TIER 2 MILK RUN STUDY IN AUTOMOTIVE PARTS WITH OPTIMIZATION AND FRUGAL MINDSET

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AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN LOGISTICS AND SUPPLY CHAIN MANAGEMENT

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ABSTRACT

In emerging market, majority of private companies who have to play against each other by setting competitive price to seize their economical opportunity. Frugal mindset is one of management philosophies extensively addressed in order to gain that opportunity. Transport resource management goal is also found to be achieved by applying the concept of frugal mindset as well. Currently, direct delivery is utilized widely for transportation between Tier 1 and Tier 2 with low truck filling ratio which wastes number of vehicles. In this study, milk run is selected as a logistics management scheme with an integrated process. This scheme also supports the frugal mindset by maximizing profit with minimum transport resources. There are three algorithms to solve vehicle routing problems for milk run route optimization: 1) greedy algorithm to maximize loading volume, 2) heuristic algorithm to generate possible networks, and 3) integer linear programming to develop a network optimization. With the result from an optimization model, it can improve transport cost 48% from current condition by reducing total distances and also number of vehicles. This improvement benefits in value creation in terms of economic value, cutting cost and lowering retail price for product; environmental value, reducing Greenhouse Gases (GHGs) emissions with the lower number of vehicles; and social

value, reducing number of accident events and giving low income people more opportunities to own low cost products enhancing better quality of life.

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LIST OF DEFINITIONS

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CEO	Chief Executive Officer	2
GHGs	Greenhouse Gases	3
Tier 1	Companies who supply components directly to Original Equipment Manufacturer (OEM)	4
Tier 2	Companies who supply some components to Tier 1 for making some processes before supplying to Original Equipment Manufacturer (OEM)	4
CBU	Completely Built Unit	7
INSEAD	Institut Européen D'administration Des Affaires, the business school of the world	11
BOP	Base of the Pyramid	14
KPI	Key Performance Index	16
VRP	Vehicle Routing Problem	17
TSP	Traveling and Salesman Problem	17
KP	Knapsack Problem	17
ILP	Integer Linear Programming	17
VOC	Vehicle Operating Cost	21
SCF	Standard Conversion Factor	22

LIST OF EQUATIONS

Name	Equation	Page
KP	$\textbf{Maximize} \quad \sum_{i=1}^{n} v_i x_i$ $\textit{Subject to} \quad \sum_{i=1}^{n} w_i x_i \le W$ $x_i \in \{0,1\}; \quad \forall i$ $\textbf{Minimize} \quad \sum_{i=1}^{n} c_i x_i$ $\textit{Subject to} \quad \sum_{i=1}^{n} w_i x_i \le W$ $x_i \in \{0,1\}; \quad \forall i$	25
ILP	$\textbf{Minimize} \quad \sum_{(i,j)\in A} D_{ij} x_{ij}$ $\textit{Subject to} \quad \sum_{(i,j)\in A} x_{ij} = 1; \quad \forall i \in N$ $\sum_{(j,i)\in A} x_{ji} = 1; \quad \forall i \in N$ $\sum_{(i,j)\in A: i\in S, j\in S} x_{ij} \le \lvert S\rvert - 1; \ \forall S \subset N,$ $2 < \lvert S\rvert < N - 2$ $x_{ij} \in \{0,1\}; \quad \forall (i,j) \in A$	30

CHAPTER 1

INTRODUCTION

1.1 Background

The competiveness is one of the key factors to overcome rivals especially in the emerging market where the most population has tight budget with low income. The price should be lower than competitors; however, the company must keep customer's satisfaction with good quality. The challenge is how to find the way to cut the unnecessary cost and expands the profit portion, consistent with the company's annual target. This study mainly focuses on reducing the transportation cost, which is the large part of logistics cost as shown on **Figure 1.2.** Meanwhile, the delivery should synchronize with customer demand at the right time and the right place with the right cost. There are three levels of scenario in this study which involves using strategical, tactical, and operational view to approach and improve in study processes.

