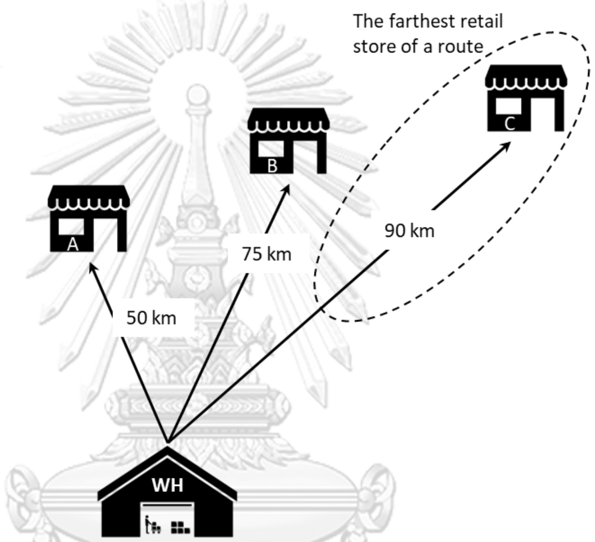


Figure 22: An example of the farthest retail store of a route

Distances between the warehouse and the retail store a = 50 km.

Distances between the warehouse and the retail store b = 75 km.

Distances between the warehouse and the retail store c = 90 km.

2. Calculating the service cost

2.1. Finding the semi-fixed cost of the farthest retail store of this trip that is based on the farthest store from the depot, the number of drivers, and a type of selected vehicles of a considered trip from Table 5. In this example, the retail store c locates the farthest from the warehouse with 90 km and this route is serviced by a four-wheel vehicle with one driver. Therefore, the semi-fixed cost of the farthest retail store of this trip that is picked from Table 5 is equal to 110 THB.

2.2. Calculating the service cost of other retail stores in the same route, excepting the farthest retail store of the route. A rate of the service cost of others retail stores is fixed with 75 THB/retail store/driver for every type of vehicles. This cost can be calculated as Equation 7.

$$The\ service\ cost\ of\ other\ retail\ stores, excepting\ the\ fartest\ store\ of\ a\ trip\ (THB) = 150\ THB$$

2.3. Summing up the service cost of the trip

The service cost of a trip is equal to the sum of the service cost from step 2.1 and step 2.2 that is equal to 260 THB. In addition, Figure 23 illustrates the service cost of this trip.

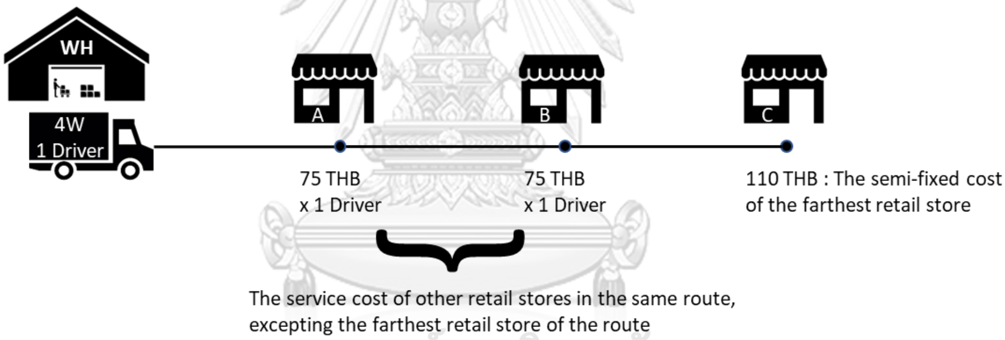


Figure 23: An example of the service cost calculation

3. Calculating the total travelled distance cost

   Figure 24 represents a route of this example and a travelled distance of each path. Then the total travelled distance of this trip can be calculated that is equal to 165 km and this trip is transported by a 4-wheel vehicle that contains the multiplier cost from Table 4 equal to 6.63 THB/km. So that the total travelled distance cost is calculated by using Equation 6 and it is equal to 1,093.95 THB

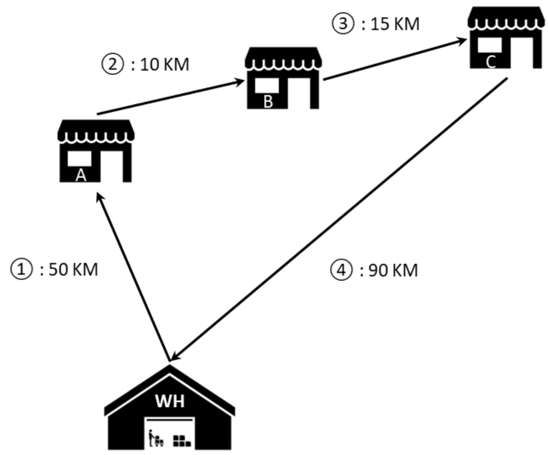


Figure 24: An example of the total travelled distance cost

4. Calculating the total transportation cost

   The total transportation cost of this trip is calculated by using Equation 5 that equals to 1,353.95 THB.

- Fatigue driving policy

The 3PL company is required to comply with legal requirements of working hours of drivers that are issued by the labour relation act of Thailand to ensure safety of drivers and other people on the road. Therefore, the 3PL company issues a fatigue driving policy to manage working and resting hours of drivers and to manage routing operations for long-duration trips. Two schemes of a driving and resting hour pattern are implemented due to the fatigue driving policy. Furthermore, these schedules are a driving and resting hour pattern for single driver per trip, which is illustrated by Table 6, and a driving and resting hour pattern for two drivers per trip, which is shown by Table 7.

Working Hours	Resting Hours	Cumulative Total Working Hours	Notes
4 hours	-	4 hours	• A driver operates work continuously for 4 hours.
-	30 minutes	4.5 hours	• A driver rests for 30 minutes.
4 hours	-	8.5 hours	• A driver resumes driving continuously for 4 hours.
-	30 minutes	9 hours	• A driver rests for 30 minutes.
2 hours	-	11 hours	• A driver agrees to perform an overtime for 2 hours and then this will be the end of a shift.

Table 6: A schedule for a single driver per trip

Driver	Working Hours	Resting Hours	Cumulative Total Working Hours	Notes
Driver1	4 hours	-	4 hours	• The first driver operates work continuously for 4 hours.
	-	30 minutes	4.5 hours	• The first driver rests for 30 minutes.
	4 hours	-	8.5 hours	• The first driver resumes driving for 4 hours.
	-	30 minutes	9 hours	• The first driver rests for 30 minutes. After that the second driver takes turn driving, while the first driver breaks for 9 hours.
Driver2	4 hours	-	13 hours	• The second driver operates work continuously for 4 hours.
	-	30 minutes	13.5 hours	• The second driver rests for 30 minutes.
	4 hours	-	17.5 hours	• The second driver resumes driving for 4 hours.

	-	30 minutes	18 hours	• The second driver rests for 30 minutes. After that the second driver is replaced by the first driver and the second driver breaks for 9 hours

Table 7: A schedule for two drivers per trip

For a singer driver per trip, from Table 6, this could be described as that a driver starts driving for four hours, then a break duration is required for 30 minutes. Next, the driver resumes driving for four hours, then the driver rests for 30 minutes. Almost every trip, the driver is willing to do overtime driving with extra two hours due to the limited working hours of the labour relation act of Thailand. Therefore, it could be concluded that driving hours of the single driver per trip that abide by the regulations are 10 hours, not including 1 hour break. Hence, the total driving hours per trip of a single driver that includes both driving hours and breaking hours should not exceed 11 hours. Moreover, drivers may be required to work extra three hours from Table 6 due to unexpected incidents, for example, an accident, a traffic problem, so that total working hours of the single driver may prolong to be 14 hours. Nonetheless, unexpected incidents are not concerned in this research, thus the limited total time of the one driver per trip that counts from a vehicle leaving the warehouse for the transportation until it returning to the warehouse is 10 hours.

For the long duration trip, it means that a trip requires driving hours more than 10 hours to visit all retail stores, thus two drivers per trip are requested. A driving pattern for two drivers is represented in Table 7. This driving schedule could be explained as that the first driver drives for four hours and then breaks for 30 minutes. After that the first driver continues driving for four hours and rest for 30mintues. Next, it will be a driving turn of the second driver. The second driver operates the work with the same pattern as described for the first driver, while the first driver rests in a truck's cabin during the operation of the second driver. Then, these drivers take turn driving as assigned by the schedule until delivering all packages. Furthermore, even in the regulation of the two drivers per trip is not limited the total working hours in the trip, the normal routine of the total travel time of the two drivers per trip should not be longer than 36 hours according to the interview of the manager of the 3PL company. Therefore, this research will limit the total time of the two drivers per trip with 36 hours.

- Store types

Due to several kinds of demands and building locations of retail stores, the retail company constructs several types of retail stores, i.e. hypermarket, extra, department store, talad and express. The size of each type of retail stores is illustrated in *Table 8*.

Types of retail stores	Size (square metre)	Supermarket zone	Plaza zone
Hypermarket	8,000-10,000	Yes	Yes
Extra	8,000-15,000	Yes	Yes
Department store	8,000-12,000	Yes	Yes
Talad	600-1,200	Yes	No
Express	250-450	Yes	No

Table 8: Store types of the retail company

- Locations of retail stores and the number of orders

Orders that are required to fulfill from retail stores vary from day to day in terms of branches of the retail stores and the total number of requirements of each retail store. Consequently, locations of retail stores and the number of orders that are required the fulfillment vary in each day. According to the collected data for the seven-day operation, locations of retail stores in terms of provinces in Thailand and the total number of orders are shown in Table 9.

- The total transportation charge

The relationship between the 3PL company and the retail company is that the 3PL company provides vehicles and drivers for transporting packages from the warehouse of the retail company to retail stores of the retail company accordingly to the transportation plan that is generated by the retail company. After that vehicles and drivers return to the warehouse. Hence, the retail company is considered as a client of the 3PL company. The retail company agrees to pay the 3PL company the total transportation cost that occurs in the transportation plan plus 10 percent of the total transportation cost that can be considered as a service fee. In addition, the total transportation charge that the retail company pays the 3PL company is formularised by *Equation 8*.

$$\text{The total transportation charge from the 3PL company} \\ = \text{The total transportation cost} + (0.1 \times \text{The total transportation cost})$$

Equation 8: The total transportation charge from the 3PL company

Where; the total transportation cost can be computed by *Equation 5*.

Provinces in Thailand	The delivery date						
	22-Feb	23-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb
Ang Thong	5	6	1	6	0	6	1
Bangkok	220	257	113	229	89	234	132
Chachoengsao	10	19	22	10	21	10	22
Chai Nat	6	6	2	6	2	6	2
Chanthaburi	2	9	7	6	6	6	10
Chiang Mai	2	3	4	5	4	6	4
Chiang Rai	3	3	3	3	3	3	3
Chon Buri	20	35	21	43	18	46	46
Chumphon	3	0	2	1	2	4	2
Kamphaeng Phet	5	5	5	5	5	5	5
Kanchanaburi	5	10	12	6	10	6	12
Khon Kaen	0	0	1	0	0	0	0
Krabi	5	5	5	5	5	5	5
Lampang	2	2	2	2	2	1	2
Lamphun	0	0	0	2	0	0	0
Lop Buri	18	5	23	5	21	5	18
Nakhon Nayok	2	9	9	2	9	2	9
Nakhon Pathom	10	18	26	7	21	7	26
Nakhon Ratchasima	1	4	4	1	4	1	4
Nakhon Sawan	10	8	10	8	10	8	8
Nakhon Si Thammarat	0	0	1	0	0	0	1
Nan	1	1	1	2	1	1	1
Nonthaburi	53	25	46	51	17	53	20
Pathum Thani	16	45	55	13	48	16	55
Phatthalung	1	0	1	1	1	1	1
Phayao	2	1	3	1	2	3	1
Phetchaburi	4	6	4	5	4	5	4
Phichit	2	2	2	2	2	2	2
Phitsanulok	2	4	4	5	3	6	4
Phra Nakhon Si Ayutthaya	37	25	23	25	21	25	23
Phrae	1	1	1	1	1	1	1
Phuket	6	4	6	6	5	6	5
Prachin Buri	3	13	15	3	13	3	14
Prachuap Khiri Khan	5	3	3	4	3	6	3
Ranong	2	1	2	1	2	1	2
Ratchaburi	5	10	13	6	10	6	13
Rayong	6	5	7	6	6	7	5
Sa Kaeo	3	10	12	3	11	3	12
Samut Prakan	56	46	41	40	32	40	36
Samut Sakhon	3	22	28	4	24	4	26
Samut Songkhram	1	3	4	1	3	1	4
Saraburi	21	4	23	4	22	4	23
Sing Buri	4	4	2	4	2	4	2
Songkhla	3	3	6	5	3	6	3
Sukhothai	2	2	2	2	2	2	0
Suphan Buri	8	8	4	8	3	8	4
Surat Thani	6	4	6	6	6	7	6
Tak	3	4	6	3	5	3	6
Trang	1	1	1	1	0	0	0
Trat	2	8	8	2	8	2	8
Uttaradit	1	1	1	1	1	1	1
Total number of orders	589	670	603	568	493	588	597

Table 9: Locations of retail stores and the number of orders

- Constraints of the transportation plan
    - The capacity constraint

According to the information of vehicle details, the limited number of each type of vehicles is provided for the transportation and each type of vehicles provides the different maximum capacity. The capacity constraint restricts that in each trip of the transportation plan, each selected vehicle must not transport sets of requirements greater than the maximum capacity.

- The total time constraint

A total time of a trip is counted from that a vehicle leaves the warehouse to deliver packages until it returns to the warehouse after finishing the trip and the total time of the trip must not exceed the total working hours of a driver due to the fatigue driving policy. Moreover, the total time constraint of each trip depends of the number of required drivers per trip. The total time constraint for one-driver per trip is limited with 10 hours, while the total time constraint for two-driver per trip is restricted by 36 hours.

- The accessibility constraint

For the accessibility constraint, an express retail store type is the smallest-sized retail store compared with other types of retail stores, then an unloading area of the retail store is small. Hence, only some types of vehicles can access to deliver products that are four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo. Whereas, other types of retail store do not contain this constraint. Hence, a set of requirements of each express retail store is not greater than the maximum capacity of the largest-sized vehicle that can access the express retail store that is a 10-wheel truck.

3.2 The route planning system

The route planning system in this research means that a system of allocating heterogenous vehicles to service customers, which are retail stores in this case, and arranging visited locations in each route. Additionally, the number of drivers of a trip is also concerned. A solution approach is to apply the VRP metaheuristic that is simulated annealing (SA) for planning a route scheme. A solution process of metaheuristics comprises of classical constructive heuristics and classical improvement heuristics, whereas SA enhances the local search process to accept an unimproved solution. Accepting a worse solution during Neighbour solutions constructing scheme will aid the algorithm to escape from being trapped in a locally optimal solution. This research desires to generate the route planning system that minimise the total transportation cost. In addition, the total transportation cost composes of the travelled distance cost and the service cost that are described in a previous section.

This route planning system will be utilised everyday after accepting products' requirements from retail stores. This daily routing plan will provide a route of every selected vehicles. The number of required vehicles in each type, the sequence of retail stores and the number of required drivers for each trip are informed. All products' requirements should start delivering within one day after receiving requirements of demands from retail stores, which is 24 hours of working hours since the warehouse operates 24 hours a day. Furthermore, the limited total time of each trip depends on the number of required drivers of the trip. The total time of one-driver per trip is restricted by 10 hours, whereas the total time of two-driver per trip is limited by 36 hours. Apart from that the number of daily required vehicles is limited due to a contract between the 3PL company and the client. If the limited number of vehicles is not enough for transporting all requirements, remaining unserved demands will be included in the next following day transportation requirements. Each vehicle starts the operation at the warehouse for loading products into a container of each vehicle, then each of them delivers products until the last location of retail stores in a trip. After finishing the trip, each vehicle will go back to the warehouse.

3.3 System description

This section explains about collaborative functions that include in the routes planning system in order to achieve the transportation plan that provides the minimum cost. Furthermore, inclusive issues and exclusive issues in this system are mentioned. Subsequently, inputs and constraints of the system are also described.

- System's objective

  To minimise the total transportation cost of the transportation plan for the 3PL company

- System's decision variable
  1. A selected type of vehicles for each trip
  2. A sequence of visited locations in each route

- Scope of the routes planning system
  1. The routes planning system is developed for the 3PL company to service the company's clients.
  2. Solutions of the system are the transportation plans that assign details of each route, e.g. a type of a selected vehicle, the number of drivers, the sequence of visited locations.
  3. The number of vehicles at the beginning of the day is fixed everyday due to the contract between the 3PL company and the client.
  4. Obtained solutions from the system are not relevant to the allocation of drivers and vehicles.
  5. Any unforeseen incidents are not considered in this system.
  6. If limited number of vehicles is not enough for delivering products on each day. The remaining products will be postponed delivering in the next following day.
  7. Total transportation costs comprise of travelled distance costs and service costs.
  8. All planned routes begin and finish at the warehouse.

9. Two types of paths occur in the route planning systems that are, firstly, paths between the warehouse and customers, secondly, paths between customers and customers.
10. A capacity constraint is only considered in terms of volume (m^3).
11. Due to the VRP solution approach, locations in the system can be classified by two categories that are a supplier, which is presented as the warehouse, and customers, which are represented as retail stores.

- Assumption of the routes planning system
    1. Vehicles in the system comprise of eight types that are four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo, 18-wheel trucks small, 18-wheel trucks, and ten-wheel trucks with trailers and the limited number of each type of vehicles is 33 units, 19 units, 4 units, 41 units, 5 units, 9 units, 40 units, and 7 units, respectively. These quantities of vehicles will be available as based fleets in everyday of working routine.
    2. The maximum capacity of four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo, 18-wheel trucks small, 18-wheel trucks, and ten-wheel trucks with trailers are 4.8 m^3, 9 m^3, 19 m^3, 25 m^3, 37 m^3, 41 m^3, 44 m^3, and 55 m^3, respectively.
    3. The total number of retail stores in the system equals to 947 stores that are illustrated in *Table 9*. Only express retail stores cannot be delivered products by 18-wheel trucks small, 18-wheel trucks, and ten-wheel trucks with trailers and this condition is considered as the accessibility constraint. While other types of retail stores can be accessed by all types of vehicles.
    4. Each type of vehicles contains different cost in terms of travelled distance cost and services cost.
    5. A set of total requirements of a retail store that is assigned by the retail company is considered in terms of volume (m^3).
    6. A set of total requirements of a retail store (m^3) that is assigned by the retail company is not allowed to split.

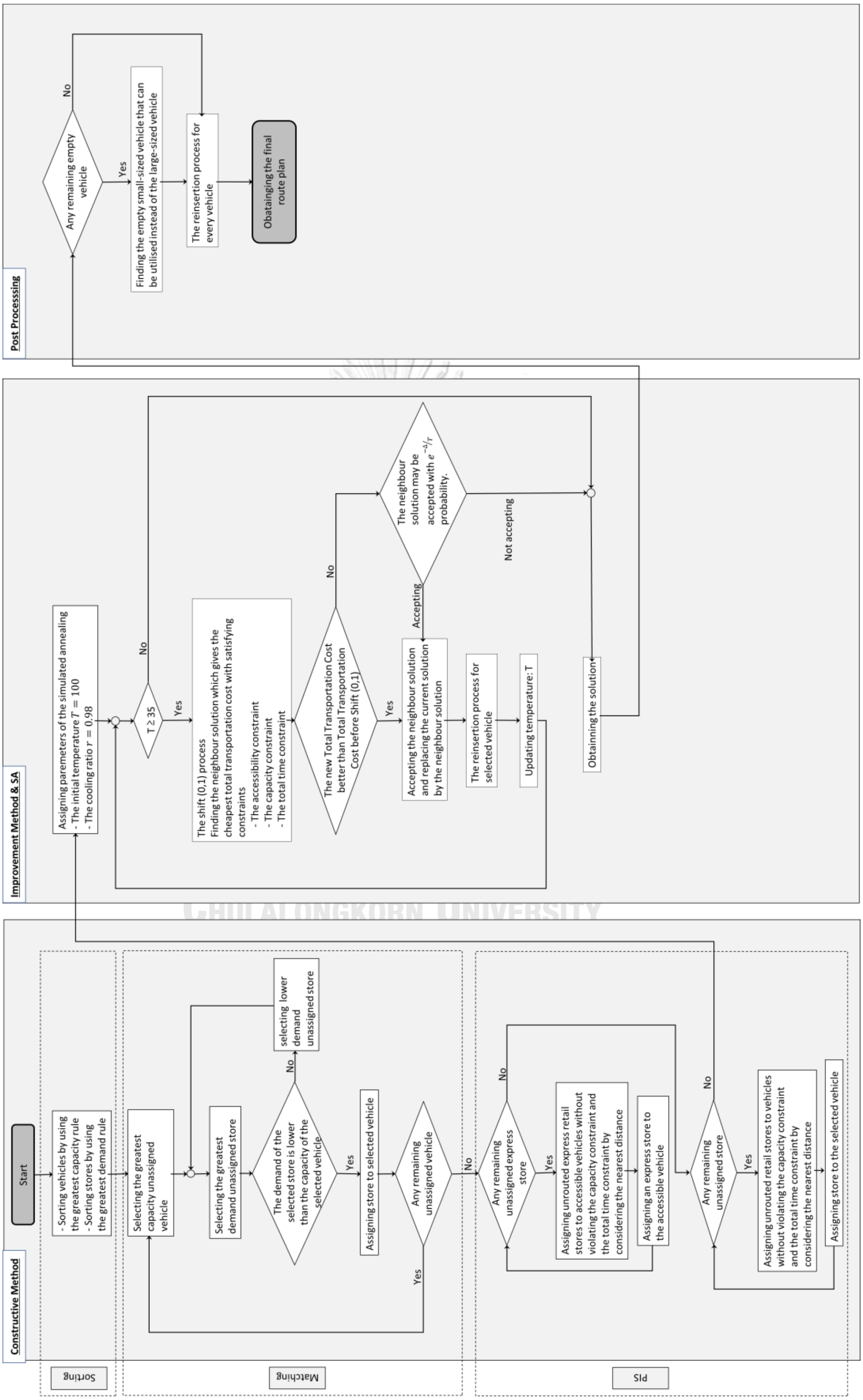
7. In case that a set of total requirements of a retail store is greater than the maximum capacity of the largest-sized vehicle in terms of volume (m^3), the set of total requirements of the retail store is separated into more than one set by the retail company. So that this retail store will be visited more than once at a day. Otherwise, for a normal case that a set of total requirements of a retail store does not exceed the maximum capacity of the largest-sized vehicles in terms of volume (m^3), the retail store will be visited only one time per day.
8. Due to the accessibility constraint, a set of total requirements of each express retail store is not greater than the maximum capacity of the largest-sized vehicle that can access the express retail store in terms of volume (m^3).
9. Packages of every retail store can be delivered together without any restrictions.
10. An unloading time of every retail store is the same, which is 60 minutes per retail store.
11. Distances between locations in the system are calculated as the displacement.
12. Travelled times have a linear relationship with travelled distances.
13. Drivers drive vehicles at constant speed with 60km/hr.
14. The total time of one-driver per trip route and the total time of two-driver per trip route are limited with 10 hours and 36 hours, respectively. These limited total times of drivers are considered as the total time constraint.
15. The required number of drivers per trip depends on the total time of each trip.
16. The number of drivers in a system is unlimited.
17. There is one warehouse in the system.
18. Vehicles begin and terminate at the warehouse.
19. The capacity constraint is restricted in terms of volume of each vehicle.
20. Uncontrollable factors are not considered during the study of the route planning system, for example, traffic, accident, disaster.

- The system's constraints
    1. A capacity constraint in terms of volume (m^3)
    2. A total time constraint in terms of working hours for one driver per route and two drivers per route
    3. An accessibility constraint for express retail stores
- The system's inputs
    1. Locations of the warehouse and retail stores
    2. Sets of total requirements of every retail store in terms of volume (m^3)
    3. The limited number of vehicles in each type
    4. A store type of each retail store
    5. The maximum capacity of each type of vehicles in terms of volume
    6. Costs of each type of vehicles in terms of travelled distance cost and service cost
    7. Constant vehicles' speed
    8. The limited total time of a trip for both one-driver per trip and two-driver per trip
    9. Travelled distances between locations in terms of the displacement
    10. Travelled times between locations
    11. An unloading time of every retail store

3.4 Conceptual design of the system

In this section, a conceptual scheme and overall processes of the proposed method that is used for generating the routes planning system are described. The routes planning system applies a simulated annealing (SA) metaheuristics approach in order to generate the route planning system that minimises the total transportation cost. According to the chapter of the literature reviews, a metaheuristic solution method for the VRP is embedded with classical heuristic methods that are the constructive heuristic method and the improvement heuristic method. Furthermore, these classical heuristics could be done by abundant methods, whereas selected methods that are applied with the logic of SA metaheuristic are illustrated below.

Figure 25: The overall processes of the proposed method



The Figure 25 represents overall processes of the proposed method. The proposed method begins with the sorting process of both vehicles and retail stores. For vehicles, they will be sorted by the greatest capacity rule. A procedure of the greatest capacity rule is to rearrange vehicles by sequencing them from the greatest capacity to the smallest capacity in terms of volume. On the other hand, a procedure of the greatest demand is to arrange an order of retail stores by sequencing them from the greatest demand to the smallest demand. After sorting both vehicles and retail stores, both of them will be matched. The first greatest capacity vehicle will be paired with the first greatest demand retail store. Then, the next order of the greatest capacity vehicle will be matched with the next order of the greatest demand retail store that can be assigned to the selected vehicle without violating constraints of the problem. This matching process is repeated until every vehicle contains one retail store. Next, constraints of the problem that are an accessibility constraint, a capacity constraint, and a total time constraint are checked. If these three constraints are satisfied, the PIS process will begin. Otherwise, the matching process must be revised. After finishing the matching process, there will be only 158 retail stores that are assigned to vehicles. Hence, unrouted retail stores remain, since the range of the total number of retail stores in each day is between 489 stores and 669 stores according to the collected data.

Next, the PIS process is applied in order to route remaining unrouted retail stores, so that an initial solution will be obtained. An insertion criteria of the PIS process that is chosen for the proposed method is the NFIC. Hence, unrouted retail stores will be inserted into vehicles by considering the shortest distance, while all constraints must be satisfied. Furthermore, all types of retail stores cannot be considered to insert in vehicle simultaneously because at the end of the PIS process express retail stores remain unrouted and vehicles that are able to access these express retail stores are not available. Since, express retail stores are restricted to be serviced by specific types of vehicles. If express retail stores are not formerly assigned to accessible vehicles, these vehicles will be used up to service other types of retail stores before all express retail stores will be routed. Consequently, an initial solution cannot be completed. To solve this issue, the PIS process is divided into two stages. At the first stage, the PIS process is applied to express retail stores. At the end of each iteration, an unrouted express retail store that provides the best insertion criteria is assigned to a vehicle. Then, three constraints that are the accessibility constraint, the capacity constraint, and the total time constrain are checked. If they are passed, the PIS process for the next unrouted express retail store will proceed. Otherwise, the PIS process at this iteration will selected an unrouted express retail store that provides the next best insertion criteria and satisfies all constraints. The PIS process for express retail stores is repeated until all express retail stores are routed. After that the PIS process for other remaining types of unrouted retail stores begins. Procedures of the PIS process for other types of retail stores are the same as the PIS process for express retail stores. After all retail stores are assigned to vehicles without violating any constraints of the problem, then the initial solution is obtained.

Next, the SA metaheuristic process is applied to the proposed method. A significant benefit of the metaheuristic approach is that aiding a solution approach escapes from being trapped in a local optimal solution. At the beginning of the SA process, parameters of the SA metaheuristic that are suitable to the problem are required to identify. These parameters comprise of an initial temperature, a final temperature, and a cooling ratio. Then, a local search process proceeds by applying the shift (0,1) process. In addition, a reason of selecting the shift (0,1) process is described as following. Since finding all combinations of every route in a solution is impossible due to a computing time of a size of the problem, an appropriate method for finding Neighbour solutions with limited computing time should be applied. During the PIS process, all vehicles in the system are utilised, thus the number of required vehicles should be reduced. Due to the purpose of reducing the number of required vehicles, the shift (0,1) process could aid the proposed method to resolve this issue. A characteristic of the shift (0,1) process is to shift one retail store from a route to another route. This will be a chance that all customers from one route could be transferred to other routes with the better result than the current solution. Then, a vehicle that is used for servicing these customers will be deleted from the solution. Therefore, the shift (0,1) process is an appropriate neighbourhood scheme for the proposed method. After proceeding the shift (0,1) process, a Neighbour solution from the shift (0,1) process that provides the best solution at each iteration in terms of the total transportation cost is obtained, while three constraints that are the accessibility constraint, the total time constraint, and the capacity constraint are satisfied. Next, the cost of the current solution and the cost of the Neighbour solution will be compared and accepted in the following fashion. Hence, following processes could be categorised into two schemes that are whether accepting the Neighbour solution of the shift (0,1) or not.

In case of the acceptance, the Neighbour solution must satisfy either two following cases. Firstly, the Neighbour solution provides cheaper total transportation cost than the current solution. Secondly, the Neighbour solution provides more expensive transportation cost than the current solution but the Neighbour solution is accepted by the probability $e^{-\Delta/T}$. Consequently, the current solution is replaced by the Neighbour solution. Additionally, in the case that a temperature of the algorithm is high and the Neighbour solution provides slightly worse solution than the current solution, the chance of accepting the worse Neighbour solution is high. Next, an applied process after accepting the Neighbour solution is the reinsertion process to a route that receives another retail store, which can be called a receiving route. Then, a combination of the receiving route that provides the best total transportation cost will be picked and the total time constraint will be checked. After that the temperature of the system at the current iteration is updated and checked. If the current temperature is higher than the final temperature, the next iteration of the shift (0,1) process will continue to find other Neighbour solutions. On the other hand, if the current temperature is equal to or less than the final temperature, the post processing process will proceed. The post processing process begins with the adapted multi-transfer process that is to transfer a route that is serviced a large-sized vehicle to an available small-sized vehicle in order to reduce the total transportation cost. Next, the reinsertion process will be applied to every route, then the best combination of the reinsertion process of each route that provides the best total transportation cost and satisfied the constraints is selected. Lastly, after finish the reinsertion process for all routes, the solution from the proposed method is obtained.

In case of the non-acceptance, the Neighbour solution of the shift (0,1) provides worse result than the current solution and the Neighbour solution is not accepted to be the new solution. Hence, the current solution is brought to the post-processing process, then all subsequent processes are the same as described in the previous scenario.

3.5 The proposed method

3.5.1 Initial solution

Since the insertion heuristic is proposed by (Solomon 1987) for generating an initial solution for the VRPTW, several researchers apply this initial solution scheme to their considered variants of the VRP, for example, VRPTW (Chiang and Russell 1996), VRPHF (Penna, Subramanian et al. 2013). Nevertheless, to apply the insertion heuristic method to a specific type of problems, an insertion criteria and insertion strategy should be considered and adjusted to be suitable for a considered problem. For the insertion criteria, (Penna, Subramanian et al. 2013) randomly selects between the nearest feasible insertion criterion (NFIC) and the modified cheapest feasible insertion criterion (MCFIC) at each iteration during producing an initial solution. However, for this research only NFIC will be applied to the proposed model because both travelled distance cost and service cost that are components of the total transportation cost are based on travelled distances on each route. Additionally, both NFIC and MCFIC are tried applying to the proposed model. The results of these strategies represent the MCFIC requests much longer time than the NFIC, while the total transportation costs from both strategies are not much different. Therefore, NFIC is proper to apply to the proposed model with an appropriate time. For the insertion strategy, two approaches that are used for deciding to insert which remaining unrouted customers into which routes that are SIS and PIS. For SIS, this strategy is applied to the HVRP by (Penna, Subramanian et al. 2013) and this scheme could be described as following. In each iteration, only one route is examined to be inserted by a remaining unrouted customer that provides the best insertion criteria, which is already selected to be considered. On the other hand, for PIS, in each iteration every unrouted customer is tried to be inserted into every route. Then, an unrouted customer and a route that give the best insertion criteria will be selected to be a solution of this iteration. This means that, for each iteration, PIS considers every combination of insertions between all unrouted customers and all routes in a system. In other words, PIS considers the selected criteria of the insertion more comprehensive than SIS, thus PIS is applied to the proposed method.

Aside from that, to apply the insertion heuristic to the problem, seed customers are required to examine. Moreover, there are several approaches for selecting seed customers, for example, a randomly choosing method is utilised by (Penna, Subramanian et al. 2013). A procedure of the random method is that an unrouted customer is randomly selected and it is randomly inserted in an empty vehicle. After that, this customer and this vehicle are eliminated from the consideration of seed customers. Next, this process is repeated until every vehicle contains a seed customer. Furthermore, this random method of the seed customers' assignment is tired applying to the problem in this research but an infeasible solution occurs during the PIS process. Since a retail store that requires a great amount of demands cannot be inserted into any vehicles because these vehicles are already fulfilled by demands of other stores. Then, there is no enough available space of any vehicles to service this retail store. Additionally, (Penna, Subramanian et al. 2013) suggests that if the infeasible solution occurs, all processes of the insertion should restart. To avoid a repetition of the insertion process, other initial solution approaches are reviewed.

(Jiang, Ng et al. 2014) states that the sorting approach to decide that which vehicle and which customer are appropriate for utilising in the next sequence affects the quality of an initial solution. Therefore, (Jiang, Ng et al. 2014) applies the greatest capacity rule for the sequence of vehicles and the greatest distance rule for the sequence of customers. Aside from that, according to a literature of (Gheysens, Golden et al. 1984), the first step that the author applies for the clustering stage after obtaining the seed customers is analogous to the sorting procedure from (Jiang, Ng et al. 2014). For the seed customers, they are sequenced according to the farthest distance from the depot, for example, the first ordered seed customer is the seed customer that locates farthest from the depot. For vehicles, they are arranged based on the greatest capacity, e.g., the first ordered vehicle is the vehicle that has the largest capacity. Nevertheless, due to the considered problem in this research, locations of retail stores are not related to amounts of requirements. If the greatest distance rule for sorting retail stores and the greatest capacity rule for sorting vehicles are applied, some retail stores will not be able to be assigned to routes during the parallel insertion process of the proposed method. Since some retail stores that locate nearby the warehouse but have the great number of requirements are not firstly considered. Then, during the insertion process, none of vehicles that have enough space for serving these retail stores is available. Therefore, two rules for sorting retail stores and vehicles that are applied to the proposed method are the greatest demand rule and the greatest distance rule, respectively. For example, the first ordered retail store is a retail store that requires the largest demands, whereas the first ordered vehicle is a vehicle that has the largest capacity and the sorting process for both vehicles and retail stores is illustrated in Figure 26.

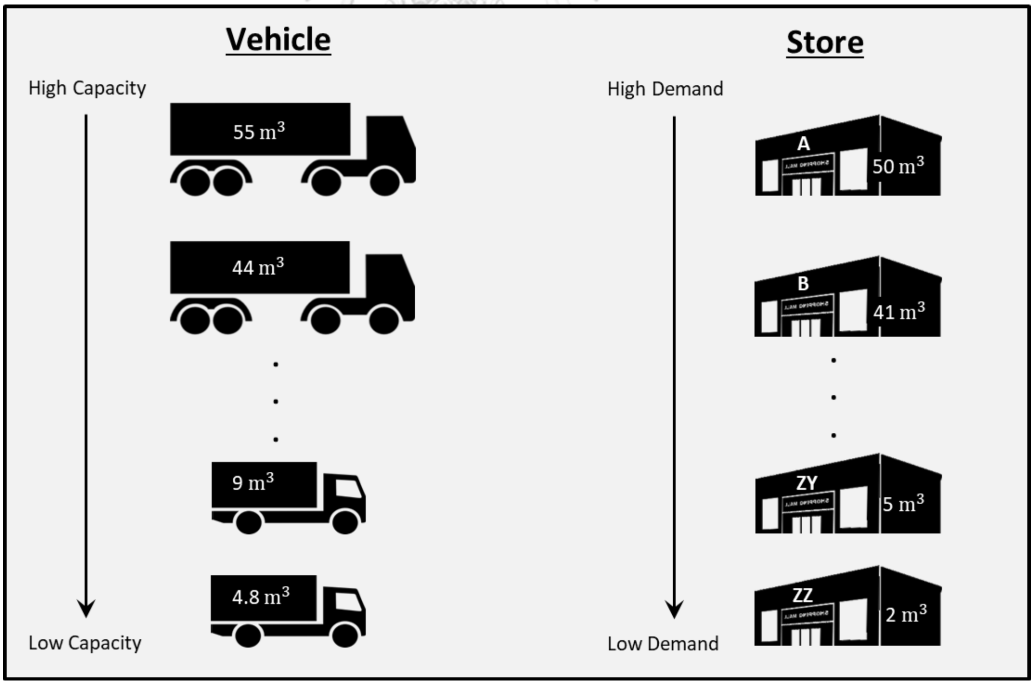


Figure 26: The sorting process for vehicles and retail stores

After sorting retail stores and vehicles, the matching approach between sorted vehicles and sorted retail stores is proceeded to assign a seed customer, which is a seed retail store in this research, to every vehicle. The assigning seed customers process of the proposed method is explained as that, the greatest-sized vehicle will be matched with the greatest-demand retail store, while constraints of the problem are satisfied. Then, the next greatest-sized vehicle will be paired with the next greatest-demand retail store that can be serviced by the vehicle without violating constraints of the problem. This matching process will repeat until every vehicle in the system contains one retail store. In addition, the assigning process is illustrated in Figure 27.

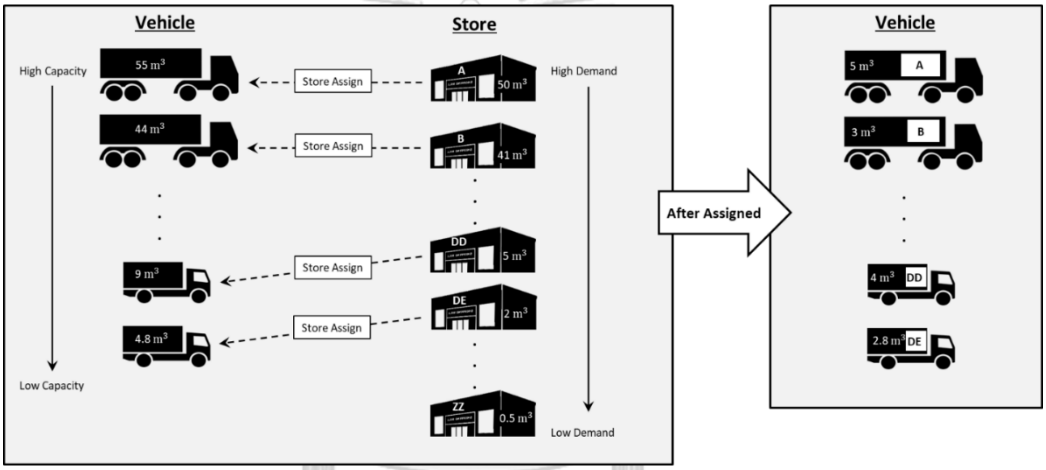


Figure 27: The assigning seed retail store process

Next, the PIS process begins with express stores, since this type of store is restricted by the accessibility constraint that does not allow 18-wheel small trucks, 18-wheel trucks, and 10-wheel trucks with trailers to deliver packages. The PIS process for the express retail stores is shown in *Figure 28*. After all express stores are assigned to accessible vehicles by considering the best insertion criteria at each iteration. Then, the rest of unrouted retail stores are assigned to vehicles by examining the best insertion criteria at each iteration until all retail store are routed and it is exemplified in *Figure 29*.

Furthermore, the whole process of the initial solution of the proposed method is illustrated in an Example 5.

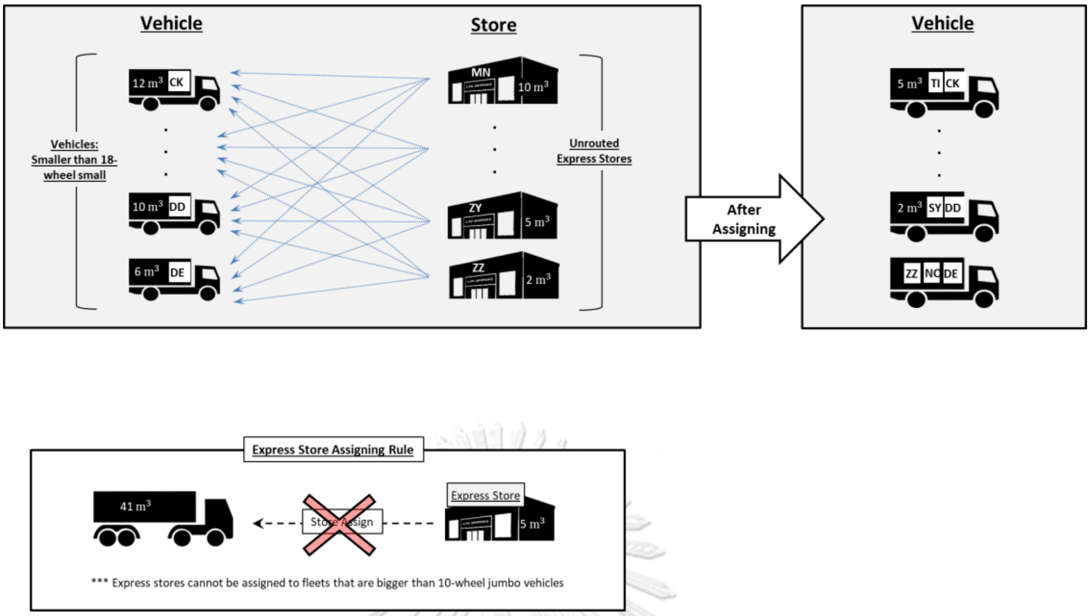


Figure 28: The PIS process for express retail stores

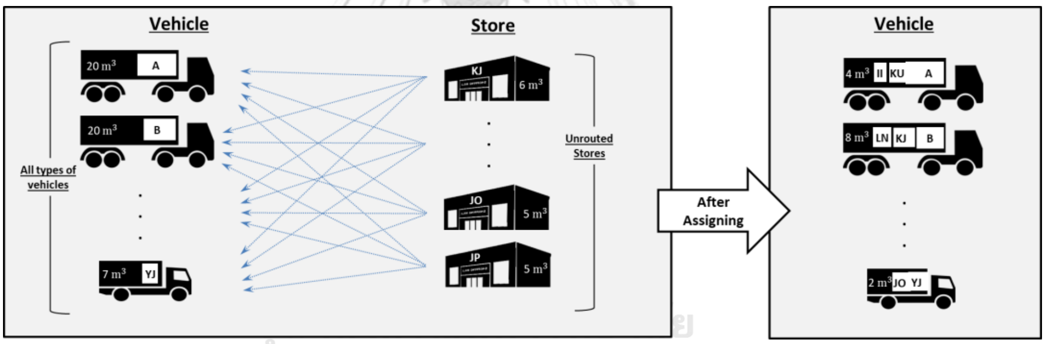


Figure 29: The PIS process for remaining unrouted retail stores

Example 5

1. Sorting

- The greatest capacity rule for vehicles

According to Table 3, it represents the total number of vehicles in each type, while in this example Table 10 shows the sequence of vehicles that is sorted by the greatest capacity rule. In addition, Table 10 contains a variable of vehicle, k_a^{type}, in the system that $type$ means a type of vehicles and a means the specific number of each vehicle.

The order of vehicles	Types of vehicles	Total capacity of vehicles (cube)	The variable of vehicles
1	10-wheel with trailer	55	$k_1^{10-wheel\ with\ trailer}$
2	10-wheel with trailer	55	$k_2^{10-wheel\ with\ trailer}$
3	10-wheel with trailer	55	$k_3^{10-wheel\ with\ trailer}$
. . .			
9	18-wheel	44	$k_9^{18-wheel}$
. . .			
48	18-wheel small	41	$k_{48}^{18-wheel\ small}$
. . .			
57	10-wheel jumbo	37	$k_{57}^{10-wheel\ jumbo}$
. . .			
62	10-wheel	25	$k_{62}^{10-wheel}$
. . .			
103	6-wheel	19	$k_{103}^{6-wheel}$
. . .			
107	4-wheel jumbo	9	$k_{107}^{4-wheel\ jumbo}$
. . .			
126	4-wheel	4.8	$k_{126}^{4-wheel}$
. . .			
158	4-wheel	4.8	$k_{158}^{4-wheel}$

Table 10: Sorting vehicles

- The greatest demand rule for retail stores

The number of retail stores that requires to deliver packages varies in each day and the range number of retail stores is between 489 retail stores and 669 retail stores according to seven days of the collected data. A symbol that represents a retail store is $n_{the\ specific\ number\ of\ store}^{the\ type\ of\ store}$, for example, $n_1^{express\ store}$ means that the retail store number 1 is an express store. Then, all retail stores are sorted from the greatest number of requirements to the least number of requirements and an example of the rearrangement is illustrated in Table 11.

The order of customers	Type of customers	Total requirement of customers (cube)	The variable of customers
1	Hypermarket	50	$n_1^{Hypermarket}$
2	Hypermarket	45	$n_2^{Hypermarket}$
3	Hypermarket	30	$n_3^{Hypermarket}$
. . .			
158	Extra	18	n_{158}^{Extra}
. . .			
200	Talad	5.2	n_{200}^{Talad}
201	Express	4.5	$n_{201}^{Express}$
. . .			
600	Express	0.51	$n_{600}^{Express}$

Table 11: Sorting retail stores

2. Matching

A consideration of inserting retail stores into routes during the PIS process is to evaluate the value of the insertion criteria, which is the NFIC, that occurs from inserting unrouted retail stores into routes at each iteration until all retail stores are assigned to vehicles. Therefore, every vehicle should contain at least one retail store before starting the PIS process, which is called as a seed retail store, in order to use as an index for calculating values of the NFIC of every combination between seed retail stores of every vehicle and remaining unrouted retail stores. An approach of assigning seed retail stores to vehicles is that to match the first order of the vehicle due to the greatest capacity rule with the first order of the retail store, which requires the number of demands equal to or less than the capacity of the selected vehicle, due to the greatest demand rule. Next, the matching process repeats until the last order of the vehicle contains a seed retail store and the matching process is represented in Figure 30 . Moreover, the accessibility constraint must be satisfied, so that the express store type cannot be matched with specific three types of vehicles that are 18-wheel small trucks, 18-wheel trucks, and 10-wheel trucks with trailers.

After finishing this matching process, the number of routes will be equal to the number of vehicles in the system and each route contains only one retail store (Table 12). Moreover, retail stores that are not assigned to any vehicles in this step can be called as unrouted retail stores. Then, these unrouted stores will be allocated to vehicles during the PIS process.

The order of vehicles	Types of vehicles	Total capacity of vehicles	The variable of vehicles
1	10-wheel with trailer	55	$k_1^{10-wheel\ with\ trailer}$
2	10-wheel with trailer	55	$k_2^{10-wheel\ with\ trailer}$
3	10-wheel with trailer	55	$k_3^{10-wheel\ with\ trailer}$
⋮			
9	18-wheel	44	$k_9^{18-wheel}$
⋮			
48	18-wheel small	41	$k_{48}^{18-wheel\ small}$
⋮			
57	10-wheel jumbo	37	$k_{57}^{10-wheel\ jumbo}$
⋮			
62	10-wheel	25	$k_{62}^{10-wheel}$
⋮			
103	6-wheel	19	$k_{103}^{6-wheel}$
⋮			
107	4-wheel jumbo	9	$k_{107}^{4-wheel\ jumbo}$
⋮			
126	4-wheel	4.8	$k_{126}^{4-wheel}$
⋮			
158	4-wheel	4.8	$k_{158}^{4-wheel}$

The order of customers	Type of customers	Total requirement of customers	The variable of customers
1	Hypermarket	50	$n_1^{Hypermarket}$
2	Hypermarket	45	$n_2^{Hypermarket}$
3	Hypermarket	30	$n_3^{Hypermarket}$
⋮			
158	Extra	18	n_{158}^{Extra}
⋮			
200	Talad	5.2	n_{200}^{Talad}
201	Express	4.5	$n_{201}^{Express}$
⋮			
600	Express	0.51	$n_{600}^{Express}$

Figure 30: The matching process

Route number	Types of vehicles	Routes from the matching process	The variable of vehicles
1	10-wheel with trailer	$R_1 = \{n_1^{Hypermarket}\}$	$k_1^{10-wheel\ with\ trailer}$
2	10-wheel with trailer	$R_2 = \{n_2^{Hypermarket}\}$	$k_2^{10-wheel\ with\ trailer}$
3	10-wheel with trailer	$R_3 = \{n_3^{Hypermarket}\}$	$k_3^{10-wheel\ with\ trailer}$
. . .			
9	18-wheel	$R_9 = \{n_9^{Hypermarket}\}$	$k_9^{18-wheel}$
. . .			
48	18-wheel small	$R_{48} = \{n_{48}^{Hypermarket}\}$	$k_{48}^{18-wheel\ small}$
. . .			
57	10-wheel jumbo	$R_{57} = \{n_{57}^{Hypermarket}\}$	$k_{57}^{10-wheel\ jumbo}$
. . .			
62	10-wheel	$R_{62} = \{n_{351}^{Express}\}$	$k_{62}^{10-wheel}$
. . .			
103	6-wheel	$R_{103} = \{n_{158}^{Extra}\}$	$k_{103}^{6-wheel}$
. . .			
107	4-wheel jumbo	$R_{107} = \{n_{176}^{Talad}\}$	$k_{107}^{4-wheel\ jumbo}$
. . .			
126	4-wheel	$R_{126} = \{n_{201}^{Express}\}$	$k_{126}^{4-wheel}$
. . .			
158	4-wheel	$R_{158} = \{n_{351}^{Express}\}$	$k_{158}^{4-wheel}$

Table 12: Routes from the matching process

3. The PIS process

The purpose of the PIS process is to route remaining unrouted retail stores after the matching process. To deciding a position of a vehicle that is suitable for assigning an unrouted retail store into a route, the insertion criteria is used to justify this statement. In each iteration, each of remaining unrouted retail stores will try to insert after every routed retail store in every route. Then, a position that an unrouted retail store tries to insert in a vehicle that provides the best value of the insertion criteria without violating any constraints is selected. In addition, three constraints that are considered at each iteration are the total time constraint, the total capacity constraint, and the accessibility constraint. Then, the unrouted retail store is assigned to the position of the vehicle that provides the best insertion criteria accordingly. After that this unrouted retail store is eliminated from the set of unrouted retail stores and a next iteration of the PIS process begins again. Additionally, the PIS process repeats until the set of unrouted retail stores is empty. Nevertheless, considering all types of retail stores during the PIS process concurrently will generate an infeasible solution because express retail stores remain unrouted at the end of the PIS process. Since the number of express retail stores that is required to deliver products is plentiful in each day. If the proposed method does not give priority to the express retail store type during the PIS process, other types of retail stores will be assigned to vehicles that are able to access express retail stores instead. Consequently, vehicles that can be accessible to express retail stores are used up. Hence, the proposed method gives priority to the express retail store type by firstly applying the PIS process to express retail stores until all of them are assigned to accessible vehicles. After that, the PIS process will be applied to other types of retail stores. Furthermore, procedures of the PIS process are separately illustrated into two examples. Example 6 demonstrates the PIS process of express retail stores, while Example 7 exemplifies the PIS process of other types of retail store.