There are several philosophy management such as lean engineering and frugal engineering. Most people are familiar with lean for increasing value and reducing wastes; however, it is interesting in gaining more study which relates to frugal engineering because it is a powerful and ultimately essential approach to develop products and services in the emerging markets (Vikas et al., 2010). It also enhances how to maximize value to customers while minimize nonessential cost. Pitta et al. (2008) suggested that the price is supposed to be more competitive by lowering retail prices of products while providing economic-driven opportunities (cited in Melissa and Jöran, 2017, p. 1). Originally, frugal engineering would greatly benefit for the poorest population to manage the resource constraints. The over-engineered product will be developed to offer the greatest value to mass customers at the bottle of pyramid in emerging markets with an affordable price. By contrast, with the rapid growth of these markets, billions of consumers are quickly moving out of poverty in China, India, Brazil, and other emerging nations as Thailand to middle class (Vikas et al., 2010). These new middle classes are interested in affordable products (Melissa and Joran, 2017). Therefore, frugal philosophy can enhance these classes by serving affordability within their own budget (Mokter, 2017) which is not only for economic values to business model but also combines with environmental value with the minimum resource utilization and social benefit for providing opportunities to millions of low income people to own low cost products (Eugenia et al., 2016). Moreover, it is not only expanded in emerging markets but also industrial countries by addressing markets that are not adequately served (Melissa and Jöran, 2017). Therefore, markets are expanded more broadly to low-income population for having opportunity to own the products with low cost. The word "*Frugal engineering*" first coined by Carlos Ghosn in 2006, CEO of Renault- Nissan alliance, who was impressed with Indian engineers' ability to launch the low-cost car, Tata Motors' Nano. This car model could access millions of people to have their own car, enhancing an opportunity for growth. Guillerm Wille, former Managing Director at GE India, also mentioned that "the beauty of the Indian market is that people demands everything in the world, but cheaper and smaller." (cited in Nirmalya, 2012). Ghosn applied and set the frugal as one of mindsets in his organization. To achieve affordable price, the limited resources will be spent with the highest purpose; in the other word, it is considered to maximize outcome with the minimum resources. The efficient logistics management can control and manage transport resource management. Tiwari and Herstatt (2014) defined the value proposition of frugal products and services as decreased total ownership cost, robustness, user-friendliness and economies of scale, aligning with sustainability agenda both from ecological and social perspective, so the unnecessary cost is cut down as the value that customers are not willing to pay (cited in Eugenia and Julia, 2016).

In order to link supply with demand, the synchronization with customers is important for an organization to serve customers' satisfaction with better quality, better delivery and better cost. Supply chain and logistics management are reviewed to find how to manage flow of value to offer greater value to customers at acceptable cost with supply chain thinking. Subject to quality standard, any inefficient activities have to be eliminated. Customers satisfy timely delivery with reliable and reasonable transport cost. In this study, transport resource management will be deeply studied how to minimize usage of the resources such as number of vehicles, which will impact on transportation cost. Additionally, there is indirect ecological impact on the environment clean chain such as reducing Greenhouse Gases (GHGs) emissions, reusing some possible resources, reducing hazardous components that effects to the environment.

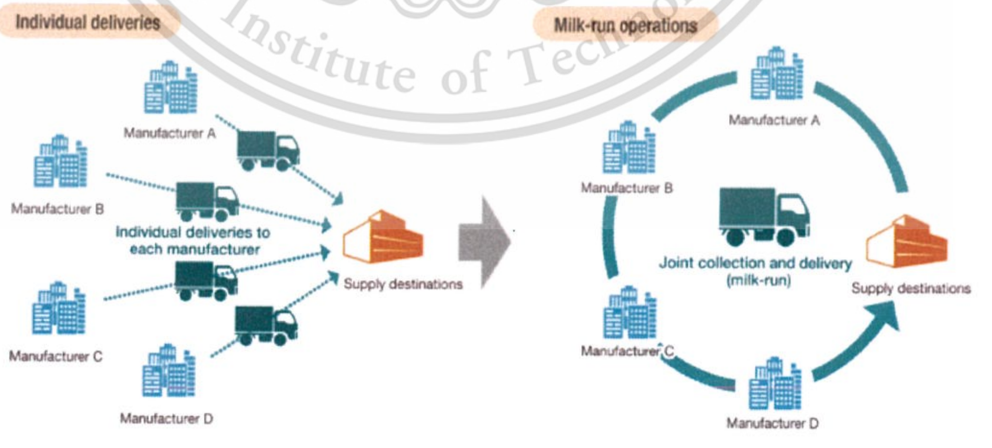

Figure 1.1 Comparison of Direct Delivery and Milk Run Delivery

Source: Nippon Express NEC Logistics (Thailand) Co., Ltd (2017)

One of the famous logistics management schemes called milk run scheme as shown on **Figure 1.1.** It was first launched by a milk company in United State, trying to manage routing delivery and vehicles with mixed loaded of milk bottles and exchange the empty bottles delivering back to the company. The scheme was a reliable and frequent service, bringing fresh milk on a daily basis (Euclides, 2013). Many company, especially in automotive manufacturing have applied this scheme widely. Dávid et al. (2013) described the goals of milk run planning by minimizing number of vehicles via minimum time consuming (Dávid et al., 2013). This scheme will be conducted in the study for transportation cost reduction with milk run optimization model developing through algorithms to solve vehicle routing problems between Tier 1 and Tier 2. Milk run scheme can improve their supply chain and logistics management for delivering the better value to customers.

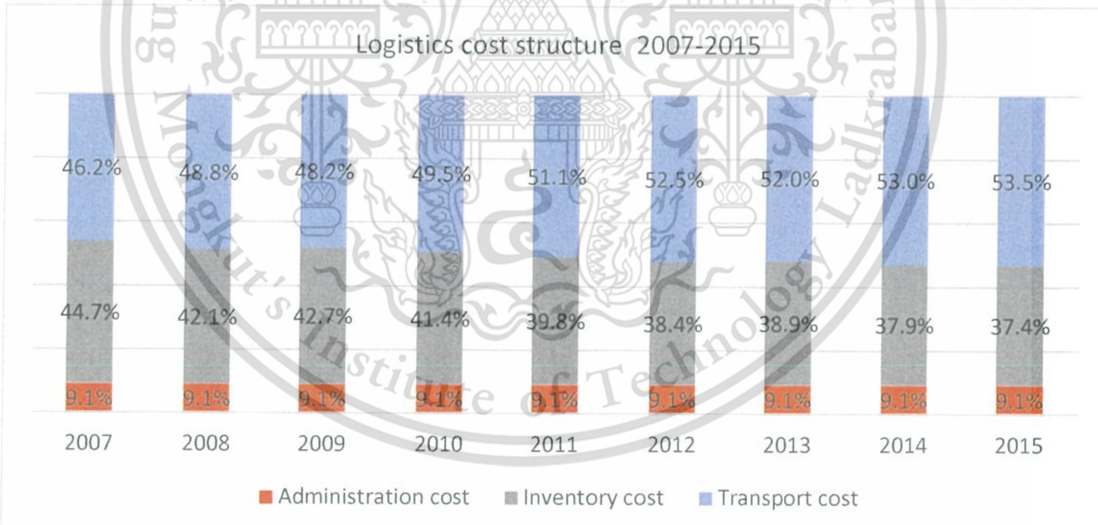

Figure 1.2 Thailand's Logistics Report 2016

Source: Thailand's Logistics Report (2016), Office of the National Economic and Social Development Board

In term of logistics, transportation cost is a large portion of logistics cost as 53.5% in 2015 and the trend is gradually increased, according to the statistical data from **Figure 1.2**. This study will focus on increasing transport efficiency with the optimized cost and timeliness. In order to manage transportation, the milk run with optimization is one of the best methods in logistics viewpoint such as optimizing route of transportation, number of vehicle, lead-time, minimum environmental impact from Greenhouse Gases (GHGs) emissions, and inventory area. Next chapter is to clarify the current problem of the chosen case study.

1.2 Problem Statement

Vehicle routing and scheduling are important parts of transport resource management which consider the most effective way to deliver products or goods to the next customers. There are two main problems in vehicle routing and scheduling as following: 1) how to minimize number of vehicles required to achieve the job, 2) how to deliver inconsistent amount of goods and products as efficient as possible. The efficiency means to maximize the amount of product moving on the vehicles and minimize vehicles mileage. It is essential to provide a balance between supply and demand for offering service to customers under an acceptable cost.

In this study, we investigated in transportation performance between Tier 1 and Tier 2 which are all direct scheme and applied widely among Tier 2. This scheme is good for high volume with full truck delivery. However, in case of small volume but high frequency of delivery like this case. The problem is the unfulfilled truck, low utilization which lead to use too many vehicles and overlap transport routes causing the complicated long distances. Mostly, Tier 2 supplies component parts to Tier 1 by their own trucks directly. Sometimes, it is full truck, otherwise it is less than of a truck depending on the exclusive demand of Tier 1. However, there are some Tier 2 who already applied milk run for multiple destinations of their Tier 1 customers. In this study, the focus is mainly on Tier 2 who supplies parts to Tier 1 directly and exclusively with low density of truck.

According to the data from the case study, the density of truck is around 30%-40% per one 6-wheel truck in each delivery. The cost is high in term of the logistics cost on both transportation and handling. Tier 2 has to manage the delivery through the following processes such as loading, unloading, internal handling, keying data, especially in requiring too many unfulfilled trucks for support. It also causes double handling in Tier 1 in the process of receiving such as unloading and loading, sorting and putting away. Current transportation management is not reliable to fix schedule, so it causes too much time consuming for handling management. To increase the utilization of truck, cyclic transportation system is required with the fixed route and schedule, then the logistics cost is able to reduce. Furthermore, the environment impact is decreased in term of Greenhouse Gases (GHGs) emissions linking to the lower number of vehicles. Vehicles routing problem would be the main issue to solve how to limit number of vehicles and minimize transportation cost with the discrete optimization model. The research methodology will start from heuristic to exact method in order to get an optimized result.

1.3 Objectives of the Study

To answer the problems as stated earlier, there are four main objectives set for this study as following:

- To review transport situations and characteristics in an automotive manufacturer through its supply chain with related parties such as suppliers Tier 1 and Tier 2.