Example 6

From Figure 31, at the first iteration of the PIS process for express retail store, every route contains only one seed retail store that is assigned to each vehicle from the matching process. At this stage, every express retail store that remains unrouted tries to insert after every retail store of routes that are serviced by four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, ten-wheel trucks jumbo. After that only one unrouted express retail store that provides the best insertion criteria and satisfies constraints of the problem is selected to insert in the route. Furthermore, the insertion criteria that is applied to the proposed method is the NFIC. Therefore, the unrouted retail store that is placed in the route with the shortest distance and satisfies the constraints will be inserted in the route at each iteration. This example assumes that an express retail store $n_{281}^{Express}$ provides the best insertion criteria after inserting in a route R_{62} at this iteration. Hence, the express retail store $n_{281}^{Express}$ will be inserted in the route R_{62} at this iteration and the express retail store $n_{281}^{Express}$ will be deleted from a set of unrouted express retail store.

For the second iteration, the route R_{62} contains two retail stores and it is illustrated in Table 13. At this iteration, unrouted express retail stores try to insert after retail stores of each route that are served by accessible vehicles. After that the selection process of an unrouted express retail store that will be inserted into a route is the same as a previous iteration. The PIS process for express retail stores repeats until all express retail stores are routed.

Route number	Types of vehicles	Routes from the matching process
1	10-wheel with trailer	$R_1 = \{n_1^{Hypermarket}\}$
2	10-wheel with trailer	$R_2 = \{n_2^{Hypermarket}\}$
3	10-wheel with trailer	$R_3 = \{n_3^{Hypermarket}\}$
⋮		
9	18-wheel	$R_9 = \{n_9^{Hypermarket}\}$
⋮		
48	18-wheel small	$R_{48} = \{n_{48}^{Hypermarket}\}$
⋮		
57	10-wheel jumbo	$R_{57} = \{n_{57}^{Hypermarket}\}$
⋮		
62	10-wheel	$R_{62} = \{n_{351}^{Express}\}$
⋮		
103	6-wheel	$R_{103} = \{n_{158}^{Extra}\}$
⋮		
107	4-wheel jumbo	$R_{107} = \{n_{176}^{Talad}\}$
⋮		
126	4-wheel	$R_{126} = \{n_{201}^{Express}\}$
⋮		
158	4-wheel	$R_{158} = \{n_{351}^{Express}\}$

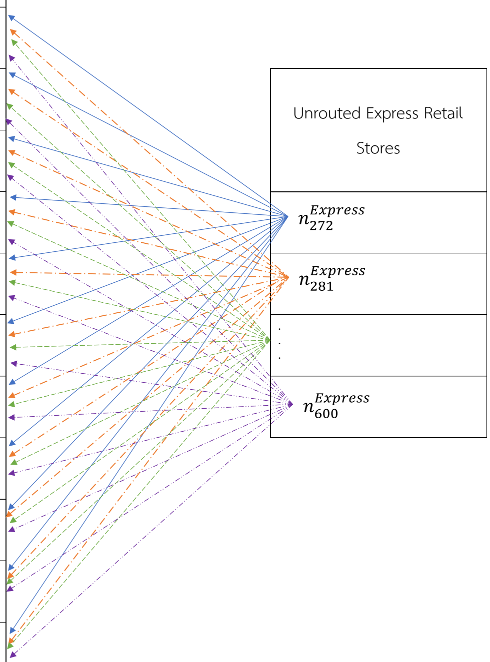


Figure 31: The first iteration of the PIS process of express retail stores

Route number	Types of vehicles	Routes
1	10-wheel with trailer	$R_1 = \left\{n_1^{Hypermarket}\right\}$
2	10-wheel with trailer	$R_2 = \left\{n_2^{Hypermarket}\right\}$
3	10-wheel with trailer	$R_3 = \left\{n_3^{Hypermarket}\right\}$
. . .		
9	18-wheel	$R_9 = \left\{n_9^{Hypermarket}\right\}$
. . .		
48	18-wheel small	$R_{48} = \left\{n_{48}^{Hypermarket}\right\}$
. . .		
57	10-wheel jumbo	$R_{57} = \left\{n_{57}^{Hypermarket}\right\}$
. . .		
62	10-wheel	$R_{62} = \left\{n_{351}^{Express},\ n_{281}^{Express}\right\}$
. . .		
103	6-wheel	$R_{103} = \left\{n_{158}^{Extra}\right\}$
. . .		
107	4-wheel jumbo	$R_{107} = \left\{n_{176}^{Talad}\right\}$
. . .		
126	4-wheel	$R_{126} = \left\{n_{201}^{Express}\right\}$
. . .		
158	4-wheel	$R_{158} = \left\{n_{351}^{Express}\right\}$

Table 13: The second iteration of the PIS process of express retail stores

Example 7

After finishing the PIS process for express retail stores, other types of retail stores remain unrouted, thus the PIS process is applied to route other types of remaining retail stores. At each iteration, the remaining unrouted retail stores try to insert after every retail store of every route and this is represented by Figure 32. Since other types of retail stores excepting express retail stores can be accessed by every type of vehicles, during the PIS process of other types of retail stores, every unrouted retail store can try to insert in every route. After that an unrouted retail store that gives the best insertion criteria and satisfies constraints of the problem will be selected to insert in a route. Then, the PIS process repeats until a set of unrouted retail stores is empty.

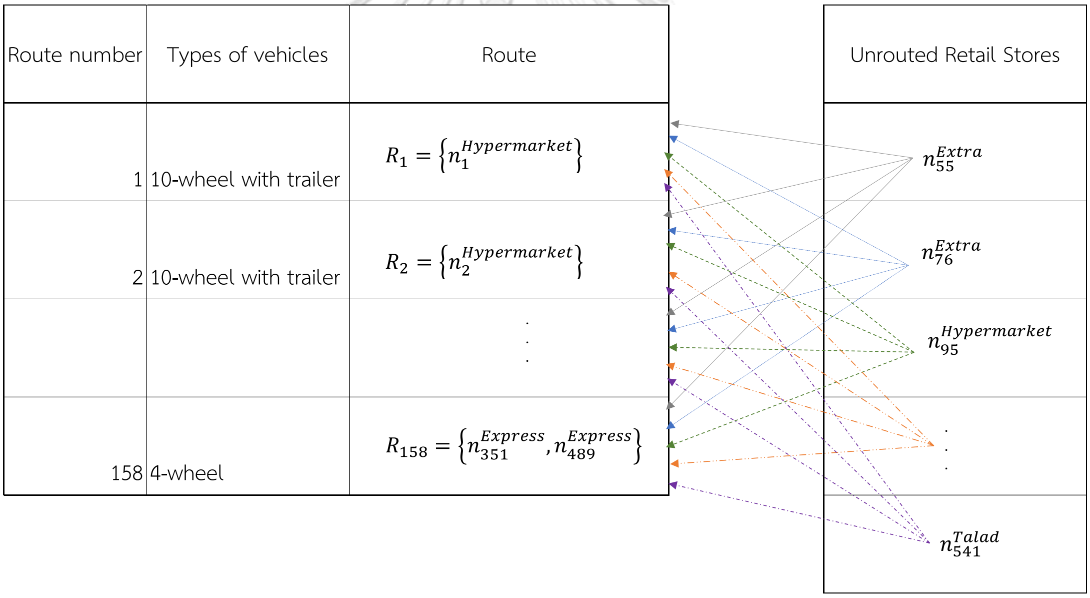


Figure 32: the PIS process of remaining unrouted retail stores

3.5.2 The simulated annealing

According to a literature of (Chiang and Russell 1996), results of this literature that are applied the SA metaheuristic solution approach represent that the SA metaheuristic could provide superior results in terms of the small number of required vehicles for servicing customers in a problem. Furthermore, (Tavakkoli-Moghaddam, Safaei et al. 2007) applies the SA metaheuristic to solve the HVRP and the researcher tests the performance of the SA metaheuristic on small-sized problems and large-sized problems. Results illustrate that the SA metaheuristic can achieve the lower bound solutions in almost small-sized instances, while the SA metaheuristic provides worse results on large-sized problems than the lower bound with 25 percent range. Apart from that (Osman 1993) also states that the SA metaheuristic provides an improved solution with the smaller number of requirements of vehicles in some instances compared with descent algorithms. Since the considered problem in this research requires to enhance the capacity utilisation and a favourable benefit of apply the SA metaheuristic is to request the small number of vehicles. So that the SA metaheuristic should lead to the reduction of required vehicles for serving packages with high capacity utilisation.

Due to the approach of the SA metaheuristic in the chapter 2, the SA approach comprises of several steps and these steps are adjusted to the problem of this research. The approach of the SA metaheuristic that is applied to the problem of this research will be illustrate in Figure 33.

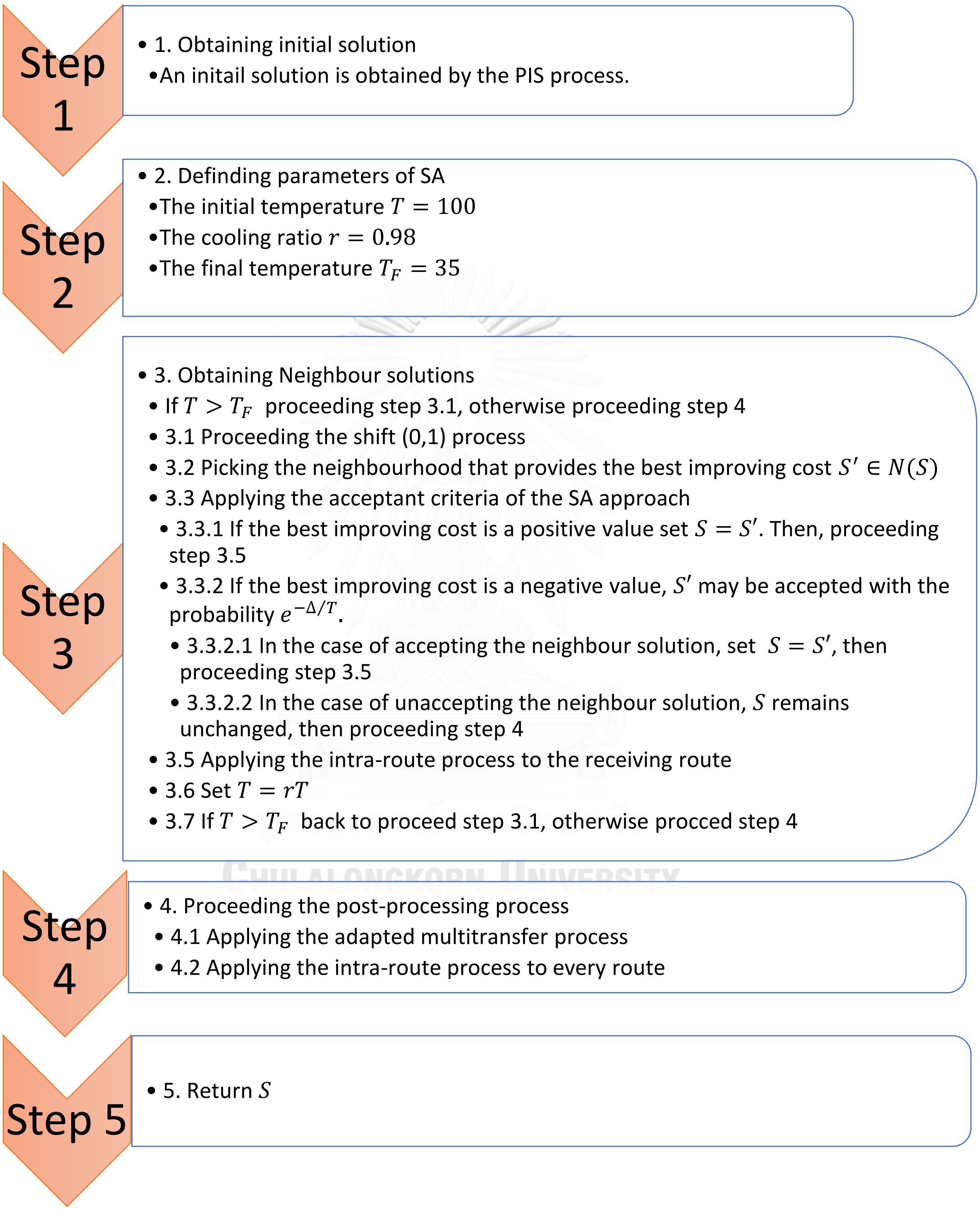


Figure 33: The simulated annealing process

According to the Figure 33, it could be explained as that in the step 1 is to obtain the initial solution, while the procedure of generating the initial solution is already explained in the previous section. For the step 2, the parameters of the SA metaheuristic are specified that are the initial temperature, the cooling ratio, and the final temperature. Furthermore, the origin of these parameters is explained as followed. At the beginning of the SA approach, the initial temperature should be high enough to allow the appropriate number of iterations of the local search process to search Neighbour solutions in the solution space. For the cooling ratio (*r*), the applied value is 0.98 due to the suggestion of (Chiang and Russell 1996) that examines values of *r* between 0.85 and 0.95. Experimental results show that the higher value of the ratio prolongs the time to finish the process. Whereas the higher value of the ratio enhances the solution, since it allows the local search process to search more solutions through the solution space. Additionally, (Chiang and Russell 1996) states that the value *r* equals to 0.95 provides the best results to the author's problem. For the final temperature, this parameter is experimental with the problem of this research by examining the amount of improving cost. At the value of 35 temperature, the improving cost of the problem is small and the total running time of the model is quite long. Therefore, the value of the final temperature, with 35, should be the appropriate value. Apart from that detailed processes of the Neighbour solution, which is the step 3 in the SA approach, and the post-processing process, which is the step 4 in the SA approach, will be explained in the following section.

3.5.3 Neighbour solution

An approach that is applied to the proposed method is the λ-interchange process. Since this method is widely applied by other researchers and one of them experimentally compares the quality of solutions that are obtained from a neighbourhood scheme of the *k*-node interchange mechanism of (Christofides and Beasley 1984) and a neighbourhood scheme of the λ-interchange mechanism of (Osman 1993). Results of the comparison show that the λ-interchange neighbourhood scheme provides a better result for a large-sized problem with 417 nodes of customers and 55 vehicles that is analogous to the size of the problem of this research. Apart from that the number of required vehicles in a solution should be reduced after applying the shift (0,1) process, since during the PIS procedure all vehicles in the system are utilised. While, the shift (0,1) operator means that a customer from one route tries to shift to another route, so there is a chance that all retail stores of a route can be shifted to other routes. Then, a vehicle that is used for servicing this route can be deleted from the solution. Hence, the λ-interchange Neighbour solution approach is an appropriate Neighbour solution scheme of the proposed method. In addition, the shift (0,1) process that is proceeded in each iteration of the proposed method is illustrated in Figure 34 and the shift (0,1) will be further explained in the following section.

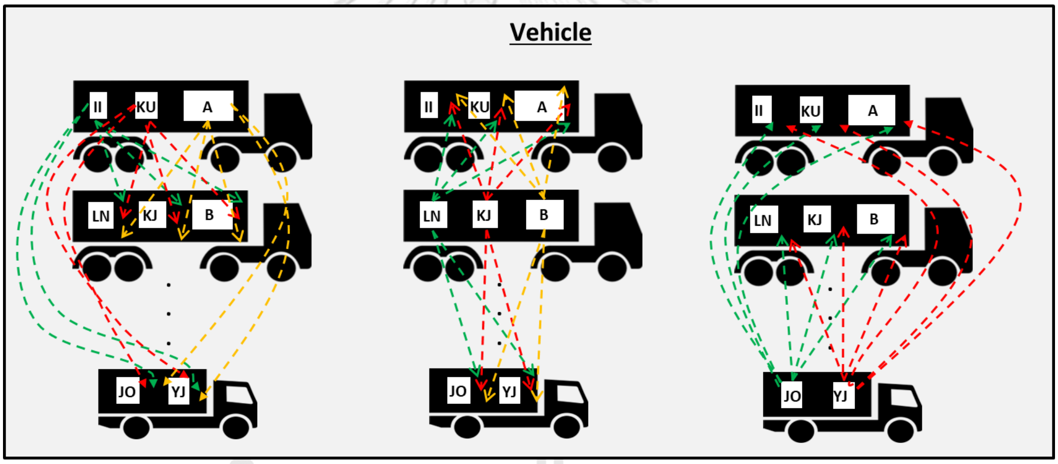


Figure 34: An example of the shift (0,1) process

3.1Proceeding the shift (0,1) process

After obtaining an initial solution, a local search process is applied in order to find Neighbour solutions of the current solution that might provide the better solution than the current one. The Neighbour solutions could be obtained by perturbing the current solution and the shift (0,1) process is applied in this research due to favourable reason that are explained previously. In addition, a procedure of the shift (0,1) at each iteration is explained as following.

1. Every retail store of every route is tried to insert after other retail stores on other routes and it could be seen in Figure 35. Furthermore, the Figure 35 could be described as that the first retail store of the first route is tired to insert after all of retail stores of other routes. Then, the second retail store of the first route does the same thing until the last retail store of the last route is tried to insert after retail stores of other routes. In addition, three constraints that are the total time constraint, the total capacity constraint, and the accessibility constraint are checked. If the shift (0,1) process of a retail store does not satisfy these constraints, the retail store does not allow to shift to that route.

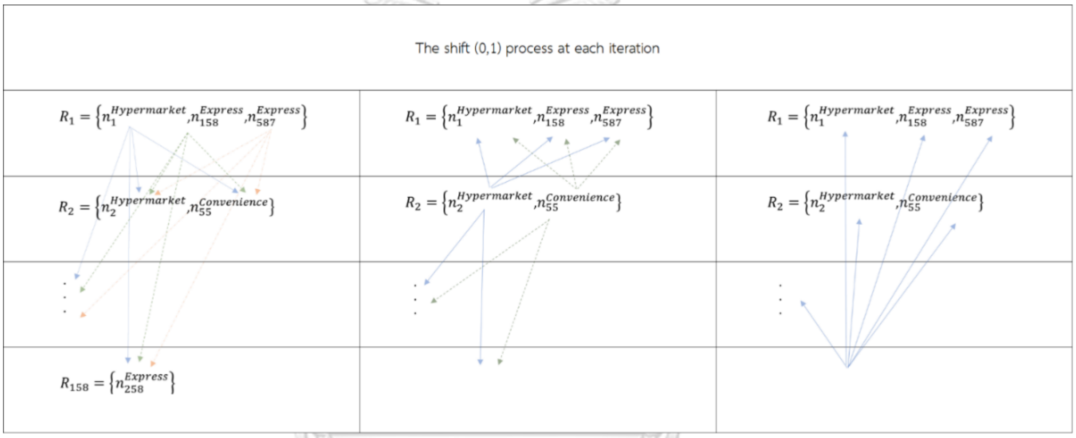


Figure 35: the shift (0,1) process

2. Every shift (0,1) process of each retail store, which satisfies all constraints after trying to insert after retail stores of other routes, is required to calculate an improving cost of the shift (0,1) process. The improving cost can be formularised by Equation 9. Moreover, values of the improving cost could be both positive and negative. The positive value means that the shift (0,1) process of a retail store at this location improves the total transportation cost, whereas the negative value means that the shift (0,1) process of a retail store at this location does not improve the total transportation cost. Furthermore, the way that the proposed algorithm records the improving cost of the shift (0,1) process at each iteration is to only record the best improving cost that is found from the

beginning of the shift (0,1) process until the finishing of all combinations of the shift (0,1) process. An example of the recording approach of the best improving cost at one iteration is illustrated as following.

For example, at the beginning of the iteration, the 1st retail store of the 1st route is shifted to a position after the 1st retail store of the 2nd route and this shift (0,1) satisfies all constraints of the problem. Then, the improving cost of this shift is calculated and it assumingly equals to 1000 THB, which is the currently best improving cost of this iteration. Next, the 1st retail store of the 1st route is shifted to a position after the 2nd retail store of the 2nd route, whereas this shift (0,1) does not satisfy the constraints. Hence, the improving cost of this shift (0,1) is not calculated and the best improving cost that is found so far is still 1000 THB. Next, the 1st retail store of the 1st route is shifted to a position after the 3rd retail store of the 2nd route and this shift satisfies the constraints. Then, the improving cost of this shift (0,1) is calculated and it assumingly equals to 1500 THB. Hence, the best improving cost that is found so far is updated to be 1500 THB. Next, the shift (0,1) process will be repeated until all combinations of shifting every retail store to every route are accomplished. After that the best improving cost at this iteration is obtained. In addition, two positions of the shift (0,1) process that provides the best improving cost at this iteration is also recorded as a shift (0,1) candidate for a further decision. These two positions are that firstly, the position of a retail store that will be moved from a current route, which can be call a giving route. Secondly, the position of the other route, which can be call a receiving route, that this retail store will be moved to.

$$
\begin{aligned}
&The\ improving\ cost\ of\ the\ shift\ (0,1)\ process \\
&= (the\ transportation\ cost\ of\ the\ giving\ route\ before\ the\ shift(0,1) process \\
&+ the\ transportation\ cost\ of\ the\ receving\ route\ before\ the\ shift(0,1) process) \\
&- (the\ transportation\ cost\ of\ the\ giving\ route\ after\ the\ shift(0,1) process \\
&+ the\ transportation\ cost\ of\ the\ receving\ route\ after\ the\ shift(0,1) process)
\end{aligned}
$$

Equation 9: The improving cost of the shift (0,1) process

Where; The giving route means that the route that gives the retail store to the receiving route during the shift (0,1) process.

The receiving route means that the route that receives the retail store from the giving route during the shift (0,1) process.

3.2Applying the acceptant criteria of the SA process

This step is applied for accepting a Neighbour solution that is the shift (0,1) candidate, which provides the best improving cost during the shift (0,1) process. At each iteration of the shift (0,1) process, the Neighbour solution will be accepted as the following fashion.

3.2.1 For the first scenario, if the Neighbour solution from the shift (0,1) procedure provides the positive value of the best improving cost, the shift (0,1) process will proceed. The customer of the giving route will be transferred to the location of the receiving route that is associate to the best improving cost of this iteration. Additionally, the positive improving cost means that the Neighbour solution is better than the current solution in terms of the total transportation cost.

3.2.2 For the second scenario, if the Neighbour solution from the shift (0,1) process provides the negative value of the best improving cost, the shift process may proceed with the probability $e^{-\Delta/T}$. This decision probability comes from the SA metaheuristic in order to avoid being trapped in the local optimal solution. Since, the SA metaheuristic allows a non-improving solution with the probability and this statement could be referred to the hill climbing process out of the local optimum. Furthermore, the negative improving cost means that at this iteration of the shift (0,1) process, there is no shifting move that provides the better solution than the current solution. Due to the probability of the acceptance of the Neighbour solution, it will lead to two situations that are either to accept the neighbourhood or not to accept the neighbourhood. In addition, processes that will occur after these two conditions are different and they will be explained as following.

3.2.2.1 For the case of the acceptance, the shift (0,1) process will proceed. The selected retail store from the giving route will shift to the receiving route in the location that provides the best improving cost. After that the next process will be the intra-route neighbourhood of the receiving route.

3.2.2.2 For the case of the unacceptance, the process of the shift (0,1) will stop. Then, the current solution, which may come from either the initial solution or the previous iteration of the shift (0,1) process, of this iteration will be obtained to execute in the post-processing procedure.

3.4Intra route for the receiving route

After obtaining a solution from the inter-route process, the reinsertion process is applied to a receiving route that receives a retail store from another route in order to rearrange a sequence of retail stores and to find the shortest path of the receiving route before repeating the next shift (0,1) process. Furthermore, the reinsertion process of (Penna, Subramanian et al. 2013) is adjusted to the problem of this research, then the reinsertion process is separated into two approaches that depends on the number of retail stores in a route. These two approaches of the reinsertion are described as following.

1.For the number of retail stores equals to one to nine

The reinsertion process will proceed through all combinations of each route and an example is represented in Example 8.

Example 8

1. Obtaining a receiving route R_2 of the solution S from the shift (0,1) process that contains the number of retail stores 3 retail stores. Since, the number of retail stores in the route is less than nine stores, all combinations of the reinsertion process are proceeded.

$$S = \{R_1, R_2, \dots, R_{100}\}$$
$$R_2 = \{n_{1,}^{Express} n_2^{Hypermarket}, n_3^{Express}\}$$

2. Applying the reinsertion process with all combinations to the selecting route. In addition, the number of all combinations of each route is equal to the factorial number of customers in a route and these routes must satisfy all constraints. Combinations of these route are represented in Table 14.

	The Reinsertion Process
The first combination (original route)	$R_2 = \{n_{1,}^{Express} n_2^{Hypermarket}, n_3^{Express}\}$
The second combination	$R_2'^1 = \{n_{1,}^{Express} n_3^{Express}, n_2^{Hypermarket}\}$
The third combination	$R_2'^2 = \{n_{2,}^{Hypermarket} n_1^{Express}, n_3^{Express}\}$
The fourth combination	$R_2'^3 = \{n_{2,}^{Hypermarket} n_3^{Express}, n_1^{Express}\}$
The fifth combination	$R_2'^4 = \{n_{3,}^{Express} n_1^{Express}, n_2^{Hypermarket}\}$
The sixth combination	$R_2'^5 = \{n_{3,}^{Express} n_2^{Hypermarket}, n_1^{Express}\}$

Table 14: The reinsertion process

3. The total transportation costs of every route are calculated and there are represent in Table 15.

	The Reinsertion Process	The Total Transportation Cost (THB)
The first combination (original route)	$R_2 = \{n_{1,}^{Express} n_2^{Hypermarket}, n_3^{Express}\}$	1,200
The second combination	$R_2'^1 = \{n_{1,}^{Express} n_3^{Express}, n_2^{Hypermarket}\}$	960
The third combination	$R_2'^2 = \{n_{2,}^{Hypermarket} n_1^{Express}, n_3^{Express}\}$	1,100
The fourth combination	$R_2'^3 = \{n_{2,}^{Hypermarket} n_3^{Express}, n_1^{Express}\}$	1,300
The fifth combination	$R_2'^4 = \{n_{3,}^{Express} n_1^{Express}, n_2^{Hypermarket}\}$	1,250
The sixth combination	$R_2'^5 = \{n_{3,}^{Express} n_2^{Hypermarket}, n_1^{Express}\}$	1,050

Table 15: The cost of the reinsertion process

4. Selecting the best route in terms of the total transportation cost. According to Table 15, a route $R_2'^1$ provides the cheapest cost, then an original route R_2 is replaced by $R_2'^1$ in the solution *S*.
5. Obtaining the neighbour solution S' of the solution S

$$S' = \{R_1, R_2'^1, \ldots R_{100}\}$$

2. For the number of retail stores is more than nine stores

The high number of retail stores will generate the large number of combinations of the reinsertion process, for example, the number of combinations of a route that contains 10 stores equals to 10! = 3,628,800 combinations. These numerous amount of combinations require a lot of time to compute, so that the appropriate number of generating alternative combinations of the route should be defined to shorten the computing time. In addition, the number of 1,000 combinations of the reinsertion that is generated randomly for each route can provide a good result with appropriate time for generating solution. Apart from that procedures of the reinsertion with more than nine retail stores per route are the same as the previous section excepting that the limited number of the combinations equals to 1,000 combinations for a selected route.

3.5.4 Post Processing

- The adapted multi-transfer process

After reviewing the VRP solution process of (Jiang, Ng et al. 2014), the researcher applies the post processing process in order to enhance results that are obtained from the researcher's proposed method. The author states that if small-sized fleet is capable to service a route of a large-sized fleet, then the large-sized fleet should be replaced by the small one. Since the small-sized fleet consumes cheaper cost than the large-size fleet in terms of the travelled cost and the service cost, thus the total transportation cost could reduce. The adapted multi-transfer process in this research is adapted from the multitransfer process from the literature of (Jiang, Ng et al. 2014). In this research, the transfer will only proceed in case that a small empty vehicle is able to service all customers from the other route that is served by a larger-sized fleet in terms of volume. Then, the whole route of the large-sized fleet will be transferred to the small-sized fleet, while a sequence of retail stores in the route remains unchanged. The adapted multi-transfer process is illustrated in Figure 36. Moreover, an example of the adapted multi-transfer process is illustrated in Example 9.

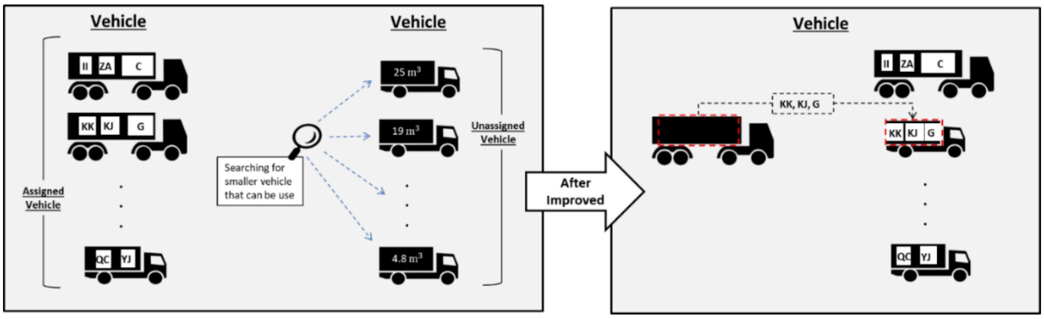


Figure 36: The adapted multi-transfer process

Example 9

1. After obtaining the solution from the shift (0,1) process, the availability of all types of empty vehicles excepting the largest-sized vehicle will be checked. Then, they will be sorted from the smallest-sized vehicle to the largest-sized vehicle in terms of volume and these are illustrated in Table 16.

Type of vehicles	The number of empty vehicles (units)	Capacity (m^3)
4-wheel	2	4.8
4-wheel jumbo	1	9
6-wheel	2	19
10-wheel	1	25
10-wheel jumbo	2	37
18-wheel small	3	41
18-wheel	9	44

Table 16: The total number of empty vehicles in each type

2. The smallest-sized empty vehicle will be selected as a candidate vehicle for the transfer. According to Table 16, the smallest-sized empty vehicle is a 4-wheel vehicle and its capacity is 4.8 m^3. Then, other routes that are delivered by larger-sized vehicles in terms of capacity will be analysed by using step 2.1

2.1. If at least one route is delivered the number of demands that is equal to or less than the capacity of the selected smallest-sized vehicle that is 4.8 m^3 in this example by a larger-sized vehicle, the step 2.2 will proceed. Otherwise, the next step will be step 3.

2.2. Selecting the larger-sized vehicle that will be transferred to the selected smallest-sized vehicle. Since one of these three following situations will occur during the adapted multi-transfer process. Therefore, three criteria in step 2.2.1, 2.2.2, and 2.2.3 are provided in order to guide the proper decision to select the large-sized vehicle that should be proceeded the transfer process. In addition, during the adapted multi-transferred process, a sequence of retail stores of a route that is selected to transfer remains unchanged.

2.2.1. If only one route is delivered demands that equal to or less than 4.8 cube by a larger-sized vehicle than a 4-wheel vehicle, all retail stores of the larger-sized vehicle will be transferred to the 4-wheel vehicle.

2.2.2. If more than one route are delivered demands that equal to or less than 4.8 cube by larger-sized vehicles and these vehicles are the same type. Then, a route of a larger-sized vehicle that contains more retail stores will be selected for transferring to the small-sized vehicle.

2.2.3. If more than one route are delivered demands that equal to or less than 4.8 cube by larger-sized vehicles and these vehicles are different types. Then, a route that is delivered by a larger-sized vehicle with the highest travelled distance cost per km will be selected for transferring to the small-sized vehicle.

2.3. Updating the number of empty vehicles of each type in Table 16 from step 1.

2.4. Repeating step 2.

3. The next smallest-sized vehicle in terms of volume will be selected as a candidate vehicle for the transfer. For example, in case that none of the larger-

sized vehicle is transported the number of requirements less than the maximum capacity of a 4-wheel truck, which is the available smallest-sized in this example. Then, a 4-wheel jumbo vehicle that is the next available smallest-sized vehicle is considered instead. On one hand, if at least one route is delivered amount of demands that equal to or less than 9 m^3 by a larger-sized vehicle than the 4-wheel jumbo vehicle. Then, the process of selecting the larger-sized vehicle that should be transferred to the 4-wheel jumbo vehicle is considered by step 2.2. After that procedures of the adapted multi-transfer of this route will proceed following through step 2.2 to step 2.4. On the other hand, if none of route is delivered amount of demands that equal to or less than 9 m^3 by a larger-sized vehicle than the 4-wheel jumbo vehicle. Then, the next smallest-sized vehicle will be considered instead, i.e. a 6-wheel vehicle has a capacity for 19 m^3. In addition, the next smallest-sized will be increased by a unit of a type of vehicles until at least one route that is served by a larger-sized vehicle can be transferred to a smaller-sized vehicle without violating constraints of the problem. After finding the properly small-sized vehicle, procedures of the adapted multi-transfer will proceed through step 2.2 to 2.4.

- The reinsertion process for all routes

After obtaining the solution $S = \{R_1, R_2, \dots, R_{100}\}$ from the adapted multi-transfer approach, the reinsertion process is applied to every route in the solution in order to find the best path in terms of total transportation cost for every route and the reinsertion process for every route is shown in Figure 37. In addition, procedures of the reinsertion in this step are the same as the reinsertion process for the receiving route during the shift (0,1) process that are explained in the previous section. Hence, the transportation plan is obtained after finishing the reinsertion process for every route.

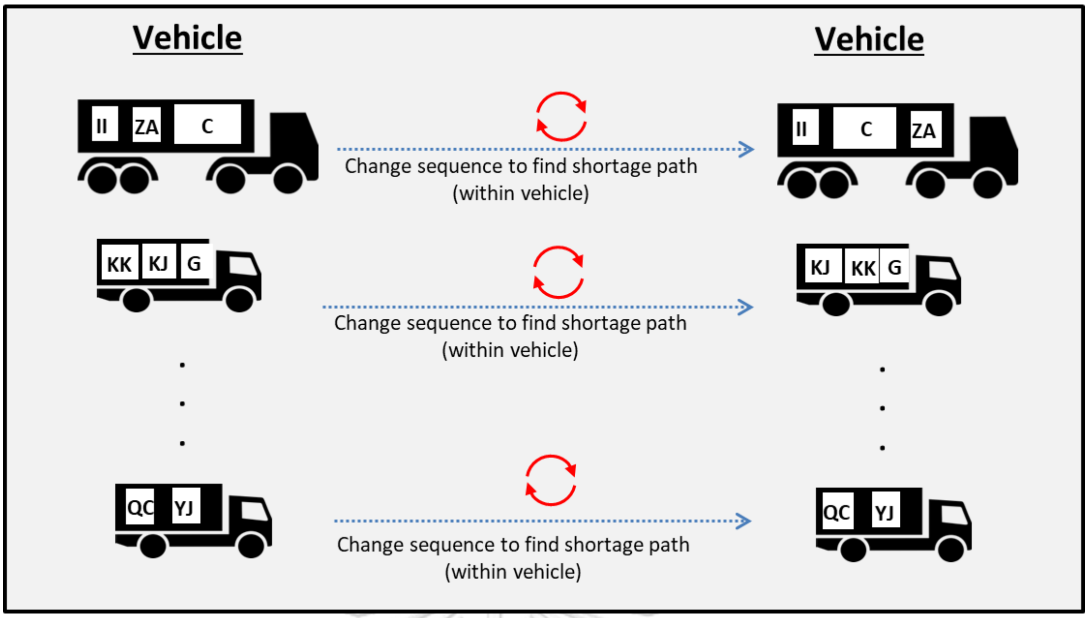


Figure 37: The reinsertion process

4. System measurement

The proposed method should be evaluated in order to perceive that the algorithm of the proposed method is efficient for producing the transportation plan and is applicable to the real situation. An objective of the system measurement is to ensure that the proposed method conforms to actual procedures of the company transportation scheme and the proposed method is able to enhance the current performance of the transportation plan of the company. Hence, the input data from the actual transportation for the consecutive seven-day operation that is illustrated in the chapter 3 is applied to the computational experiment in this chapter. To evaluate the performance of the proposed method, two major outcomes that are the total transportation cost and the capacity utilisation from three resources that are the proposed method, the comparative model and the 3PL operation are compared. A reason behind that these two outcomes are evaluated is that the cost is always a major concern to every firm since the purpose of founding the business is to earn profit. While, the capacity utilisation represents that how well the solution approach can be used to manage the resources of the firm because the requirement of one vehicle leads to other required resources, for example, fuel, drivers, maintenance operation. Therefore, if a vehicle is assigned to service customers, it should be maximally utilised. Furthermore, the comparative model that is used for comparing the performance of the route generating approaches in order to verify the proposed method comes from a suggestion of an expert of the transportation field. The expert is interviewed by questioning that which route generating approach from literatures that attends to solve the nearby scope of the problem can be applied with the real situation. After that the expert suggests that the nearest neighbour process of (Brandão 2009) is applicable to produce the transportation plan of the company, thus the constructive part of the proposed method of (Brandão 2009) is used as the comparative method. Furthermore, procedures of the comparative approach are illustrated in Figure 38.

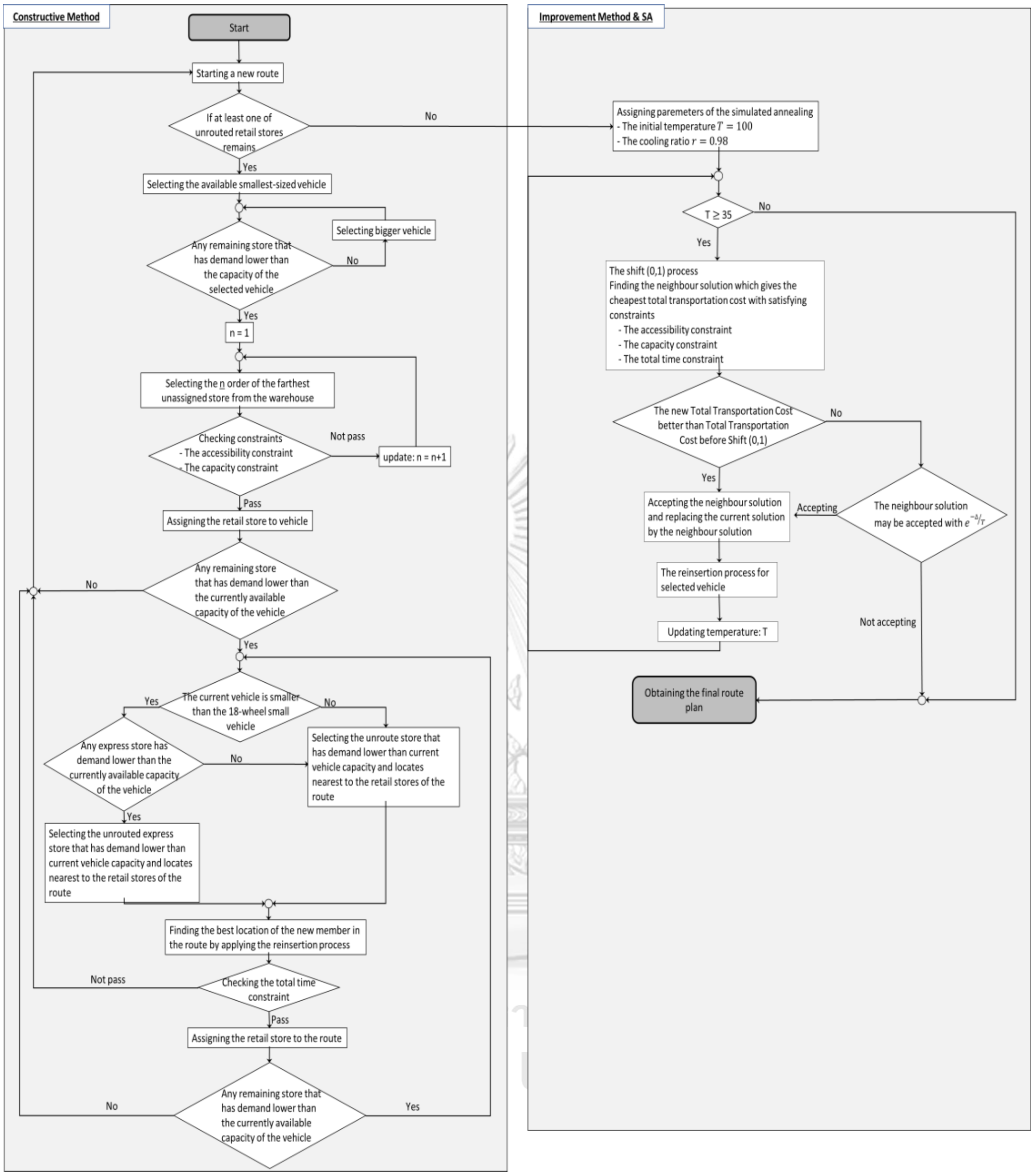


Figure 38: The comparative method procedure

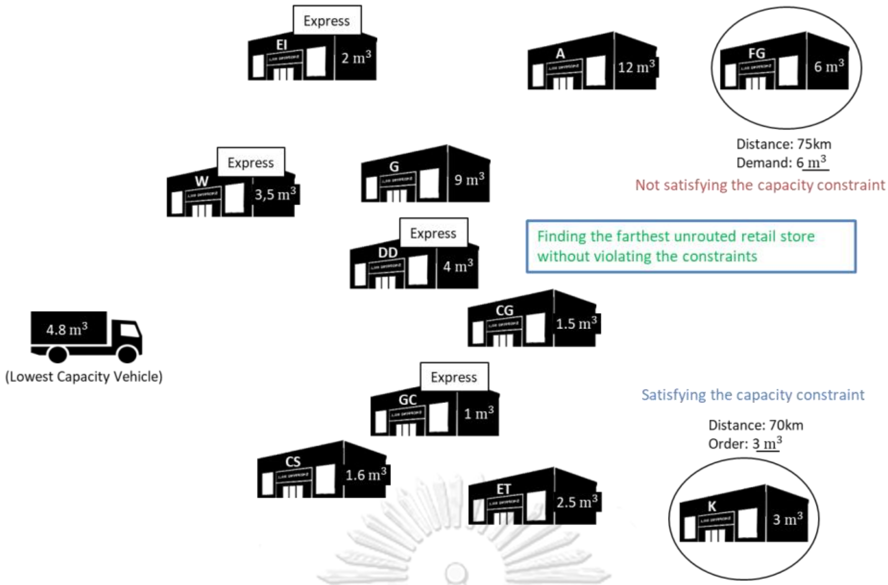


Figure 39: Finding the farthest retail store from the warehouse by using the smallest-sized vehicle

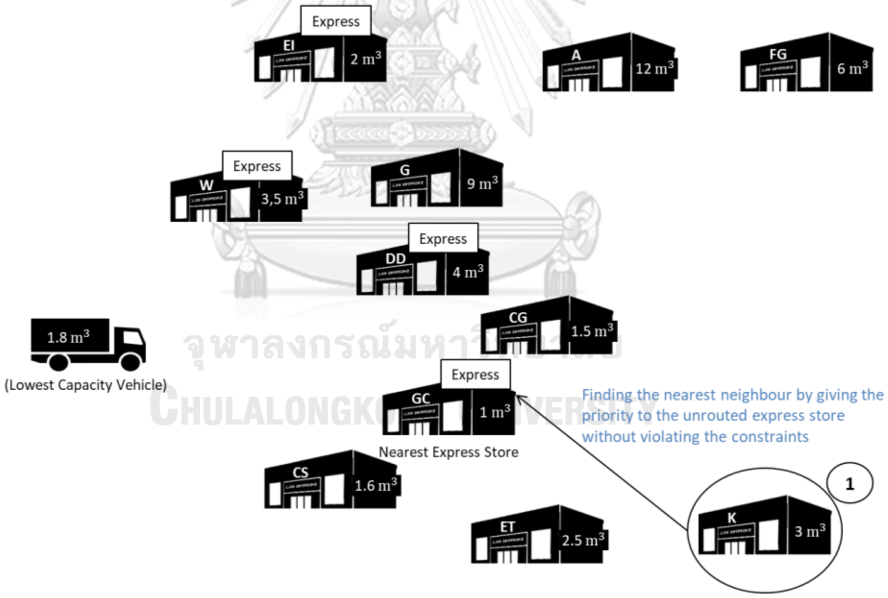


Figure 40: Finding the nearest neighbour by giving the priority to express retail stores

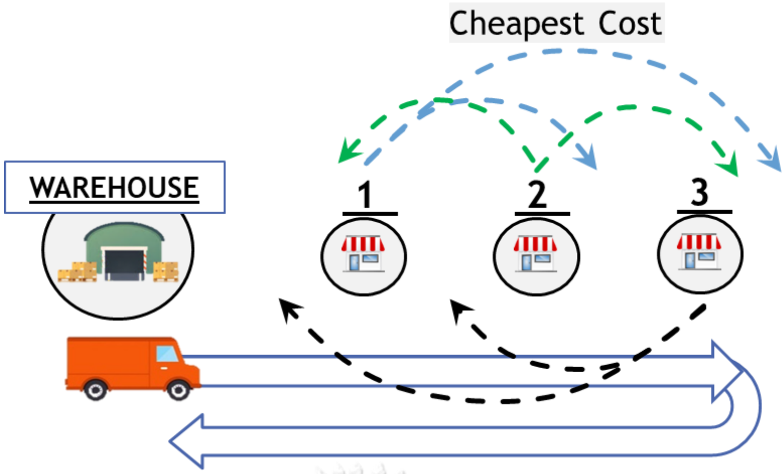


Figure 41: The reinsertion process for finding the cheapest cost within a route

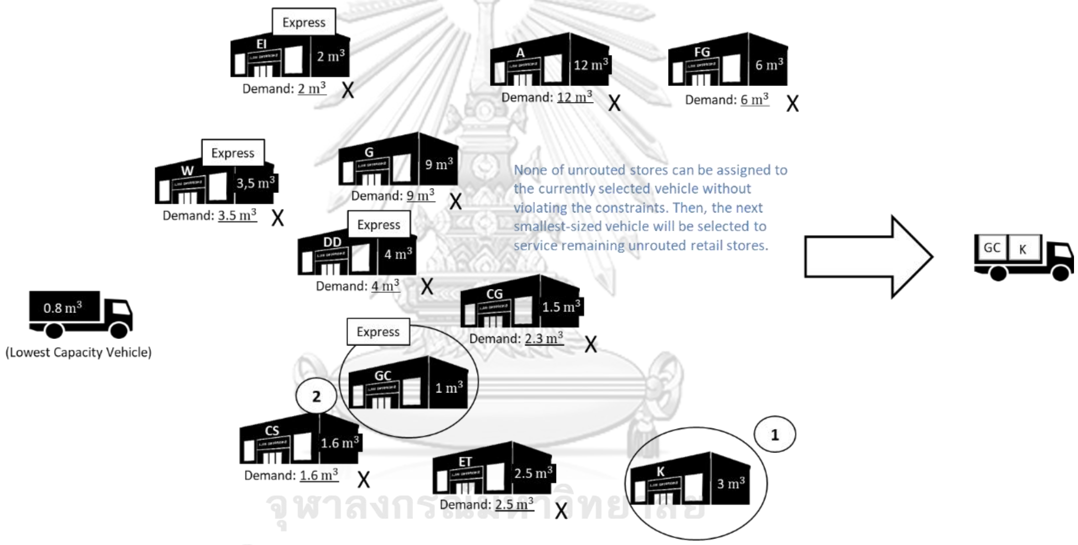


Figure 42: Finding the next nearest neighbour of the current route by giving the priority to express retail stores

The whole processes of the comparative method comprise of two phases that are a constructive stage, which is to generate a feasible initial solution of the problem, and an improving stage, which is to improve the initial solution of the problem. For the constructive phrase, it begins with starting a new route by selecting the available smallest-sized vehicle. Next, the first retail store of the route will be a retail store that locates farthest from the warehouse, while the capacity constraint and the accessibility constraint are satisfied (*Figure 39*). Then, the farthest retail store is assigned to the smallest-sized vehicle. After that a remaining capacity of the vehicle is checked. If the available capacity of the vehicle remains and at least one remaining unrouted retail store can be inserted in the vehicle without violating the capacity constraint and the accessibility constraint, distances between every retail store of the route and remaining unrouted retail store stores will be computed. Otherwise, the constructive phase will restart by starting a new route. After computing distances between every retail store of the route and remaining unrouted retail stores, a next unrouted retail store will be assigned to the route by considering the shortest distance between the unrouted retail store and the retail store of the route, while a system also gives a priority to express retail stores to be inserted in the route first (*Figure 40*). This means that if express retail stores remain unrouted and at least one of these express retail stores can be inserted in the route without violating the capacity constraint and the accessibility constraint, an unrouted express retail store that locates nearest to the retail store of the route will be selected as the nearest unrouted retail store. In addition, a reason behind is to avoid a situation at the end of the constructive phase that express retail stores remain unrouted and none of vehicles that can access to express retail stores is available for servicing. Otherwise, one of other types of remaining unrouted retail stores that locates nearest to the retail store of the route and can be inserted in the route without violating any constraints will be selected as the nearest unrouted retail store. Consequently, the nearest unrouted retail store is obtained. Next, the best location for inserting the nearest unrouted retail store in the route is examined by proceeding the reinsertion process (*Figure 41*). After obtaining the best location of the insertion, the total time constraint is checked. If the total time constraint is satisfied, the nearest unrouted retail store will be assigned to the route at the location accordingly to the best location. Otherwise, the next nearest unrouted retail store will be considered instead. Next, a set of remaining unrouted retail stores is check. If unrouted retail stores remain, the remaining capacity of the currently selected vehicle will be checked. In case that the remaining capacity of the currently selected vehicle is greater than at least one of capacity of unrouted retail stores, the next nearest unrouted retail store will be assigned to the vehicle by giving the priority to express retail stores. Otherwise, the constructive phase of the comparative method that are previously described will be repeated (*Figure 42*). After obtaining the initial solution, the improving phase will start.

For the improving stage, the shift (0,1) process is selected to be used as the intra-route Neighbour solution in order to improve the initial solution. All processes of the shift (0,1) operation that are illustrate in Figure 38 are proceeded in the same way as the shift (0,1) operation of the proposed method that are described in chapter 3.