- To review transport techniques to improve transport processes in the supply chain of the automotive manufacturer.
- To analyze the current transport situation and potential of improvement comparing with the selected techniques.
- To apply the most effective technique on practical work with the result of the study.

1.4 Scope of the Study

In the role of an automotive manufacturer, the transportation improvement will be mostly focused on Tier 1 as finished goods which supply to production line of an automotive manufacture and then suppling as Completely Built Unit (CBU) to end customers. Most automotive manufactures have improved this transport routing, between Tier 1 and an automotive manufacture, to match with their production and inventory control level. In this study, the scope is a broader view to upper stream of supply chain to between Tier 2 and Tier 1. The approach is considered as a point of view of third party as a manufacturer view who investigates the current situation with perspectives different from the current operators such as engineers and logistics operators who are sometimes too familiar with their current operations. The milk-run optimization concept will be studied on the transportation between Tier 2 and Tier 1 with several scenarios of methodologies to find the optimum solution subject to standard of quality, cost and time.

1.5 Limitations of the Study

First, there is a limitation in term of data confidential. The secondary data is obtained from an automotive manufacture; however, the data can be used for feasibility study purpose only and some identifications need to be left out.

Second, some types of necessary data, for instance, truck travel distance, speed of truck and the capacity of truck, have to be assumed based on the real-world observations and secondary data sources.

Third, this is the study based on a specific operation of a private company. The analysis result might be different of the same methodology is addressed in other companies or other operations.

Fourth, because of the limitation of the time and budget availability of this study, the vehicle operating cost is referred to previous literatures.

CHAPTER 2

LITERATURE REVIEW

Many previous works widely studied about the milk run scheme, relating to logistics and manufacturing network design. In this study, several topics is reviewed as following: 2.1) how milk run concept develops in logistics and supply chain management, 2.2) frugal engineering in an organization, 2.3) critical comparison frugal engineering and lean in term of logistics process, and 2.4) vehicle routing approach with the discrete optimization.

2.1 Milk Run Concept in Logistics and Supply Chain Management

Supply chain is a network of value creators who execute the process according to value chain in order to respond to customers. Logistics management is activities which manage flow of value to offer value to end customers. Milk run is one of logistic management schemes which integrates processes with transportation management holistically among value creators in a supply chain, especially Tier 1, Tier 2 and third-party logistics provider, supporting supply chain thinking to link all parties with more collaboration with co-planning, to enhance communication with more data sharing by a logistics system, to create value connectively from purchasing, production, and delivery until to customers (Suharitdamrong, 2014), according to **Figure 2.1** which displayed how logistics related to supply chain.

- Flow of information with collaborative planning among parties in supply chain and sharing information of demand planning for delivery,
- Logistics activities, to enhance the flow of values to customers effectively in the right time and the right place with the right cost

- Flow of material through logistics activities.

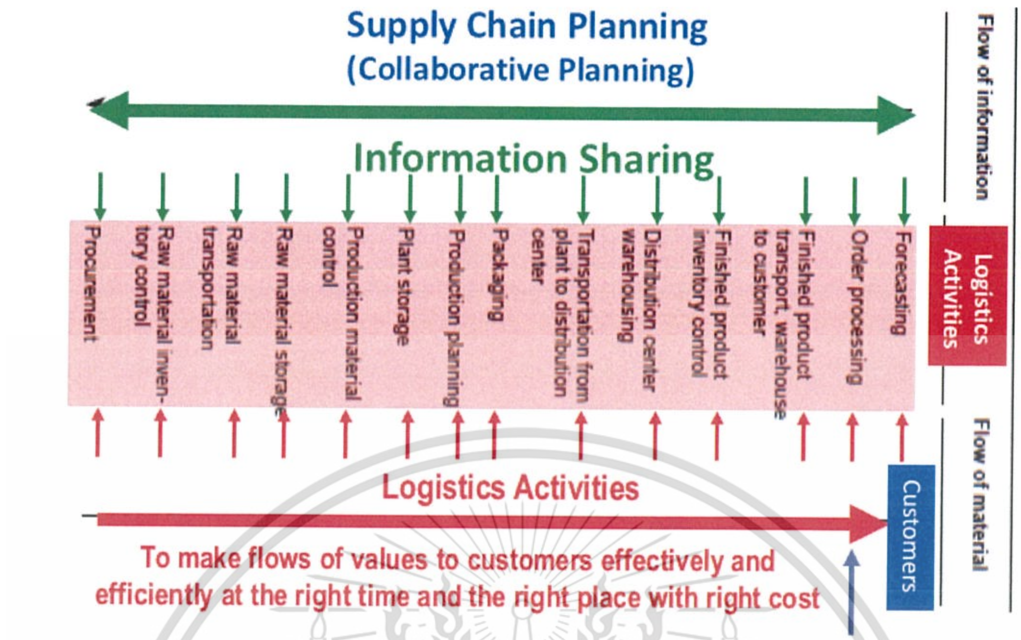

Figure 2.1 Logistics Process

Source: Suharitdamrong (2016), Introduction to Logistics and Supply Chain Management