In this research, both proposed method and comparative method are utilised for producing the transportation plan after knowing the number of orders that are required to deliver in each day. Moreover, inputs that are applied to algorithms during the computational experiment are actual information from the company for the seven-day operation and these inputs comprise of the limited number of vehicles in each type, the maximum capacity of each type of vehicles, sets of requirements of retail stores in each day, locations of retail stores, the limited total time of a trip.

To generate the transportation plan in this research, the proposed algorithm and the comparative algorithm are written in MATLAB code. Hence, these algorithms are executed on HP ENVY Notebook - 13-d029tu, Intel Core i7 with 2.5 GHz and 8 Gb memory. The purpose of this chapter is to measure the performance of the proposed algorithm by performing the computational experiment. Therefore, results that are obtained from the proposed method, the comparative method, and the company operation are analysed by resolving them into three elements that are the total transportation cost, the percentage of cost reduction and the percentage of capacity utilisation.

Restrictions and assumptions of the computational experiment are listed as following.

1. The computational experiment is organised in order to test the performance of route planning systems. The evaluation proceeds by comparing the proposed method, the comparative method and the actual transportation plan of the company.
2. Unforeseen situations and uncontrollable factors during the transportation are not considered during the computational experiment, for example, traffic, accident, disaster.
3. The total number of considered retail store during the computational experiment is equal to 947 stores and they locate in 51 provinces of Thailand and locations of retail stores and the number or orders that are required the fulfillment for the seven-day operation is illustrated in Table 9.
4. The total number of vehicles in the system during the computational experiment in each day is constantly equal to 158 units and they are classified into eight types. The number of vehicles in each type is represented in Table 3.
5. Each type of vehicles contains different cost in terms of travelled distance cost and services cost.
6. Due to the total time constraint that is equal to 36 hours, there are vehicles that will not return to the warehouse within one day, while in this research assumes that the daily available number of vehicles is constant with 158 units that is illustrated in *Table 3*.
7. A set of order of each retail store that is assigned from the client company is considered in a volume unit (m^3).
8. The capacity constraint is considered in terms of volume of each vehicle.
9. Distances that are used in the experiment is the displacement between locations, while locations are real coordinates that are latitudes and longitudes of every retail store on the geographic map. Furthermore, a route planner of the company introduces two multipliers that are a converted factor and a proportionate distance factor to multiply the displacement. The converted

factor is used for converting the change of 1° in latitude and longitude to the change of kilometer in surface distance and a value of the converted factor is 111. After that the planner takes a sample of displacements between locations in a kilometer unit to compare with real distances between the same locations, then a result finds the different proportion between the displacement and the real distance. This proportion is used as the proportionate distance factor and it equals to 1.269. In summary, the distance that is used in the experiment can be calculated by Equation 4.

$$Distance = Displacement \times The\ converted\ factor \times the\ proportionate\ distance\ factor$$

Equation 4: the calculation of distances in the computational experiment

Where; $Displacement = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$

x_1: the latitude of the location 1

x_2: the latitude of the location 2

y_1: the longitude of the location 1

y_2: the longitude of the location 2

10. A set of total requirements of each retail store (m^3) that is specified by the client cannot be split.
11. A set of total requirements of each retail store (m^3) that is specified by the client is not greater than the capacity of the biggest vehicle in the system.
12. A retail store can require more than one set of total requirements per day, if the total number of requirements is greater than the maximum capacity of the largest available vehicle.
13. A set of total requirements of each express retail store cannot be greater than the maximum capacity of the accessible largest-sized vehicle.
14. All product requirements of every retail store can be delivered in the same route without any restrictions.
15. Every vehicle begins and terminated at the warehouse.
16. There is only one warehouse in the system.
17. The capacity constraint of each type of vehicles is represented in Table 3.

18. The total working time constraint for one driver per trip is limited to 10 hours, whereas the total working time constraint for two drivers per trip is limited to 36 hours.
19. The number of required drivers in each trip depends on the total time to service the trip.
20. The number of drivers in the route planning system is unlimited.
21. The unloading time at each retail store is 60 minutes.
22. The vehicle speed is limited to 60 km/hour that is restricted by a regulation of material transportation of Thailand.
23. Vehicles are assumed to drive with the constant speed at 60 km/hour.
24. Travelled time is related to travelled distanced by a linear relationship.
25. The accessibility constraint of express retail stores is applied. This means that only five types of vehicles, which are four-wheel trucks, four-wheel trucks jumbo, six-wheel trucks, ten-wheel trucks, and ten-wheel trucks jumbo, are accessible to service express retail stores. While, other types of retail stores can be serviced by all types of vehicles.

4.1 Experiment result

4.1.1 Transportation cost

The transportation cost in this research comprises of travelled distance cost and service cost. On one hand, the travelled distance cost is a variable cost that is computed based on a type of a selected vehicle and travelled distances in a trip. On the other hand, the service cost comprises of two subcategories that are, firstly, the semi-fixed cost that considers the farthest retail store, a type of selected vehicle, and the number of drivers in a trip. Secondly, the variable cost considers the number of retail stores, which excepts the farthest retail store, and the number of required drivers in a trip.

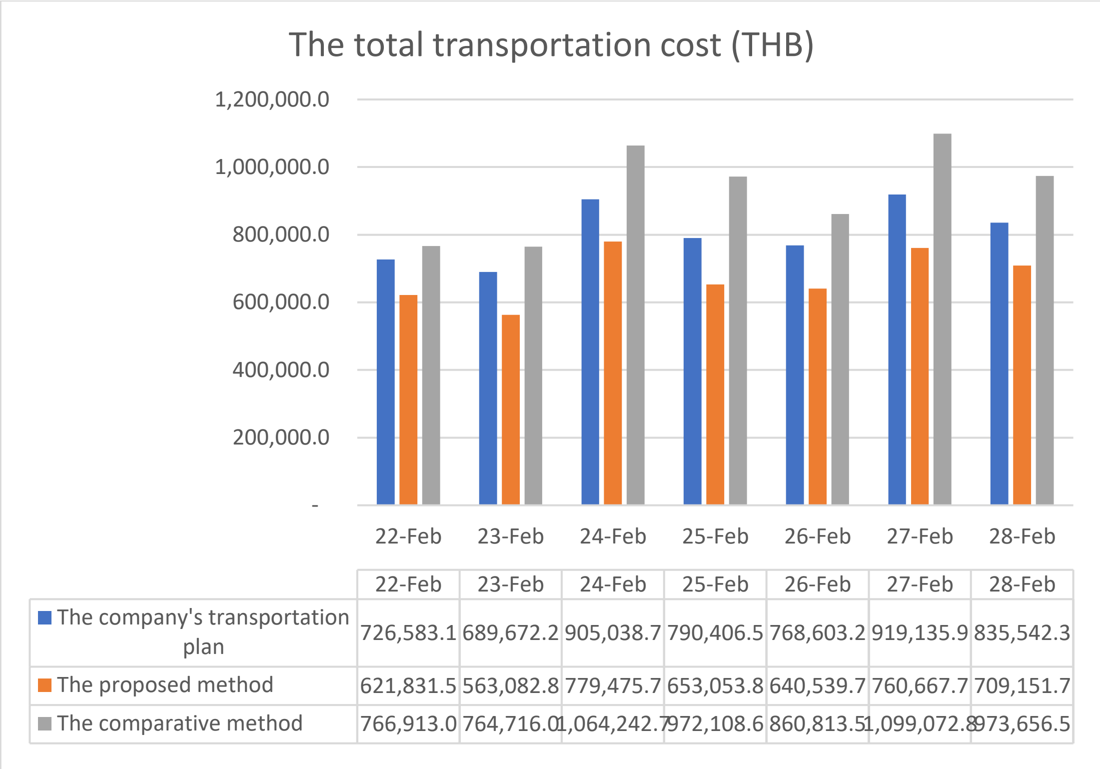


Figure 43: the total transportation cost

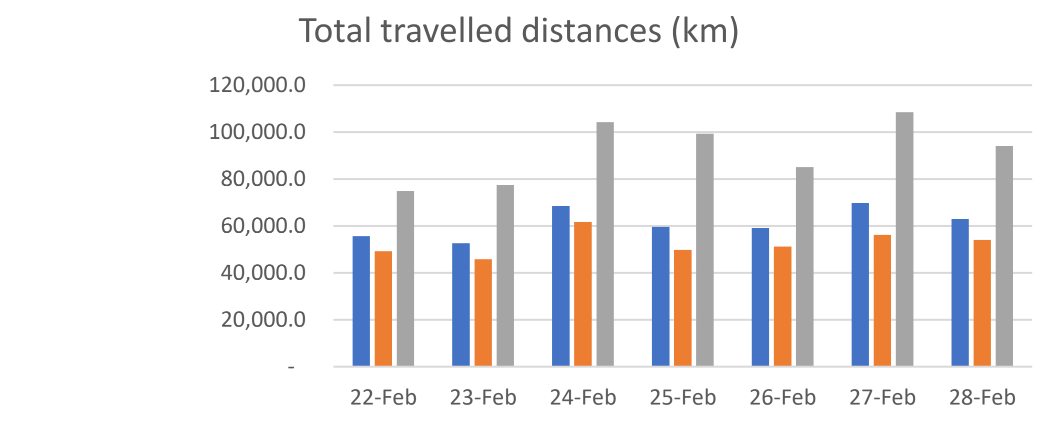
Delivery date	The company's transportation plan	The proposed method	The comparetive method
22-Feb	726,583.1	621,831.5	766,913.0
23-Feb	689,672.2	563,082.8	764,716.0
24-Feb	905,038.7	779,475.7	1,064,242.7
25-Feb	790,406.5	653,053.8	972,108.6
26-Feb	768,603.2	640,539.7	860,813.5
27-Feb	919,135.9	760,667.7	1,099,072.8
28-Feb	835,542.3	709,151.7	973,656.5
Total transportation cost (THB)	5,634,981.9	4,727,802.9	6,501,523.0

Table 17: The calculation of the total transportation cost

According to Figure 43,the total transportation costs of the seven-day operation from three route generating schemes that are the company's transportation plan, the proposed method and the comparative method are illustrated. The graph represents that the transportation costs for the seven-day operation among three approaches are fluctuated. The reason behind is that the number of order replacements and the number of retail stores vary in each day and these lead to the different requirements in the transportation plan, which are the number of vehicles, the number of drivers and travelled distances. Aside from that, the algorithm of each route generating scheme is different, so that each approach allocates retail stores into route by each distinctive way. Then, this makes dissimilar total transportation costs that are obtained from three different approaches. The performance of these algorithm in terms of cost can be concluded as following. The trend of the graph is repeated every day that is the cost of the proposed method is the lowest and it is followed by the company's transportation plan, whereas the comparative method provides the highest transportation cost. Moreover, the total transportation costs of the seven-day operation from the proposed model, the company plan, and the comparative model are calculated, which are illustrated in Table 17, and they are equal to 4,727,802.9 THB, 5,634,981.9 THB, 6,501,523.0 THB, respectively. According to the total transportation cost for the seven-day operation, the transportation cost from the proposed method is less than the cost from the company's transportation plan, with 907,179.0 THB and it is calculated into the decreasing total transportation cost percentage, with 16.1%. Whereas, the total transportation cost from the comparative method is greater than the company's transportation plan with 866,541.1 THB, which can be calculated into the increasing percentage with 15.38%. In conclusion, the decrease of the transportation cost of the proposed method represents the success of the proposed method that can be applied with the actual situation and can effectively improve the transportation plan in terms of cost, which is the majorly concerned issue of the company.

4.1.2 Travelled distance

Travelled distances of every route that are assigned in the transportation plan should be measured in order to perceive the performance of the route planning system, since the travelled distances directly impact to the total transportation cost. The travelled distances of routes can be used for illustrating the performance of the route planning system in terms of that how well the system allocates retail stores into routes and how well the system rearranges a sequence of retail stores in each route. Furthermore, in case the total travelled distances in a trip is minimised. Not only the total travelled distance cost will cheap but also the total service cost will reduce. Since, the short travelled distances mean that retail stores are properly assigned into vehicles and they are sequenced effectively. Consequently, two components of the total service cost of each route, which are the service cost of the farthest retail store and the service cost of other retail stores, are enhanced. For the service cost of the farthest retail store, the service cost of the farthest retail store in each route should be selected in the cheapest way. For the service cost of other retail stores, the total travelled time of each route will be minimised due to the shortest travelled distances, then the total number of drivers of each route, which is the multiplier number in the service cost formula, might decrease.



	22-Feb	23-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb
The company's transportation plan	55,544.2	52,573.2	68,505.6	59,713.0	59,153.6	69,716.0	62,893.5
The proposed method	49,199.6	45,719.3	61,688.5	49,810.3	51,146.2	56,281.8	54,070.8
The comparative method	74,891.7	77,547.5	104,274.4	99,302.7	85,019.2	108,464.3	94,066.4

Figure 44: The total travelled distances

Delivery date	The company's transportation plan	The proposed method	The comparetive method
22-Feb	55,544.2	49,199.6	74,891.7
23-Feb	52,573.2	45,719.3	77,547.5
24-Feb	68,505.6	61,688.5	104,274.4
25-Feb	59,713.0	49,810.3	99,302.7
26-Feb	59,153.6	51,146.2	85,019.2
27-Feb	69,716.0	56,281.8	108,464.3
28-Feb	62,893.5	54,070.8	94,066.4
Total travelled distances (km)	428,099.0	367,916.5	643,566.1

Table 18: The calculation of the total travelled distances

According to Figure 44, the graph represents the daily total travelled distances that are obtained from three different transportation plans and these three transportation plans are generated by the actual plan of the company, the proposed method, and the comparative method. During the seven-day operation, the daily total travelled distances that are obtained from the comparative method are significant greater than other two methods. While the daily total travelled distances that are generated by the company's transportation plan are steadily higher than that of the proposed method. Moreover, to compare the performance among the three methods in terms of the total travelled distances, the total travelled distances during the seven-day operation from these methods are calculated and they are represented in Table 18. The total travelled distances of the company's transportation plan equal to 428,099 km and the total travelled distances of the proposed equal to 367,916.5 km, while the total travelled distance of the comparative method equal to 643,566.1 km.

In summary, the total travelled distances from the proposed method compared with the transportation plan of the company are reduced by 60,182.5 km or 14.06%. On the other hand, the total travelled distances from the comparative compared with the company's plan method are increased by 215,467.1 km (50.33%). Hence, this statement can be concluded as that the proposed method can manage to allocate retail stores into routes and to arrange all routes in each day effectively. Then, this good management leads to the lower transportation cost than the other two methods.

4.1.3 Capacity utilisation

The capacity utilisation is another important factor in this research. According to the actual transportation plan of the company, the capacity utilisation is average 72 percent of a capacity of a vehicle in each trip, so that there is still room for improvement. Since, the ineffective management of the capacity utilisation leads to the wasted requirement of resources, for example, vehicles, drivers, fuel, thus this affects the high transportation cost. If a vehicle that is selected to deliver packages in a trip is properly utilised, the total transportation cost in each day should be enhanced.

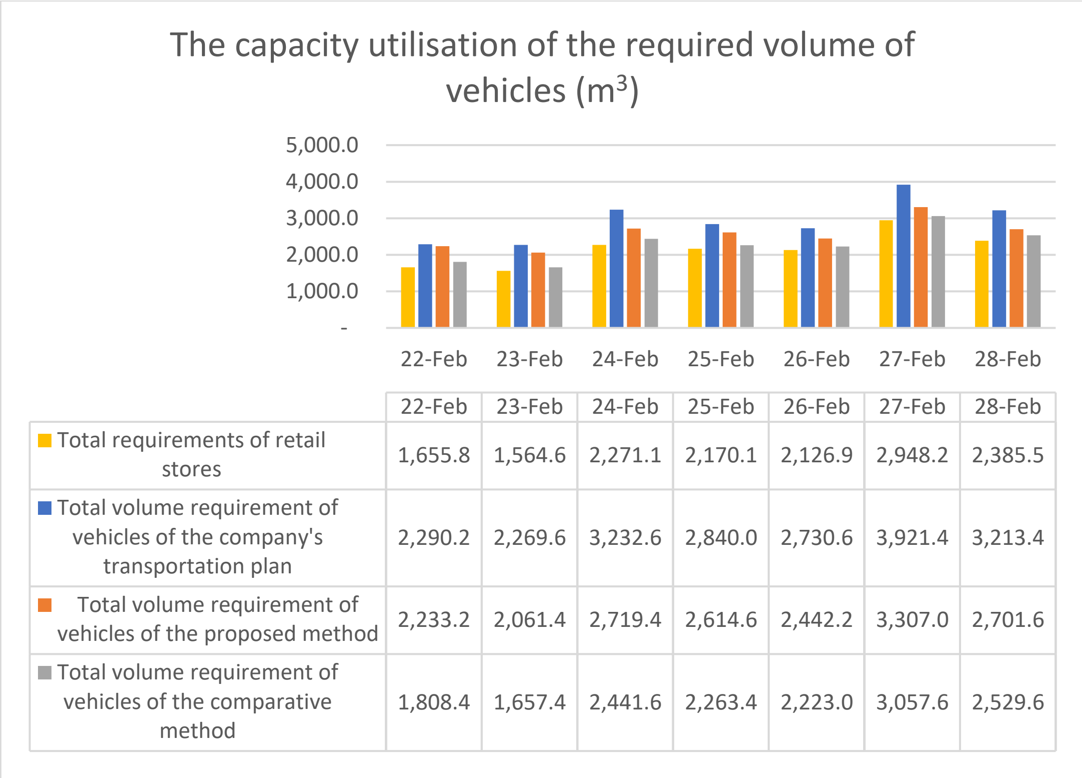


Figure 45: The capacity utilisation of the required volume of vehicles

Delivery date	Total requirements of retail stores	Total volume requirement of vehicles of the company's transportation plan	Total volume requirement of vehicles of the proposed method	Total volume requirement of vehicles of the comparative method
22-Feb	1,655.8	2,290.2	2,233.2	1,808.4
23-Feb	1,564.6	2,269.6	2,061.4	1,657.4
24-Feb	2,271.1	3,232.6	2,719.4	2,441.6
25-Feb	2,170.1	2,840.0	2,614.6	2,263.4
26-Feb	2,126.9	2,730.6	2,442.2	2,223.0
27-Feb	2,948.2	3,921.4	3,307.0	3,057.6
28-Feb	2,385.5	3,213.4	2,701.6	2,529.6
Total required volume (m^3)	15,122.2	20,497.8	18,079.4	15,981.0

Table 19: The calculation of the total requirements of retail stores and the total required volume of vehicles

Sources of the transportation plan	Total requirements of retail stores (m^3)	The total volume requirement of vehicles (m^3)	Extra required volume of vehicles (m^3)	Extra required volume of vehicles (%)
The company's transportation plan	15,122.2	20,497.8	5,375.56	35.5%
The proposed method	15,122.2	18,079.4	2,957.16	19.6%
The comparative method	15,122.2	15,981.0	858.76	5.7%

Table 20: The calculation of the extra required volume of vehicles

At the beginning the capacity utilisation is measured by comparing the total requirements from every retail stores in terms of volume with the total number of vehicles that are required for serving these retails stores in terms of volume in each day and this can be called the capacity utilisation in terms of total required volume of vehicles. Hence, the extra requirement of vehicles in terms of volume in each day should be analysed in order to perceive an effect of a capacity utilisation management on an operation of a transportation. According to Figure 45, the daily total requirements of retail stores are compared with the total number of required vehicles in terms of volume from three different route planning systems. The graph shows that the comparative model requires the least total volume of vehicles and this is followed by the proposed model, whereas the company's transportation plan requests the largest volume of vehicles. In addition, the total requirements of retail stores and the total number of required vehicles in terms of volume for the seven-day operation are calculated that are shown in Table 19, while the extra required volume of vehicles compared with the total requirements of retail stores from all three methods are represented in Table 20.

$$\textit{Capacity utilisation of each vehicle} = \frac{\textit{The total number of requirements in a trip } (m^3)}{\textit{The maximum capacity of a selected vehicle in a trip } (m^3)}$$

Equation 10: The capacity utilisation of each vehicle

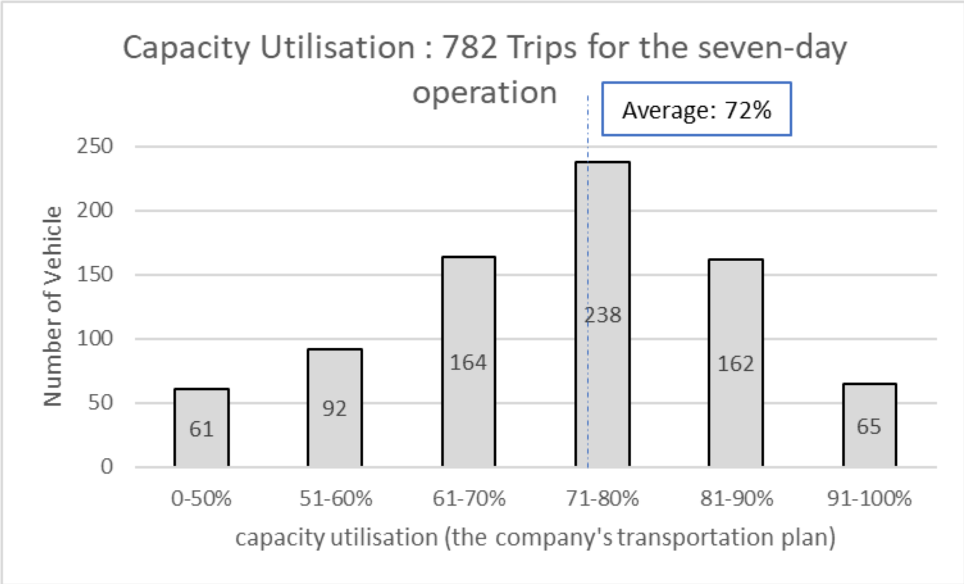


Figure 46: the capacity utilisation of each vehicle of the company's transportation plan

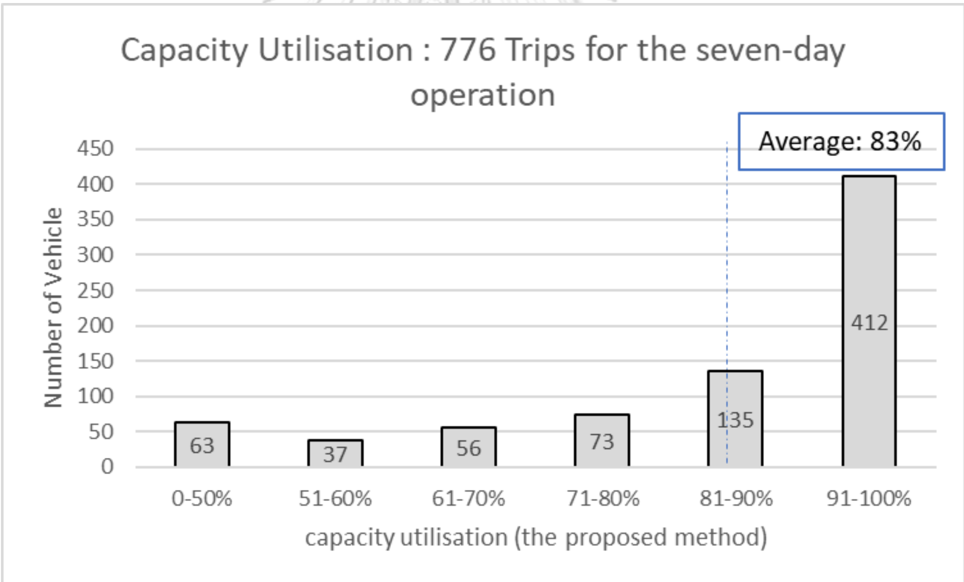


Figure 47: the capacity utilisation of each vehicle of the proposed method

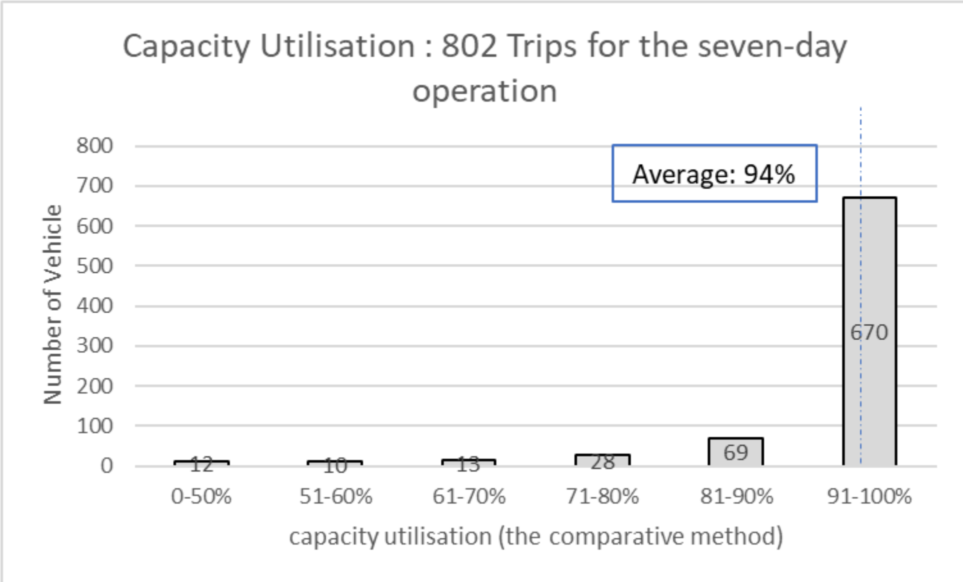


Figure 48: the capacity utilisation of each vehicle of the comparative method

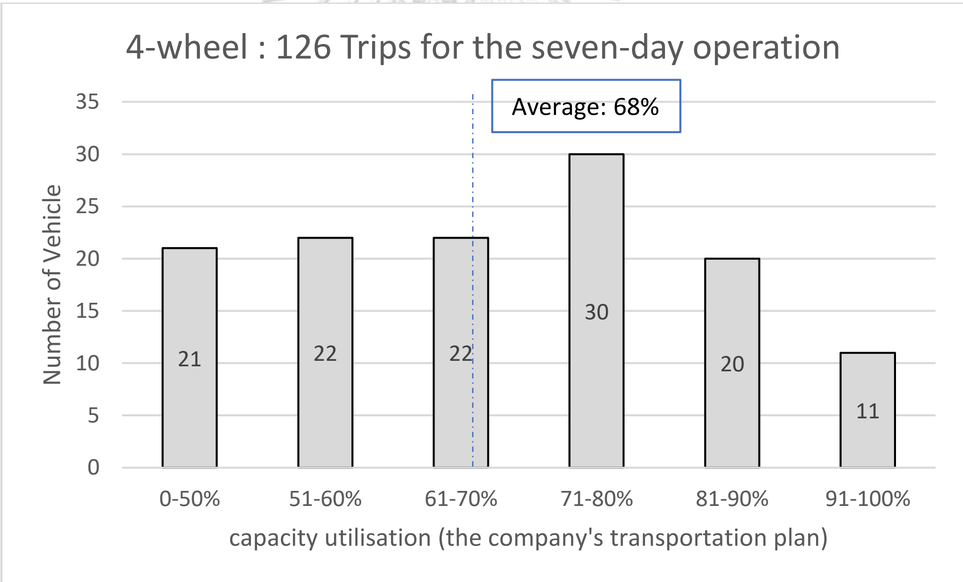


Figure 49: the capacity utilisation of four-wheel vehicles from the company's transportation plan

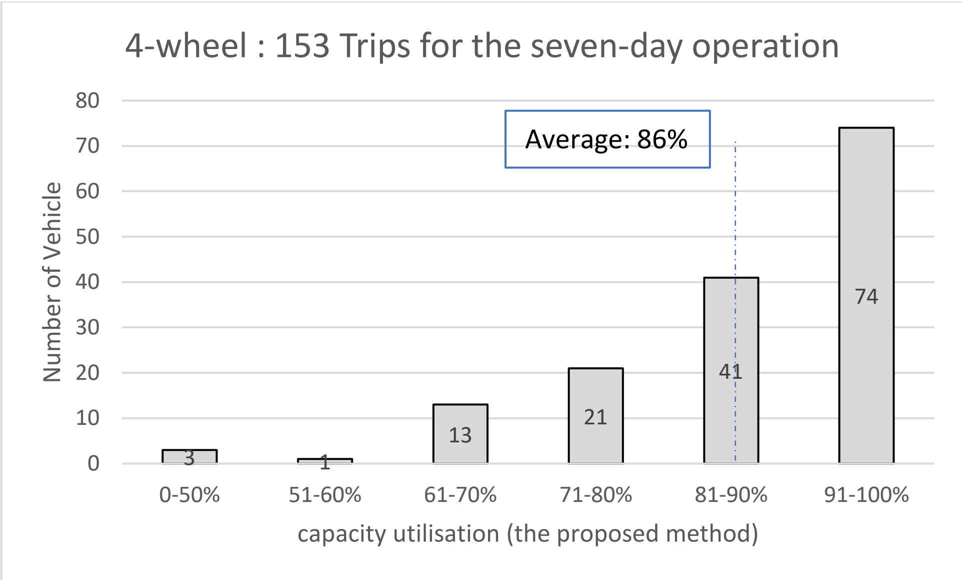


Figure 50: the capacity utilisation of four-wheel vehicles from the proposed method

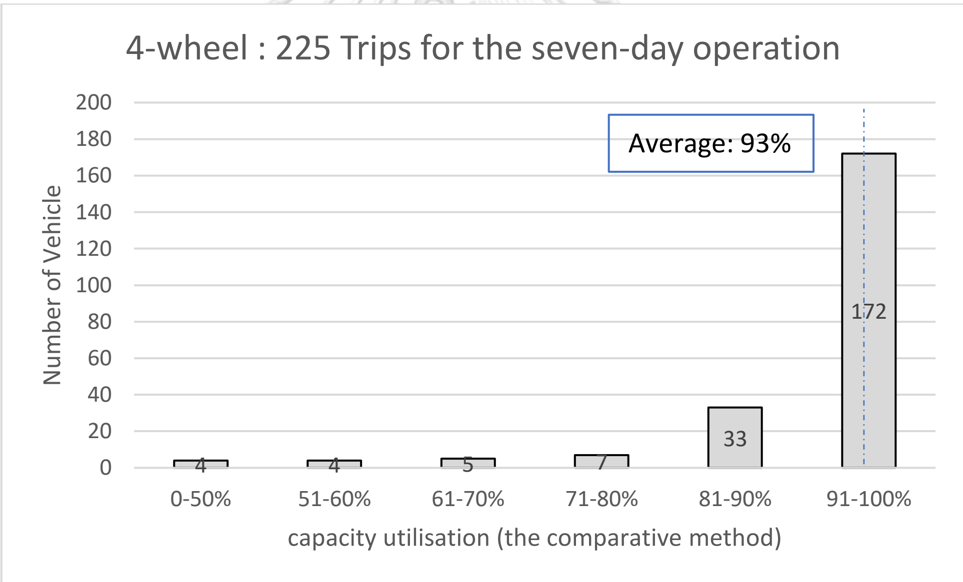


Figure 51: the capacity utilisation of four-wheel vehicles from the comparative method

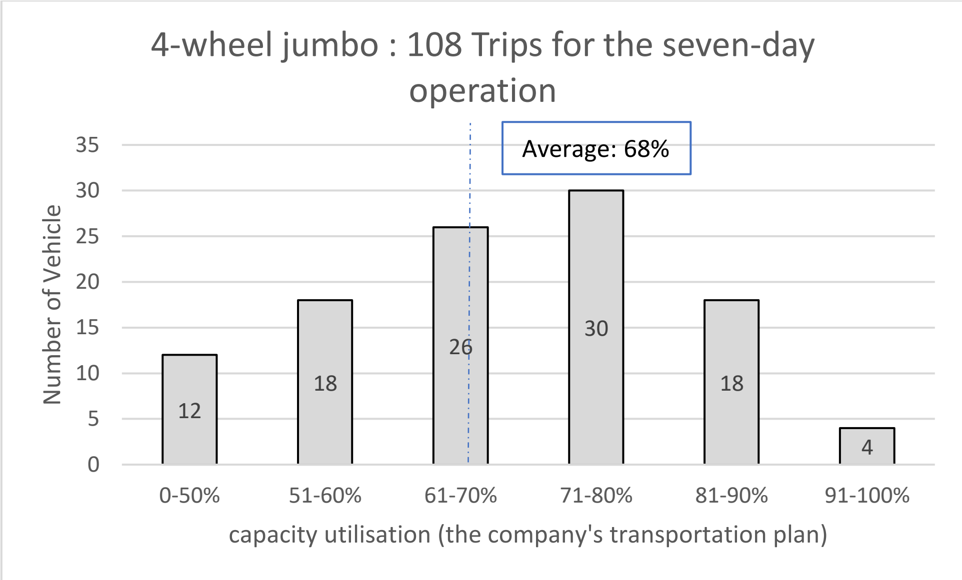


Figure 52: the capacity utilisation of four-wheel jumbo vehicles from the company's transportation plan

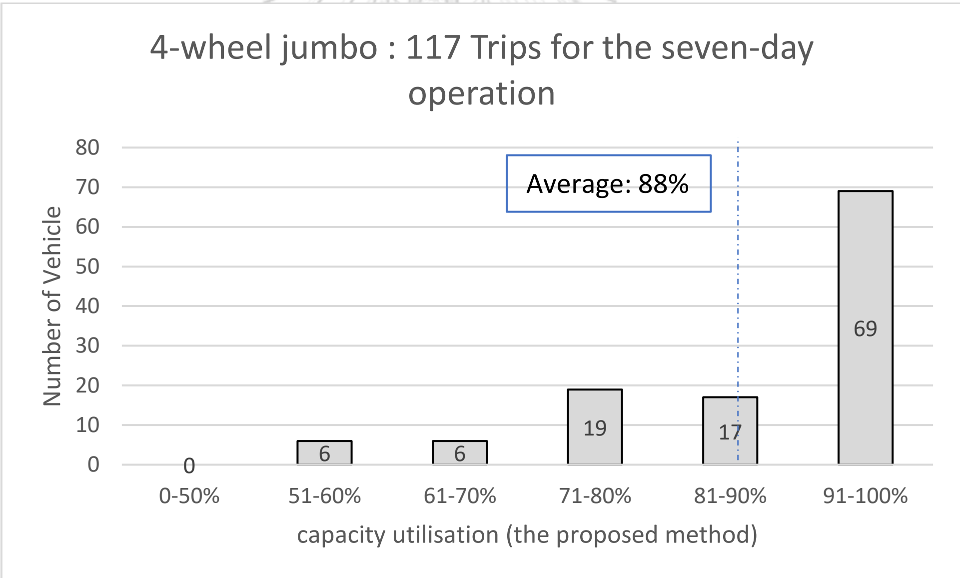


Figure 53: the capacity utilisation of four-wheel jumbo vehicles from the proposed method

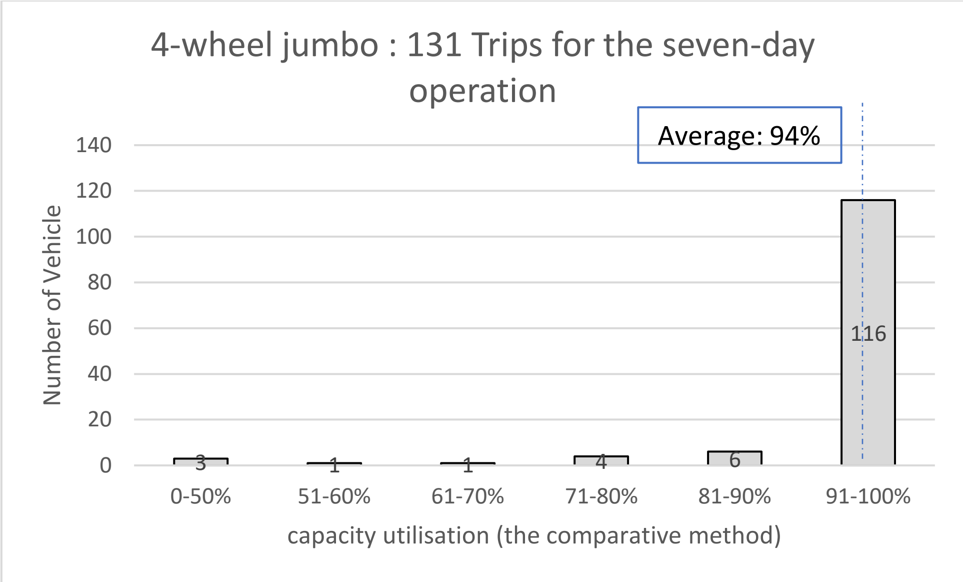


Figure 54: the capacity utilisation of four-wheel jumbo vehicles from the comparative method

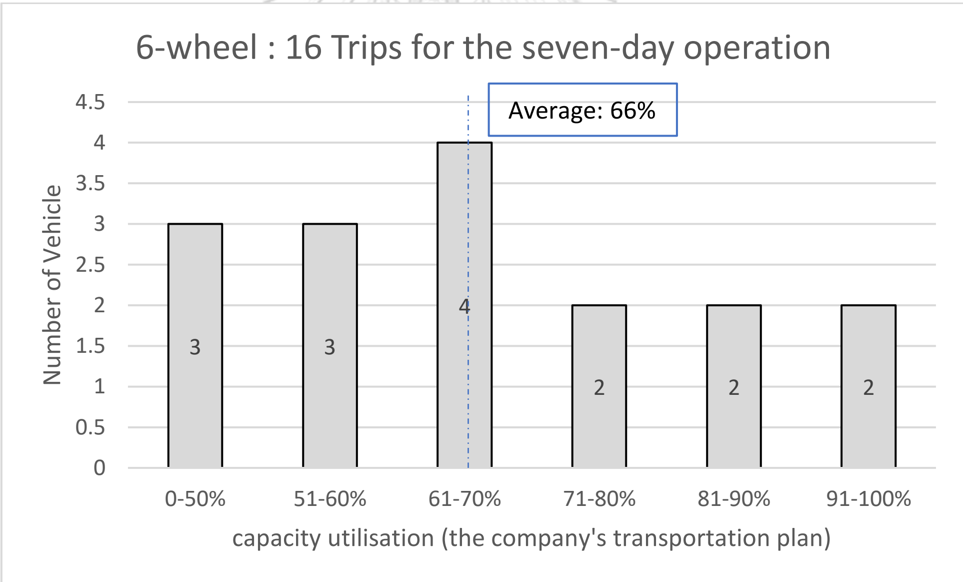


Figure 55: the capacity utilisation of six-wheel vehicles from the company's transportation plan

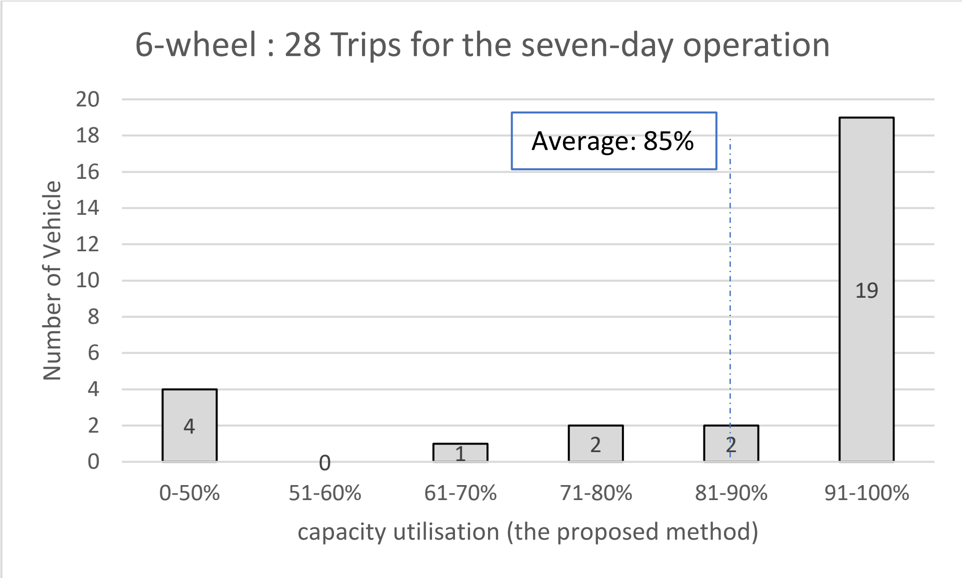


Figure 56: the capacity utilisation of six-wheel vehicles from the proposed method

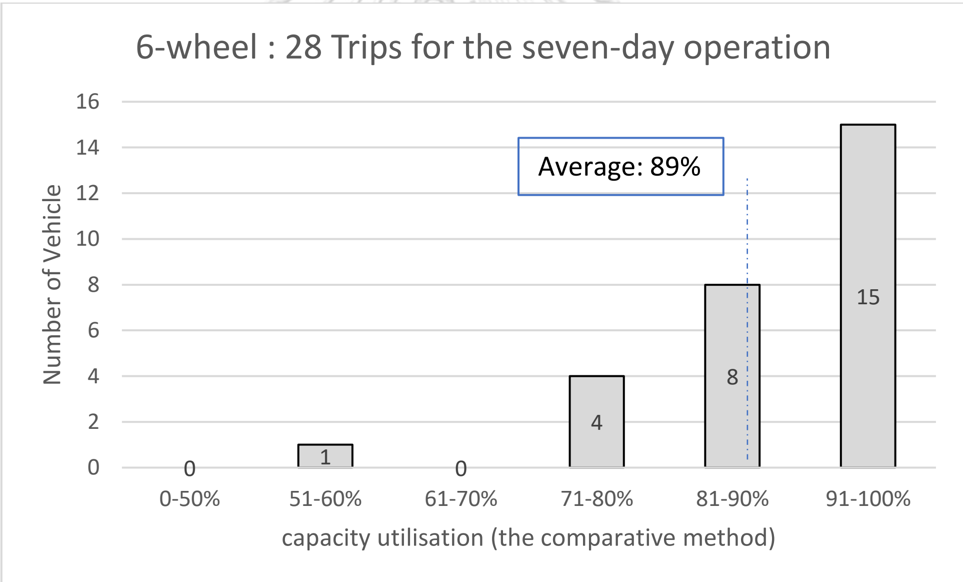


Figure 57: the capacity utilisation of six-wheel vehicles from the comparative method

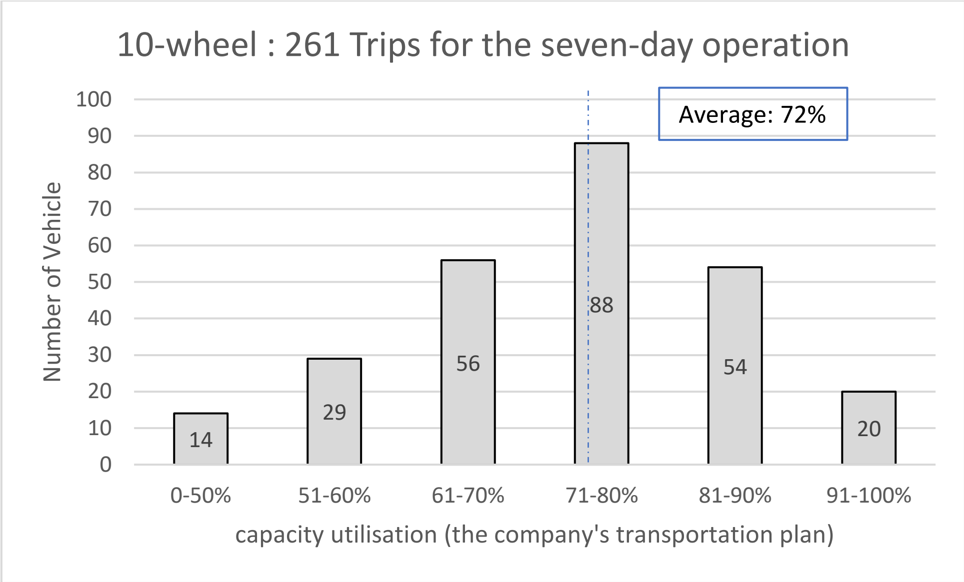


Figure 58: the capacity utilisation of ten-wheel vehicles from the company's transportation plan

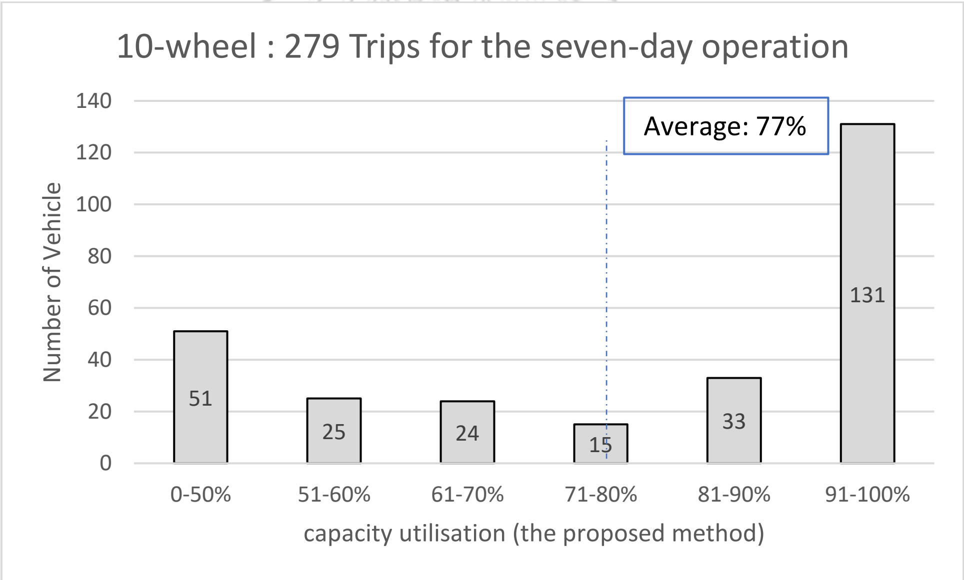


Figure 59: the capacity utilisation of ten-wheel vehicles from the proposed method

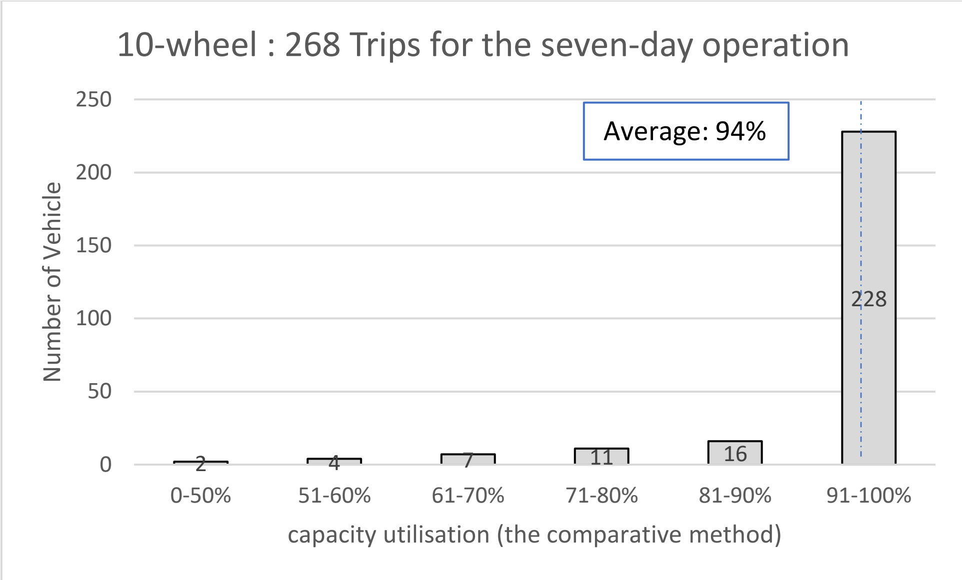


Figure 60: the capacity utilisation of ten-wheel vehicles from the comparative method

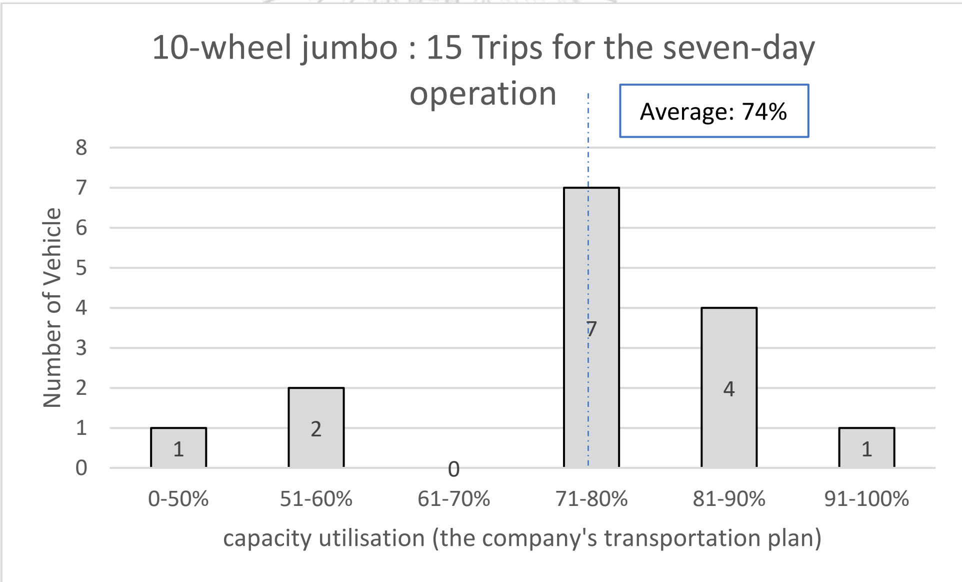


Figure 61: the capacity utilisation of ten-wheel jumbo vehicles from the company's transportation plan

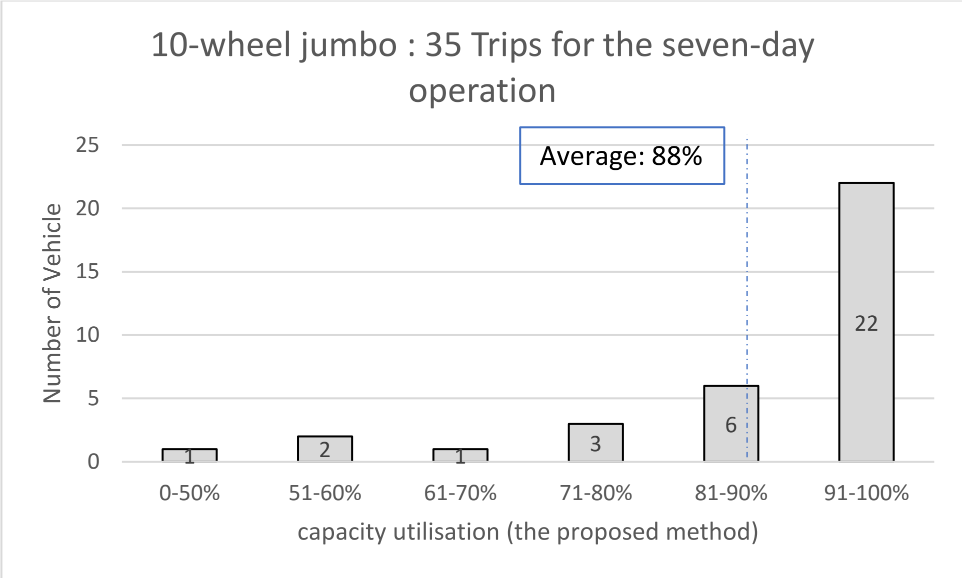


Figure 62: the capacity utilisation of ten-wheel jumbo vehicles from the proposed method