Milk run scheme enhances logistics and supply chain management to be more synchronized with customers in terms of quality, cost and time. According to the quality of transportation, the scheme has to be supported by a logistics system. This system is information sharing among related parties: suppliers, customers, and third party logistic provider which leads to be more collaborative for co-planning and solves any issues such as transportation damage, shortage, and wrong shipment. A safe logistics system is not only important for speed, but also the transportation quality for solving the mentioned issues (Toshinori et al., 2010).

The goal of milk run planning aims to minimize number of vehicles which manages truck utilization with a fixed route and time schedule. Then, the transportation cost can be saved linking to the lower number of vehicles and the shorten path of delivery (Dávid et al., 2013). With collaborative planning, it is allowed to level parts on daily basis which is more real time, flexible for the demand fluctuation, and reliable transport. The more order is placed frequently or replenished, the less lead time of waiting time will greatly reduce (Euclides, 2013). Therefore, lead time could be controlled and shorten onward, the safety stock could be optimized which the total inventory will be on visual control. Milk run can help to create a good flow of material with this frequent and reliable transport service with contracts among concerned parties, improving suppliers' communication, increasing productivity in production line with in-time supply.

Moreover, the vehicles will be utilized more efficient with the consolidated delivery which could minimize environment impact and enhance the good image to a company with sustainability way of thinking (Toshinori et al., 2010). The business is not only profit but the matter is also how long a company stand in the long run with stability and success.

2.2 Frugal Engineering in an Organization

Frugal engineering is described as an alternative approach to product development which focus to eliminate wastefulness of over-engineered product, challenges the traditional business model for R&D of Western companies, according to Radjou and Prabhu (2015) (cited in Eugenia and Julia, 2016).

"*One cannot solve a problem with the same mindset that created it in the first place.*" once is mentioned by Albert Einstein. INSEAD, the business school of the world discussed that frugal engineering is a game change strategy for the businesses compelled by cost-conscious and eco-aware consumers, employees, and governments to create offering that are simultaneously affordable, sustainable and high of quality (Frugal Innovation: a New Business Paradigm, 2018). Many western CEOs are aware of this frugal mindset or called as Jugaad mindset more broadly. Harvard Business Review published about Carlos Ghosn, Chairman and CEO of Renault-Nissan Alliance, who proactively implemented this mindset on his organizations to build the mindset among employees to offer greater value to customer at the lowest cost, then turned to be the world leading manufacturer of both electric cars and low-cost vehicles (Navi et al., 2012). This study would like to expand and develop frugal mindset in broader scope with a principle as "*do more with less*" along the supply chain to Tier 1 and Tier 2 to improve and create the value-conscious customers from the upstream to downstream more efficiently. The frugal engineering is not only all about new technologies, but also the new business model which is to combine simultaneously economic value with environmental and social benefit (Eugenia et al., 2016).

In traditional supply chain, most companies focus on cutting down prices from suppliers, some suppliers have to struggle with the cost reduction because sometimes it is cut too deep. Therefore, frugal engineering is an interesting approach to trigger differently even from lean approach. It is looked beyond to the new level of cost transparency and supplier involvement in development projects. Originally, manufactures mandate their requirements to suppliers to compete on price. In frugal engineering, the game is different to co-develop and optimize cost for the entire systems with the cost target and cost structures agreed by both manufactures and suppliers (Vikas et al., 2010).

Mourtzis et al. (2016) described a frugal innovation which focuses on exploiting the intelligent use of resources and simultaneously turns the related constraints into advantages (Mourtzis et al., 2016). To expand this challenge, this study created well-structured manufacturing networks for milk run optimization.

Moreover, Prabhu and Gupta (2014) also supported that frugal service innovation has also used three broad innovation heuristics as following (cited in Mokter, 2017):

- Combining existing materials, processes and resources through bricolage
- Reducing time, materials and human resources
- Creating self-service options to users

Therefore, the proposed methodologies are similar to use heuristics algorithms to find the optimum manufacturing network configuration.