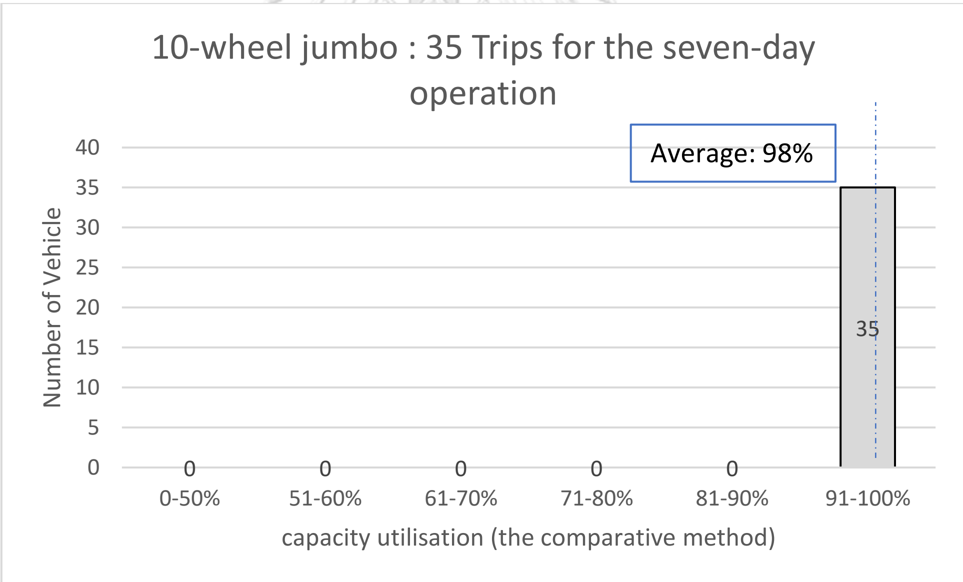


Figure 63: the capacity utilisation of ten-wheel jumbo vehicles from the comparative method

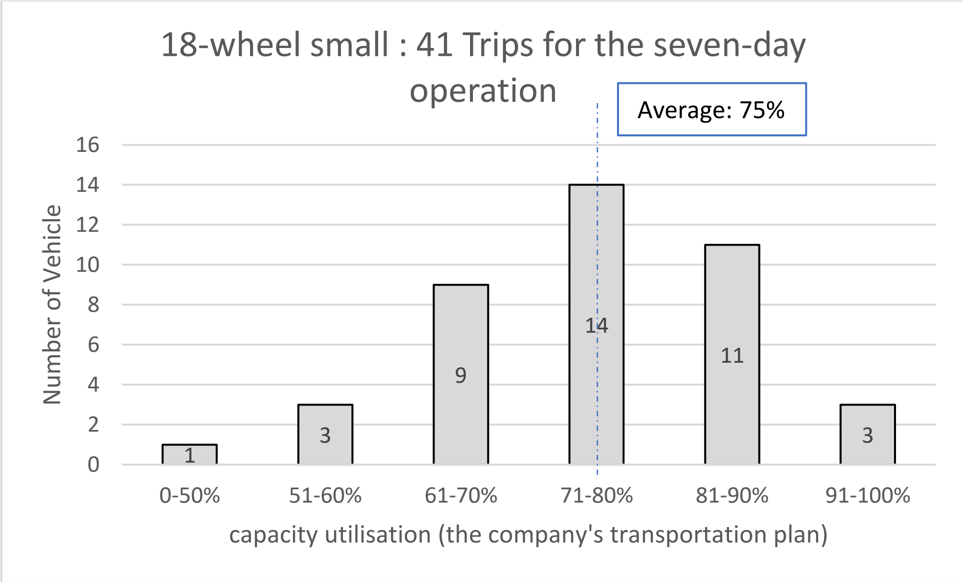


Figure 64: the capacity utilisation of 18-wheel small vehicles from the company's transportation plan

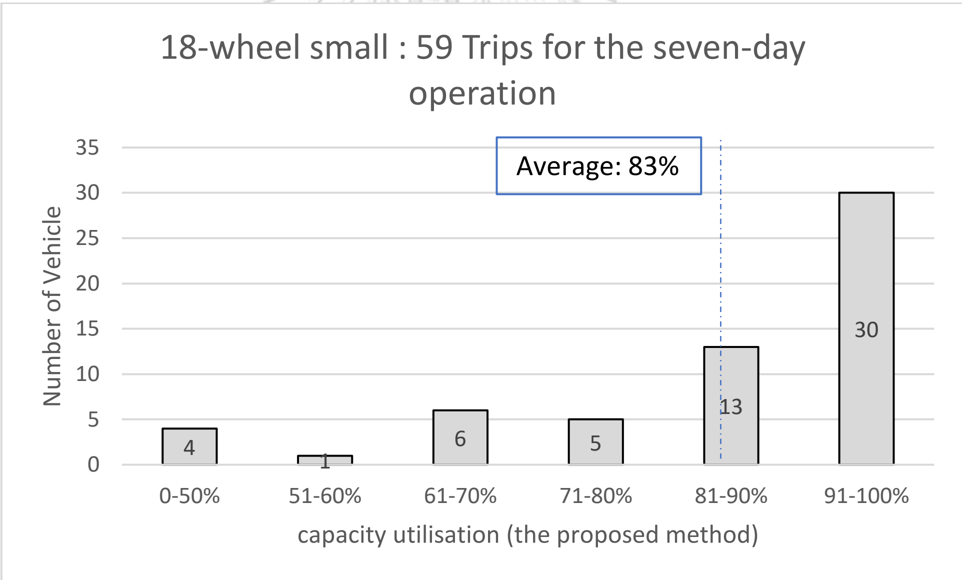


Figure 65: the capacity utilisation of 18-wheel small vehicles from the proposed method

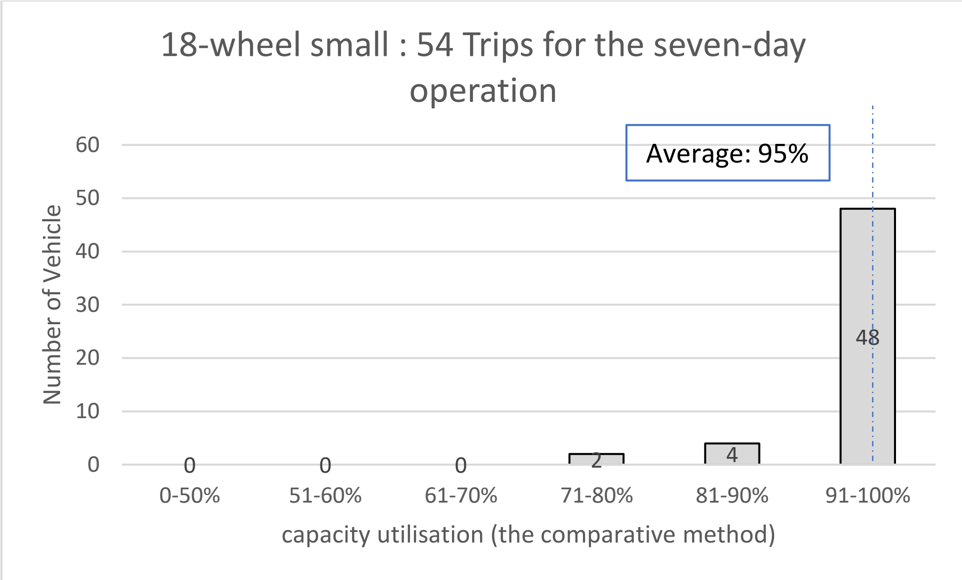


Figure 66: the capacity utilisation of 18-wheel small vehicles from the comparative method

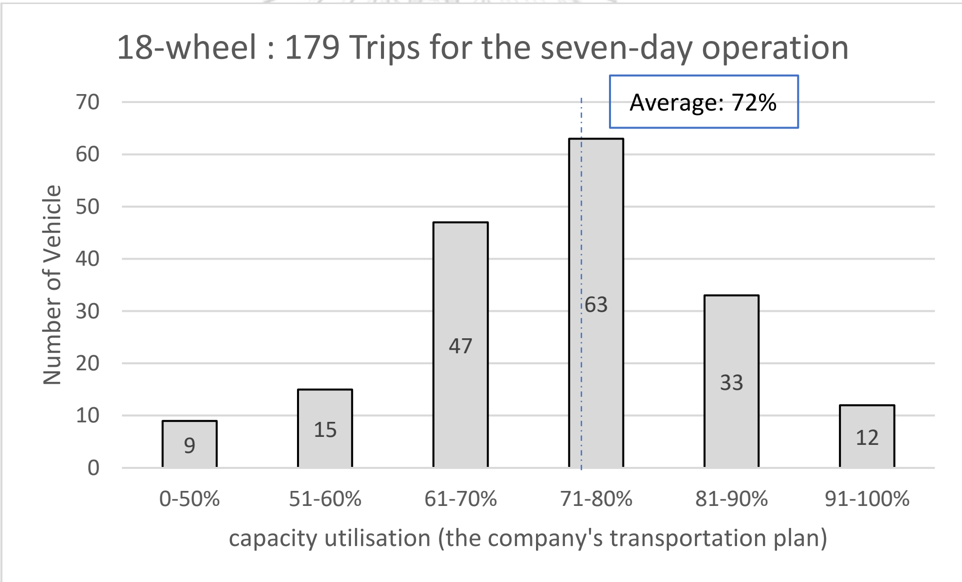


Figure 67: the capacity utilisation of 18-wheel vehicles from the company's transportation plan

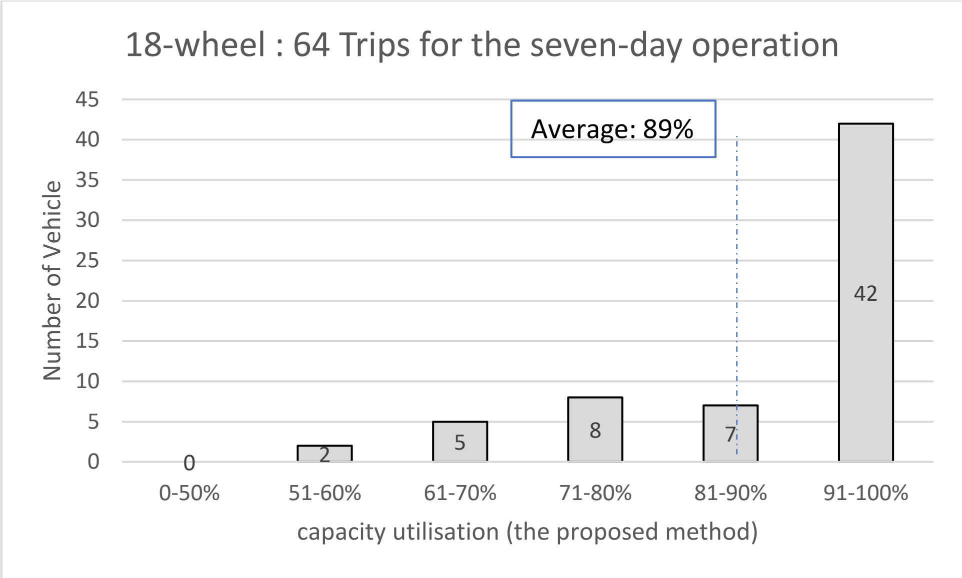


Figure 68: the capacity utilisation of 18-wheel vehicles from the proposed method

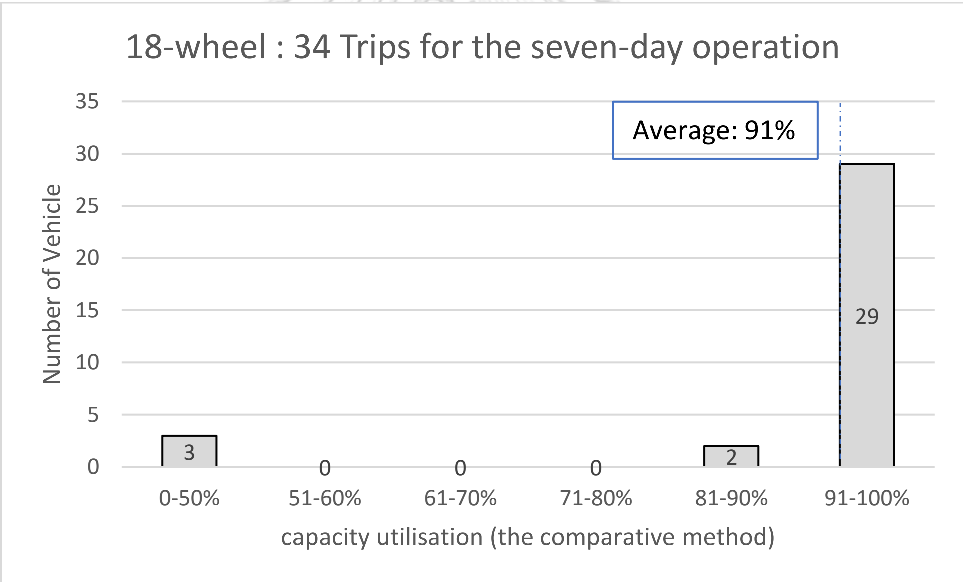


Figure 69: the capacity utilisation of 18-wheel vehicles from the comparative method

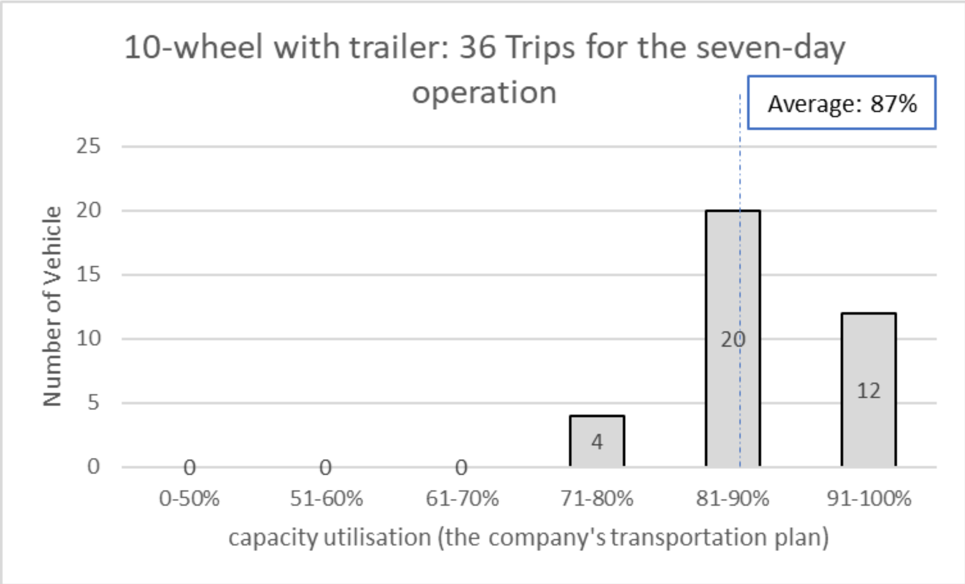


Figure 70: the capacity utilisation of ten-wheel vehicles with trailers from the company's transportation plan

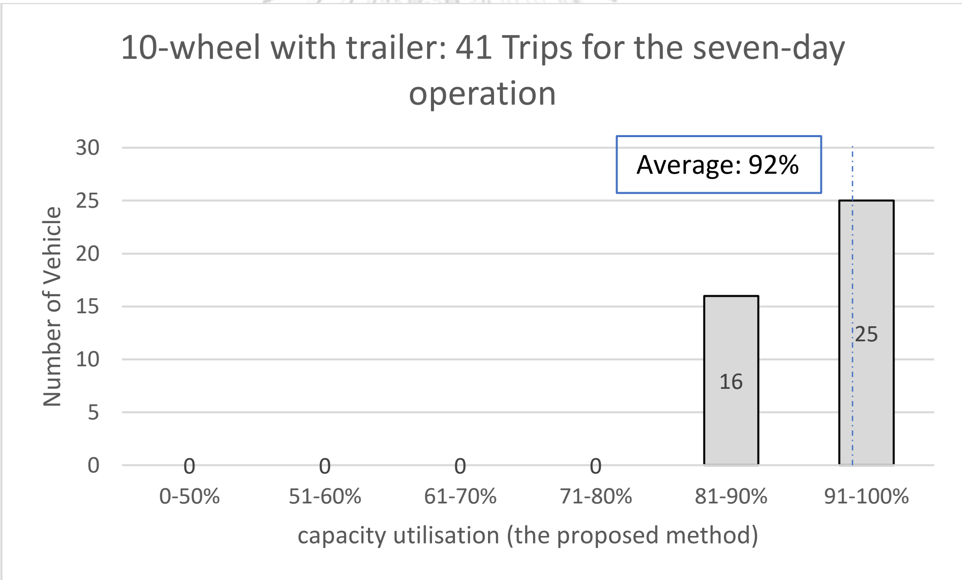


Figure 71: the capacity utilisation of ten-wheel vehicles with trailers from the proposed method

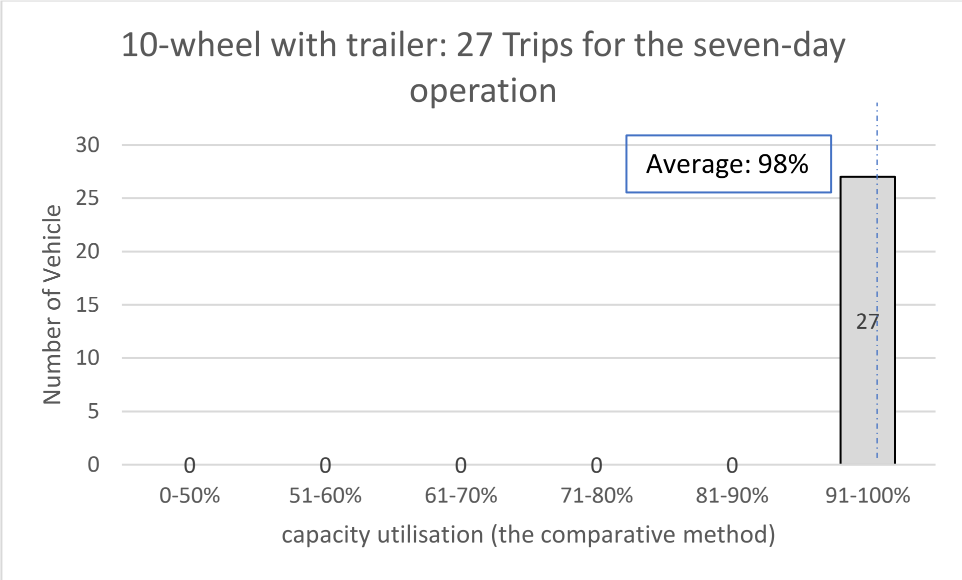


Figure 72: the capacity utilisation of ten-wheel vehicles with trailers from the comparative method

To emphasize the total number of required vehicles in terms of volume, the capacity utilisation of each vehicle in the transportation plan that are obtained from these three sources are illustrated. In addition, the capacity utilisation of each vehicle can be calculated by using Equation 10. Figure 46, Figure 47, and Figure 48 represent the total number of vehicles that is utilised in each range of the capacity utilisation for the seven-day operation from the company's transportation plan, the proposed method and the comparative method, respectively. The average capacity utilisation from every trip of the comparative method is the best among the others, with 94% and the proposed method provides the second best of the average capacity utilisation with 83%, whereas the company's transportation plan generates the worse average capacity utilisation with 72%. Furthermore, the capacity utilisation of each type of vehicles is illustrated as following. Figure 49, Figure 50, Figure 51 show the capacity utilisation of four-wheel vehicles from the company's transportation plan, the proposed method and the comparative method, respectively. Figure 52, Figure 53, Figure 54 show the capacity utilisation of four-wheel jumbo vehicles from the company's transportation plan, the proposed method and the comparative method, respectively. Figure 55, Figure 56, Figure 57 show the capacity utilisation of six-wheel vehicles from the company's transportation plan, the proposed method and the comparative method, respectively. Figure 58, Figure 59, Figure 60 show the capacity utilisation of ten-wheel vehicles from the company's transportation plan, the proposed method and the comparative method, respectively. Figure 61, Figure 62, Figure 63 show the capacity utilisation of ten-wheel jumbo vehicles from the company's transportation plan, the proposed method and the comparative method, respectively. Figure 64, Figure 65, Figure 66 show the capacity utilisation of 18-wheel small vehicles from the company's transportation plan, the proposed method and the comparative method, respectively. Figure 67, Figure 68, Figure 69 show the capacity utilisation of 18-wheel vehicles from the company's transportation plan, the proposed method and the comparative method, respectively. Figure 70, Figure 71, Figure 72 show the capacity utilisation of ten-wheel vehicles with trailers from the company's transportation plan, the proposed method and the comparative method, respectively.

According to these figures of the capacity utilisation of each type of vehicles, it can be concluded in the same trend as that the comparative method generates the transportation plan that provides the best capacity utilisation of each vehicle and this is followed by the proposed method, whereas the company's transportation becomes the worst. Consequently, in a section of the capacity utilisation in terms of the total required volume of vehicles, the comparative method requires the least total number of vehicles in terms of volume and performs the best performance among the other two sources. Even though the comparative model requests the least volumes of vehicles, the other performances of the comparative model that are the total transportation cost and the total travelled distances are the worst. While the proposed method performs the second-best performance of the vehicle requirements in terms of volume but the proposed method provides the best performance of both total transportation cost and total travelled distances. Therefore, another measurement of capacity utilisation is introduced that is the capacity utilisation with m^3-km unit. This measurement emphasizes the capacity utilisation in each trip by measuring the average capacity utilisation per kilometer (km). In other words, the purpose of this measurement is to perceive that the average vehicle load that each vehicle carries along during servicing retail stores in a trip and the capacity utilisation with m^3-km unit is calculated by using Equation 11 and an example of the capacity utilisation with m^3-km unit is exemplified in Example 10.

$$Capacity\ utilisation\ (m^3 - km) = \frac{\begin{array}{c}(vehicle\ load\ from\ the\ starting\ point\ (m^3) \times distance\ from\ the\ starting\ point\ to\ the\ 1^{st}\ drop\ (km)) \\ +(vehicle\ load\ from\ the\ 1^{st}\ drop\ (m^3) \times distance\ from\ the\ 1^{st}\ drop\ to\ the\ 2^{nd}\ drop\ (km)) + \cdots \\ +(vehicle\ load\ from\ the\ (n-1)drop\ (m^3) \times distance\ from\ the\ (n-1)drop\ to\ the\ n\ drop\ (km))\end{array}}{maximum\ capacity\ of\ a\ vehicle(m^3) \times total\ distance\ from\ the\ starting\ point\ to\ the\ n\ drop\ (km)}$$

Equation 11: The capacity utilisation (m^3-km)

Where; n = The number of retail stores in a trip

Example 10

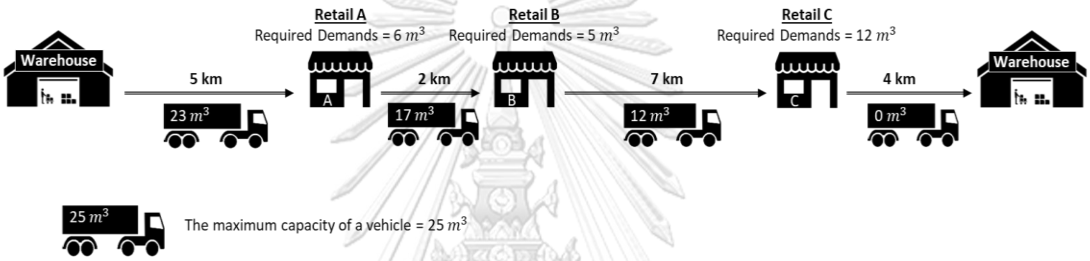
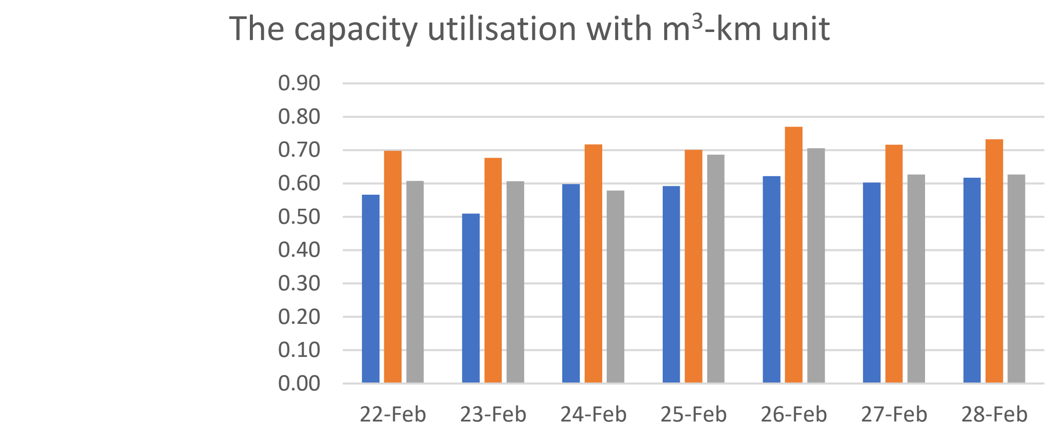


Figure 73: The example of the capacity utilisation with m^3-km unit

From Figure 73, it represents that a vehicle with the maximum capacity 25 m^3 is loaded the total requirements of every retail store in a trip that equal to 23 m^3 at a warehouse, then it travels for 5 km to arrive at the retail A. After arriving at the retail A, the requirements of the retail A that equal to 6 m^3 are unloaded, then the vehicle that currently transports 17 m^3 of the requirements continues travelling for 2 km to arrive the retail B. After that the requirements of the retail B, which equal to 5 m^3, are unloaded. Next, the vehicle that is currently loaded with 12 m^3 of the requirement travels for 7 km until it arrives at the retail C. Then, the requirements of the retail C that equal to 12 m^3 are unloaded. After delivering the requirement of the retail C, the vehicle is empty and it returns to the warehouse. Then, the capacity utilisation with m^3-km can be calculated by using Equation 11 and it equals to 0.67.

$$The\ capcity\ utilisation\ (m^3 - km) = \frac{(23(m^3) \times 5(km)) + (17(m^3) \times 2(km)) + (12(m^3) \times 7(km))}{(25(m^3) \times 14(km))}$$

$$The\ capcity\ utilisation\ (m^3 - km) = 0.67$$



	22-Feb	23-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb
The company's transportation plan	0.57	0.51	0.60	0.59	0.62	0.60	0.62
The proposed method	0.70	0.68	0.72	0.70	0.77	0.72	0.73
The comparative method	0.61	0.61	0.58	0.69	0.71	0.63	0.63

Figure 74: The capacity utilisation with m^3-km unit

According to Figure 74, the graph represents the average capacity utilisation with m^3-km unit in each day from three route planning systems. During the seven-day operation, the proposed method provides the best capacity utilisation with m^3-km for the seven-day operation. The comparative model provides the second-best performance of the capacity utilisation with m^3-km unit by defeating the company's transportation plan for the six-day operation, whereas only one day, on 24 Feb, that the transportation plan of the company slightly overcomes the comparative method. The transportation plan of the company provides the worst performance among the three route planning systems. Even though the proposed method does not provide the best performance of the average capacity utilisation of each vehicle, it provides the best performance of the total travelled distances and the capacity utilisation with m^3-km unit. These advantages mean that the proposed method considers total travelled distances and total loaded volume of requirements of each vehicle concurrently, so that each trip in the transportation plan of the proposed method is utilised effectively.