According to Jugaad Innovation book, Navi et al. (2012) points out Jugaad as to think frugal, be flexible, generate breakthrough growth and also classifies into six principles as following (Navi et al., 2012):

- Seek opportunity in adversity
- Do more with less
- Think and act flexibly
- Keep it simple
- Include the margin
- Follow your heart

The selected principle in this study is "*do more with less*". The principle is to create affordable or limit offerings and then exploit to gain a significant competitive advantage over their peers in tough economics time onward. In other words, it is how to create more value to customers with fewer resources. He mentioned about how to leverage existing networks for distribution. It focused solving problems on "Last mile". There was no need to invest in expensive logistics network, but the exist network could be leveraged to cost-effectively deliver their products and services to people in hard-to reach market which can be more accessible to consumers at the Base of the Pyramid (BOP) markets, the largest and the poorest socio-economic groups in terms of population (Navi et al., 2012). In this study, it links transport resource management with the principle "*do more with less*", referring to maximize the amount of product moved on the vehicles to satisfy customers with enough service, while minimizing number of vehicles and distances to achieve an acceptable cost. The main benefit is to optimize the transport cost with the effective logistics network management as milk run optimization study. The transport cost is reduced by bulk prices by aggregating demand from several suppliers with full load of truck. With fixed and reliable schedule, the company is able to run business more systemically and professionally with better planning and management. Logistics network is designed to optimize the number of truck utilization with better truck filling ratio. As a result, manufacturers can spend the intelligent use of transport resources such as trucks, drivers, and other resources; meanwhile, they can deliver more value to customers at less cost.

2.3 Critical Comparison Frugal Engineering and Lean

In this study, it focuses on using frugal innovation as a management philosophy base. However, there is another famous management philosophy called as lean. Eugenia and Julia (2016) discussed both approaches with a critical comparison and implications for logistics process (Eugenia et al., 2016).

Before further comparing both philosophies, lean will be explained briefly as following. Lean is described as an approach emphasizing to identify and remove the wastes and focus on value adding activities in order to serve better customers' satisfaction, according to Womack and Daniel (2003) (cited in Eugenia and Julia, 2016). The scope was started from manufacturing environments and then expanded to other sectors, evolving as a multidimensional, integrated system approach incorporating practices such as just-in- time, quality systems, cellular manufacturing and Kanban, according to Baines et al. (2006) (cited in Eugenia and Julia, 2016). Bendell (2006) also described that lean could be translated into principles and tools for manufacturing processes such as waste elimination, value stream mapping, one-piece flow, a pull system and most importantly the creation of a culture of continuous improvement (cited in Eugenia and Julia, 2016).

There are similarities and differences between both frugal and lean. In similarities, firstly, both approaches are a management philosophy converting to mindsets for employees. Second, they are all about increasing value and reducing wastes. Third, they don't develop the green products but having indirect ecological benefits, from continuous improvement in term of lean and from either simple solution or lower resource utilization in term of frugal. Forth, they both see the suppliers as partners to develop products and services meeting customer demands (Eugenia and Julia, 2016).

However, there are also several important differences. First, frugal focuses on developing products with the cheapest price and high value to customers with more creative and innovation process with the value chain improvement. Second, the improvement will focus much more on the severe resource constraints orientation and focus on developing for utilization purpose with basic function rather than entertainment purpose with fancy feature; however, lean is the strategy to avoid competition and capture new market shares. Third, main focus of lean thinking is on process efficiency orientation and considers customer value during engineering process with "*lower cost*", but frugal focus outcome efficiency orientation to design at the first place to fit the constraints of customers such as affordability with "*affordable cost*" (Eugenia and Julia, 2016).

Both approaches were explained to imply logistics processes. The frugal solution is to simplify the logistics processes but lean sometimes conducts the complex logistics processes. The implication will be discussed as following perspectives: procurement, production, distribution, and disposal, according to the **Table 2.1** (Eugenia and Julia, 2016). The highlight differences, lean procurement emphasizes on process management but frugal is how to deal with limited resources for procurement such as using off-the-shelf components instead of unique or new parts. Lean production has clear Key Performance Index (KPI) to develop such as short lead time, low inventory level. However, frugal also focuses more on local solution and simplifies production activities. Lean production satisfies customers with the lower cost and shorten lead time like a milk-run scheme. However, this research has studied on different view of frugal mindset as broader view on transport resource management, sustainability, ecological perspective with environmental impact by reducing resources utilization such as trucks, and social perspectives with affordable price targeting to BOP customers. Nevertheless, lean and frugal are complementary approaches depending on the expected improvement result and view of study, according to Bhatti et al. (2013) (cited in Eugenia and Julia, 2016).