In accordance with results from all measurements that are the total transportation cost, the total travelled distances, and the capacity utilisation, these can be concluded as following. In this research, the total transportation cost comprises of the travelled distance cost and the service cost that come from two operations of the route planning system. These operations are the allocation of retail stores into the limited number of several types of vehicles and the arrangement of the sequence of retail stores in each trip, while all constraints of the problem, which are the capacity constraint, the total time constraint and the accessibility constraint, are satisfied. Then, the operations of the transportation plan are measured by three indicators that are transportation cost, travelled distances, and capacity utilisation. For the total travelled distances and the capacity utilisation, they should be considered concurrently due to the results from three sources of the route planning system and they are described as followed.

Firstly, the proposed method provides the second-best performance of the total number of required vehicles in terms of volume and the capacity utilisation of each vehicle but the proposed method provides the best performance of the total travelled distances and the capacity utilisation with m^3-km unit. This illustrates that even the proposed method requires more volume of vehicles than the comparative method and the proposed method dose not load requirements of retail stores into each vehicle as many as the comparative method. Routes obtained from the proposed method are managed and retail stores in each route are arranged effectively. So that the proposed method provides the cheapest total transportation cost.

Secondly, for the company's transportation plan, the performance of all measurements of the capacity utilisation, which are the total number of required vehicles in terms of volume, the capacity utilisation of each vehicle, and the capacity utilisation with m^3-km unit, are the worst, whereas the performance of the total travelled distances becomes the second-best. Then, these performances lead to the second-best performance in terms of the total transportation cost.

Thirdly, for the comparative method, it provides the best performance of the capacity utilisation in two aspects that are the total number of required vehicles in terms of volume and the capacity utilisation of each vehicle and it provides the second-best performance of the capacity utilisation with m^3-km unit. Whereas the comparative method generates the worst performance of the total travelled distances and the total transportation cost.

All performances from these route planning systems illustrate that the performance of both the capacity utilisation and the total travelled distances should be balanced in order to obtain the transportation plan that provides the cheapest cost. Furthermore, the main purpose of the company is to obtain the route planning system that is able to generate the transportation plan for transporting daily requirements without violating any indicated constraints. In this research, all three sources of the transportation plan that are the company's transportation plan, the proposed method and the comparative method are capable to produce the required transportation plan. While the proposed method does not only provide the cheapest total transportation cost but also improve the performance of the company's transportation plan in terms of the capacity utilisation and the total travelled distances. These results of the proposed method are all factors that the company expects to obtain. Hence, the proposed method is suitable to generate the route plan for the company and it successfully achieves the objective of this research.

5. Conclusion and Discussion

5.1 Conclusion

Nowadays Thailand's economic is growing, and Royal Thai Government pushes forward Thailand to be an industrial country. Hence, both national and international companies operate and expand their businesses in the country. A retail store company is one of highly competitive businesses since many retail stores open at almost every corner in the country. If a customer cannot find a product from the first retail store, the customer will go to purchase the product from another shop easily. Therefore, a transportation part is a crucial issue for the retail business because the well-managed transportation makes the retail company to be responsive to customers' demands in term of both quantity and time. A studied retail company in this research is one of leading company that operates many branches of several types of retail stores, and these retail stores locate all over the country in order to serve customers that reside around the country. Apart from that the supply chain management is studied by many companies to compete against competitors in the competitive market, since nowadays a single company cannot overcome other companies in the same business segment effectively. Whereas the company that is considered itself as a part of a related supply chain and every unit in the supply chain collaborates and strengthens the chain that will make the whole chain outperforming other rivals successfully. In this research, two companies in the same retail supply chain are considered. They are the retail company and the third-party logistics provider (3PL) company, which is the case study company. The retail company decides to outsource the transportation by using the 3PL company since the transportation part can be considered as a non-core activity, and many resources are required to invest for transporting products such as vehicles, drivers. Nevertheless, three concerned issues occur in this collaboration, and these issues are a reason for operating this research. Firstly, the currently used transportation plan does not utilised vehicles efficiently. Secondly, the form of the collaboration, currently the retail company generates the daily transportation plan and the transportation plan is transferred to the 3PL company. Then, the 3PL company arranges vehicles with drivers and operates accordingly to the plan. Thirdly, the route planning system made by the retail company is not suitable with characteristics of the considered transportation. An operator is required to revise routes that provide low capacity utilisation of vehicles. This means that the current route planning system is not efficient, so that a human can find the flaw obviously. These three issues lead to three following drawbacks that are firstly, the available unused space of vehicles may be considered as waste, and the inefficient route plan leads to the high transportation cost. Secondly, the 3PL company does not have the route planning system, so that the 3PL company cannot operate as the full-service company such as providing the transportation plan and executing accordingly to the plan for a customer. Lastly, the retail company can use human resources to execute a core process of the company instead of performing the transportation plan. Hence, this research is operated to create the route planning system for the 3PL company that has the retail company as the client in order to solve these drawbacks. There are three major components in the transportation system that are the 3PL company, the warehouse of the retail company, and retail stores of the retail company. During the operation of the transportation, the 3PL company will receive three plans from the retail company. The first plan is long-term plan that is sent six weeks ahead of the actual required transportation in order to estimate the number of required vehicles and drivers. The second plan is a mid-term plan that is sent one week prior the actual required transportation in order to adjust the number of required vehicles and drivers. The last plan is exact plan which is the transportation plan that is sent one day ahead of the actual transport, and the 3PL company will transport products from the warehouse to the retail stores accordingly to the transportation plan. Since, the 3PL company is able to prepare the number of required vehicles and drivers adequately, while the transportation plan is a concerned issue that is required to be enhanced in this research. In addition, the total transportation cost of the transportation plan comprises of the service cost and the travelled distance cost. The service cost will be paid to drivers for transporting products from the warehouse to retail stores. The service cost of each trip varies from a type of vehicles, a distance between the farthest retail store of a trip and the warehouse, and the number of drivers. The travelled distance cost is the cost of using vehicles to transport products. The travelled distance cost of each trip depends on a type of vehicles and travelled distances of a trip. Apart from the cost components, major inputs of the daily transportation plan are a set of requirements of each retail store in terms of volume, locations of the warehouse and retail stores, the limited number of vehicles in each type, and distance among considered nodes in a system. Additionally, three constraints that must be satisfied during generating the transportation plan are the capacity constraints in terms of volume, the total time constraint in terms of the maximum time of a trip with 36 hours, and the accessibility constraint for express retail stores.

The objective of this research is to develop a heuristic approach of the route planning system for the 3PL company in order to improve the capacity utilisation and the total transportation cost.

After defining the problem and the expected outcome, comprehensive review of relevant literatures are conducted to find a proper approach that is appropriately applied to the problem of this research. Consequently, the route planning system required to generate in this research is similar to the vehicle routing problem (VRP). However, the VRP contains abundant variants of the problem, while the most similar variant is the heterogeneous vehicle routing problem (HVRP). Since the required transportation plan in this research is the route plan for the several types of vehicles with the limited number of vehicles in each type that is the same characteristic input of the HVRP.

A selected method for generating the route planning system in this research is the simulated annealing metaheuristic (SA). This proposed method comprises of three core processes that are the initial solution approach, the neighbor solution approach, and the post-processing process. In addition, these three core processes comprised of several sub-processes, and they will be exemplified as following. For the initial solution approach, it begins with the sorting process of vehicles by using the greatest capacity rule, which sorts the vehicles from the largest capacity to the smallest capacity in terms of volume. The retail stores will be sorted by using the greatest demand rule, which sequences the retail stores from the greatest requirement to the smallest requirement in terms of volume. Next, the matching process is to match sequenced vehicles with sequenced retail stores from the previous step. At each iteration, the largest capacity vehicle will be matched with the greatest demand retail store that can be inserted in this vehicle, and then the matching process is repeated until every vehicle contains one retail store. Moreover, constraints of the problem must be satisfied during the matching process. The next process is the PIS process for express retail stores. The purpose of this process is to assign an unrouted express retail store to a vehicle by using the nearest feasible insertion criteria (NFIC) at each iteration. The PIS process for express retail stores is repeated until all express retail stores are routed. In addition, a characteristic of the NFIC is selecting an unrouted retail store that locates nearest to the customer of the route, while all constraints are satisfied. Next, the PIS process for remaining unrouted retail stores proceeds. The operations in this step are the same as the PIS process for express retail stores except that any types of remaining unrouted retail store can be inserted in vehicles. At the end of this process, the initial solution is obtained.

For the neighbor solution process, it begins with indicating parameters of the SA metaheuristic that are the initial temperature, the cooling ratio, and the final temperature. These parameters are used for providing a chance of accepting the neighbor solution that provides worse result than the current solution in order to avoid being trapped in a local optimal solution and for stopping the neighbor solution process. After defining the SA parameters, the shift (0,1) process, which is one of the inter route processes, is proceeded to find the best neighbor solution in terms of cost at each iteration. Furthermore, a procedure of the shift (0,1) process is to shift one retail store from one route, which is a giving route, to another route, which is a receiving route. At each iteration of the shift (0,1) process, every combination of the shift (0,1) will be proceeded; and this means that every retail store will try to shift to every route. Then, the retail store, the giving route, and the receiving route that are relevant to the cheapest transportation cost and satisfied all constraints will be considered as the neighbor solution at each iteration. After obtaining the neighbor solution at each iteration, one of these following two scenarios will occur. For the first scenario, if the total transportation cost of the neighbor solution is better than the current solution, the current solution will be replaced by the neighbor solution. A change that occurs after accepting the neighbor solution is that the retail store from the giving route will be shifted to the receiving route, then the reinsertion process will be applied to the receiving route in order to find the best sequence of retail stores of the route. Next, the temperature of the system is updated. In case that the updated temperature does not meet the final temperature, the shift (0,1) process will be repeated. Otherwise, the current process will be shifted to the post-processing process. For the second scenario, if the total transportation cost of the neighbor solution is worse than the current solution, the neighbor solution may be accepted with the probability $e^{-\Delta/T}$. In case that the neighbor solution is accepted, the current solution will be replaced by the neighbor solution, then following processes will be the same as the first scenario. On the other hand, in case that the neighbor solution is not accepted, the shift (0,1) process will stop. Then the post-processing process will begin.

For the post-processing process, the adapted multi-transfer process is proceeded. The multi-transfer process is to transfer a route that is served by a large-sized vehicle to an empty small-sized vehicle. In case that a small-sized fleet is empty, and the small-sized fleet is able to serve the whole route of a large-sized fleet, then the route of the large-sized fleet will be transferred to the small-sized fleet in order to reduce the total transportation cost. While a sequence of retail store of the route remains unchanged. Next, the reinsertion process, which is one of the intra route processes, is applied to every route. A procedure of the reinsertion process is to reposition retail stores of each route in order to find the best sequence of the retail stores in terms of cost, while the total time constraint is satisfied. After finishing the reinsertion process for every route, the transportation plan is obtained.

To evaluate all processes of this research, a performance of the transportation plan of the proposed method is measured by comparing several aspects of the performance with other two sources of transportation plans, which are the transportation plan of the company and the transportation plan of the comparative method. The company's transportation plan is the exact plan that the retail company, which is the client of the 3PL company, sends to the 3PL company in order that the 3PL company transports products from the warehouse to retail stores accordingly to the plan. The comparative method is one of route generating systems that can be applied with the problem of this research per the suggestion of the expert. Results from comparing performances of these three route plans for seven-day operation inform that the proposed method outperforms the other two methods from three out of five system measurements, and these four measurements will be illustrated as following. Firstly, the total transportation cost measurement, which is the transportation plan of the proposed method, is able to reduce the total transportation cost of the transportation plan of the company with 14.67%, whereas the transportation plan of the comparative method increases the transportation cost of the company with 14.45%. Secondly, the total travelled distance measurement, which is the transportation plan of the proposed method, uses less total travelled distances than the company's transportation plan with 13.36%, while the transportation plan of the comparative method uses total travelled distances greater than the transportation plan of the company with 50.1%. Thirdly, the capacity utilisation in terms of total required volume of vehicles measurement, which is the capacity utilisation comparing between required demands of retail stores and required volume of vehicles that are used for transporting the demands, is measured. The comparative method outperforms the proposed method by requesting extra total volume of vehicles compared with the total volume of requirements, with 5.9%, whereas the proposed method requires the extra total volume of vehicles, with 20.7%. The company's transportation plan requires the greatest extra volume of vehicle with 35.5%. Fourthly, the capacity utilisation of each vehicle is a consequence of the required volume of vehicles for the transportation in each day. In case that the required volume of vehicles used for delivering products is slightly greater than the volume of the total requirements, this means that each required vehicle in the transportation plan must be maximally loaded by the requirements. A result of this measurement is that the comparative method provides the best performance, and it is followed by the proposed method, whereas the company's transportation plan generates. Lastly, the capacity utilisation with m^3-km unit measurement, transportation plans of the proposed method, and the comparative method outperform the transportation plan of the company; while the proposed method generates superior performance than the comparative method.

5.2 Discussion

5.2.1 The total travelled distances

The proposed method performs the best performance in terms of the total travelled distances since it uses the least total travelled distances compared with other two sources of the transportation plan that are the company's transportation plan and the comparative method. A reason is that a logic of the proposed method during the constructive process tries to insert a next unrouted retail store in all vehicles, then a route of a vehicle that provides the shortest distance of the insertion is selected. So that retail stores of each route locate nearby each other. On the other hand, the constructive method of the comparative method tries to maximally utilise a capacity of a currently selected vehicle. In case that the remaining capacity of the selected vehicle is not enough to transport demands of retail stores that locate nearby retail stores of the route, the remaining capacity of this vehicle is able to serve a retail store that locates far from the retail stores of the route. The algorithm of the comparative method will decide to service the far retail store in order to maximise the capacity utilisation. Even though the shift (0,1) which is the improvement procedure is applied to both algorithms, the comparative method will have less chance to improve than the proposed method. Since each route of the comparative method is almost full, then it will be hard that a retail store from one route can be transferred to the other route. Consequently, the total travelled distances of each route of the comparative method are not significantly improved. Hence, the comparative method generates a transportation plan with the greatest total traveled distances.

5.2.2. The total volume requirement of vehicles

Since the logic of the comparative method during the constructive process tries to maximally utilise a selected vehicle before selecting a next vehicle to service remaining unrouted retail stores, then a gap between the total volume requirements of retail stores and the total volume requirements of vehicles from the comparative method is small. After that, none of vehicles will be more required during the improvement process of the comparative method, thus comparative method requires the least total volume requirements of vehicles compared with the others. On the contrary, the proposed method uses every vehicle during the constructive method in order to find each group of retail stores that provide the shortest distances. Then, the shift (0,1) process is applied in order to reduce the required volume of vehicles. However, the proposed method rather focuses on the total transportation cost than the total volume requirements of vehicles in the system. So that the proposed method will not try to fulfill a remaining unused capacity of a vehicle by a requirement of a retail store that locates far from retail stores of this vehicle. Therefore, the proposed method is defeated by the comparative method in terms of the performance of the total volume requirement of vehicles, whereas it outperforms the company's transportation plan.

5.2.3 The capacity utilisation of each vehicle

This performance is a consequence of the total volume requirement of vehicles. For example, the comparative method requires the least volume requirement of vehicles, so this means that a capacity of each selected vehicles is fully loaded. In addition, the performance of the capacity utilisation from three sources is the same as the performance of the total volume requirement of vehicles. The comparative method provides the best capacity utilization, and this is followed by the proposed method, whereas the company's transportation plan generates the worst performance.

5.2.4 The capacity utilisation (m^3-km)

According to the logic of the comparative method that tries to insert retail stores into a vehicle as many as possible in order to maximise the capacity utilisation of the vehicle, there is a chance that when a remaining unused capacity of a selected vehicle is small and unable to serve demands of retail stores located nearby retail stores that are already assigned to this vehicle, while this vehicle is able to service a demand of a retail store that locates far from retail stores of this vehicle. In such case, the comparative method will decide to service the far retail store in order to fully utilise the vehicle. Whereas, each route that is obtained from the proposed method will contain retail stores located nearby each other. Even the proposed method does not utilised a capacity of each vehicle effectively as the comparative method, the total travelled distances of the proposed method are much less than the comparative method. So that the capacity utilisation (m^3-km) of the proposed method is better than the comparative method.

5.2.5 The total transportation cost

A concept of the proposed method is to generate a transportation plan considering the total travelled distances and the capacity utilisation concurrently, whereas a concept of the comparative method is to generate a transportation plan that gives a priority to the capacity utilisation of each vehicle. Hence, the transportation plan of the proposed method is unable to utilise a capacity of vehicle as effectively as the comparative method, while the transportation plan of the proposed method uses much less total travelled distances than the transportation plan of the comparative method. In addition, the total transportation cost of the considered problem in this research is based on the total travelled distances. Therefore, the proposed method generates cheaper transportation plan than the comparative method.

Delivery date	The company's transportation plan	The proposed method	The comparative method
22-Feb	726,583.1	621,831.5	766,913.0
23-Feb	689,672.2	563,082.8	764,716.0
24-Feb	905,038.7	779,475.7	1,064,242.7
25-Feb	790,406.5	653,053.8	972,108.6
26-Feb	768,603.2	640,539.7	860,813.5
27-Feb	919,135.9	760,667.7	1,099,072.8
28-Feb	835,542.3	709,151.7	973,656.5
Total transportation cost (THB)	5,634,981.9	4,727,802.9	6,501,523.0
Service fee (THB)	563,498.2	472,780.3	650,152.3
Total transportation charge (THB)	6,198,480.1	5,200,583.1	7,151,675.3

Table 21: The total transportation charge

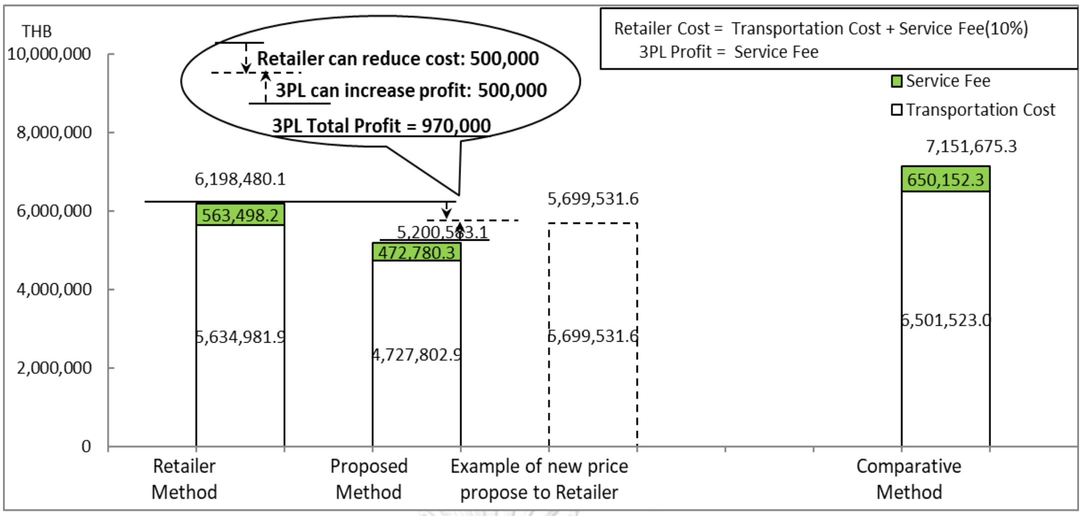


Figure 75: The example of the new transportation charge

According to *Table 21*, the transportation plan that is generated by the retail company for the seven-day operation generates the total transportation cost equals to 5,634,981.9 THB. Then, the total transportation charge that the retail company pays the 3PL company equals to 6,198,480.1 THB. This cost is calculated by the total transportation cost plus 10 percent of the total transportation cost, which is considered as the service for the 3PL company and it equals to 563,498.2 THB. In case of using the other two sources of the transportation plan, the retail company will be required to pay the total transportation charge from the transportation plan of the proposed method and the transportation plan of the comparative method that equal to 5,200,583.1 THB and 7,151,675.3 THB, respectively. While the service fee that the 3PL company will obtain from the transportation plan of the proposed method and the transportation plan of the comparative method equal to 472,780.3 THB and 650,152.3 THB, respectively. Moreover, to summarised these expenses, *Figure 75* is generated and it will be explained as following.

For the comparative method, *Figure 75* represents that the comparative method seems to be the transportation plan that provides the most benefit to the 3PL company, since it generates the greatest service fee. Whereas, the retail company is required to pay the most expensive transportation plan. Therefore, the retail company will not agree to pay more cost to use the comparative method instead of the current company’s transportation plan.

For the proposed method, *Figure 75* shows that in case of applying the proposed method to generate the transportation plan, the 3PL company will receive less service fee. Hence, it seems to be that the 3PL company should not apply this method to the company. Nevertheless, the objective of this research is that to reduce the transportation cost, to develop the route planning system for the 3PL company and to enhance the human resource of the retail company. Hence, the 3PL company should propose a new collaboration as following. The 3PL will be a full-service company that generates transportation plan and provides vehicles with drivers accordingly to the plan, while the expense of the retail company is reduced and the revenue of the 3PL company is increased. Furthermore, this statement can be illustrated by *Figure 75*. It represents that the 3PL will propose a new transportation charge at 5,699,531.6 THB to the retail company, so the retail company will reduce the expense of the company approximately 500,000 THB. On the other hand, the 3PL company will increase the revenue of the company approximately 500,000 THB. Therefore, benefits that will be obtained from the proposed method are that, firstly, the transportation charge of the retail company is reduced. Secondly, the retail company can use human resources to operate a core process of the company instead of generating the transportation plan. Thirdly, the service fee of the 3PL is increased and the 3PL is able to provide full-service of the transportation to the client.

In conclusion, the proposed method provides superior performance in every aspect of the system measurement than the route planning system of the company. Therefore, it means that the proposed method achieves the objective of this research by improving the total transportation cost and the capacity utilisation of the company effectively.

5.2.6 Research limitations

1. In the route planning system, all distances between nodes are considered as the Euclidean distance, so that the total transportation cost in this research may be underestimated.
2. During the improvement phase, the inter-route search and the intra-route search are only applied by one operator that are the shift (0,1) process and the reinsertion process, respectively. While more than one operator should be applied to enhance the solution, thus there may be a room for improvement during the improvement phase.
3. In the computational experiment, actual data from the seven-day operation is analysed, which may not long period enough to verify the proposed method.

5.2.7 Future works

1. A system that is able to find real distances between nodes should be applied in order to make the route planning system becoming more realistic and the total transportation cost will be more precise.
2. The improvement phase of the route planning system could be extended by applying other operators.
3. More data from the studied company should be considered in the computational experiment to verify the performance of the proposed method.
4. According to the suggestion of the new collaboration between the 3PL company and the client that the 3PL company should provide the full-service transportation that generates the route plan by itself and offers the new proposed transportation charge. So that the cost structure of the new proposed transportation charge should be studied.

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