Table 2.1 Lean and Frugal Engineering - Implication for Logistics Process

Logistics Process	Lean Engineering	Frugal Engineering
Procurement	Early involvement of suppliers Standardization and reduction of complex parts which enables economies of scale Cost reduction, differentiation and the security of supply	Use of locally available materials Local suppliers Use of waste/recycled products as raw materials Reduction of complex parts Early involvement of suppliers Use of off-the-shelf components
Production	Kanban, Just-in-Time/Just-in-sequence techniques Automatization Modularization Low inventory levels	Higher resource productivity Use of local available tools and skilled labor Modularization Labor intensive manufacturing
Distribution	Milk-run concepts in order to achieve shorter lead times and lower costs Customer Relationship Management Multi-channel-management Integrated services and products	Locally available, existing distribution channels Robust and resistant packaging to withstand infrastructural problems during transport in remote areas
Disposal	Easy to disassembly modular design	Easy recycling and disposal of products Easy to disassembly design

Source: Eugenia and Julia (2016), Frugal and Lean Engineering: A Critical Comparison and Implications for Logistics Processes

2.4 Vehicle Routing Approach with Discrete Optimization

To find the efficient network configuration and network design for the milk run study, the study is expanded to the discrete optimization or combinatorial optimization which is the way to find an optimal solution with the finite number of possible solutions. There are several problems in combinatorial optimization such as Vehicle Routing Problem (VRP) or Traveling and Salesman Problem (TSP), and Knapsack Problem (KP). These problems require the algorithms to approach such as exact methods (i.e. Integer Linear Programming (ILP)), heuristics (i.e. saving algorithm) and metaheuristics (i.e. local search, tabu search). There are many previous researches approaching the combinatorial optimization problems in various ways.

Dávid et al. (2013) studied about the milk run vehicle routing approach for the shop floor logistics. He selected the various approaches to find the solution in each step of VRP. First, routing started with direct graph G to consider the lay-out of shop floor where was the set of vertices and denote stations and path between stations with constraints. Then, Dijkstra's algorithm was applied to calculate the shortest path. Next, it required a feasible milk run cycle planning, so the greedy algorithm was used to calculate the next node which must be visited by the vehicle before returning to the depot, avoiding the violation for the turnaround constraints of the vehicle. Lastly, he improved more complex time constraints with local search algorithm and neighborhood functions to support in case the total time of transport is greater than the required cycle time of the milk run. The local search would run again to adjust number of vehicles. The goal of this test was to minimize the number of vehicles but still kept the same service level through minimizing the time of cycle. He also suggested for the future work that highly complex system of milk run transport needed support of systematic and optimized planning (Dávid et al., 2013).

The aim of develop a systematic approach is to make milk rum system more stable for manufacturers. There is a study that used the approaches, namely 1) mixed integer linear programming model to optimized the milk-run route, 2) loading heuristics to increase the milk run truck utilization and time interval, and 3) assignment heuristics to avoid coincidence of milk run vehicles at the depots. This paper was aimed to solve the real-life problems of manufacturers. The number of vehicles was reduced around 17% and increased container utilization from 43.7% to 70.57% of loading rate. The waiting time was reduced with the time tables for each vehicle (Aslı and Nursel, 2016).

Xufeng et al. (2016) conducted the study in supply chain of auto parts based on milk run optimization. They expected to compare a current condition with the results from selected algorithms as saving algorithm and tabu search to find the shortest distance and minimize number of vehicles. The distance could be reduced 25% and the number of vehicles was reduced up to 62% (Xufeng et al., 2016).

Chawanat and Anirut (2016) also proposed the study relating to apply an integer linear programing to solve the vehicle routing problem. They developed the result from saving algorithm result by using the result as an initial solution. The transportation distances could be reduced after running the integer linear programing 4.72% or 3,359 THB/month (Chawanat and Anirut, 2016).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Data Collection

The data is secondary data which collected from many sources such as from a company, final reports, digital google mapping, and also my own experiences. The data is separated into following topics.

3.1.1 Information of Suppliers Tier 2 and Tier 1

Supplier's survey was collected data by a car maker company which contained the list of suppliers, locations, part detail, package detail including size of box, quantity, and gross weight, and also demand volume in fiscal year 2017.

In this study, it was scoped on industrial parks which the grouping locations of suppliers would be easier for route planning. The target zones were Chonburi and Rayong where mostly suppliers were located. Then, the chosen criteria was selected a group of Tier 2 locating in the common area with a group of Tier1 in the area either Chonburi or Rayong zone. After selection, there were four of Tier 2 in Chonburi, and two of Tier 1 in Rayong.

3.1.2 Information of Capacity and Number of Vehicles

The size and capacity of vehicles are the ordinary types mostly used in the market. The number of vehicles could be calculated with delivery volume with its capacity from the supplier's survey. For example, 56 pallets per day have to be delivered. A 6-wheel truck can carry 28 pallets per truck, so there are two vehicles per day. However, the current number of vehicles can refer to the delivery scheme as direct delivery which means that there is at least one truck per a supplier.

3.1.3 Information of Vehicle Routing and Distance

In this study, the geographic information was from Google map, including routing and distances, which was a symmetric distance. One way and return trip were in equal distance, so the round trip is double distances of one way. In this study, the distances and routes are considered in large scale of study which means that the measure unit of kilometer and main road selection are reliable for conducting the study.

Google map has been widely used by the feasible studies. The information can be access quickly and sharply. Christophe (2014) also claimed in his study that the Google map could create interesting possibilities for a research, even though Google Maps and Street View have not been developed with scientific research in mind (Christophe, 2014). He also supported that there are several scientific disciplines using quick to implement these web mapping applications in their researches. For example, Olea and Mateo-Tomás (2013) proposed that biologists tapped into street view imagery to assess the habitat of certain animal species (cited in Christophe, 2014). In his study, he showed how online mapping technologies opens up several new approaches for criminologists to conduct environmental criminological research in particular. As the result of many researches, Google map could be suggested to be useful and acceptable for the feasibility process in this study.

3.1.4) Information of Transport Cost

According to Department of Land Transport, the final report was about the study of feasibility and management model of provincial truck terminal, it contained the information for the Vehicle Operating Cost (VOC) with the representative vehicles. In this report, there were four main types of transport: Light truck (Pick up), Medium truck (6-wheel truck), Heavy truck (10-wheel truck), and Articulated truck (full/semi-trailer) (Department of Land Transport, 2015). VOC was calculated from the journey of each type of vehicles including resource consumption or loss rate and then multiplies with types of expenditures. The main expenditures were on the following list:

- Fuel cost
- Lubricant cost
- Tire cost
- Spare part and maintenance cost
- Repair cost
- Depreciation and interest cost
- Labor cost
- Insurance cost
- Driver license cost
- Annual car registration cost

The information was gathered from the statistical data in 2015 for the fuel cost, lubricant oil, tire, and the selected vehicles of each types referred by the top highest car registration with Department of Land Transport in the same year. With the conditions, the average working life is 10 years, distance as 100,000 kilometers per year, speed as 60-70 kilometer per hours. The vehicle operating cost was calculated with the economic value which is the total benefit for society and nation in term of economics, so the value is excluded all the tax. In term of finance, companies have to consider value with the finance value which includes all taxes. However, there are conversion factors for converting the value to economic value as Standard Conversion Factor (SCF) 0.92 (Sadiq, 1983). Therefore, the vehicle operating cost could be converted back to the finance value, according to **Figure 2.2.**

Table 3.1 Vehicle Operation Cost for Each Type of Transportation

Type	Total gross vehicle weight (Ton)	Total available payload (Ton)	Conversion factor	2015					
				Economic value	VOC(THB /km)	VOC(THB /km/ton)	Finance value	VOC(THB /km)	VOC(THB /km/ton)
Light Truck, LT	2.6	1	0.92	525,196	5.79	5.68	570,865	6.29	6.17
Medium Truck, MT	9.5	6.9		836,320	8.93	1.3	909,043	9.71	1.41
Heavy Truck,HT	25	18.2		1,856,128	17.98	0.99	2,017,530	19.54	1.08
Articulated Truck	50.5	35.5		2,003,817	22.39	0.63	2,178,062	24.34	0.68

Source: Department of Land transport (2015), Feasibility Study of Management Model for Provincial Truck Terminal

3.2 Process of the Study from Direct to Milk Run

It starts to clarify current number usage of vehicles, loading rate and total distances based on the direct delivery scheme. Then, three algorithms such as greedy algorithm, heuristic algorithm, and integer linear programming, have brought to solve the vehicle routing problems for milk run optimization study. In this section, the overall process is explained in a big picture to see the overall flow of logical thinking process in this study. The definition and procedure of each algorithm is described more details in the next section.

The algorithms start running with greedy algorithm, heuristic algorithm and then integer linear programming respectively. The result of previous algorithms is taken to run for the next algorithms with step by step. Consequently, the process cannot be skipped or crossed together. The results are developed along these three processes. Greedy algorithm and heuristic algorithm are specific methods designing for specific problems. The result is just possible result or good enough. Last process, an integer linear programming is an exact method which the result will be an optimization. This optimization has been applied widely to many related researches for solving the vehicle routing problems. Chanawat and Anirut (2016) also mentioned in their study that the integer linear programming is a useful method for solving the vehicle routing problem (Chawanat and Anirut, 2016).

With the milk run scheme, the delivery could be consolidated with the combined number of vehicles in case that the vehicle filling ratio is not full based on the capacity of its vehicles. Therefore, these three algorithms develop the result by gradually increasing the efficiency of those vehicle utilization and then the result is the best shortest route. After running through all processes, the result is expected to show lower number of vehicles, shorter distances entirely and also higher loading rate of vehicles. With these results, both direct and milk-run scheme would be compared for the cost comparison in term of transportation cost and also the performance improvement ratio. The overall process has shown in the **Figure 3.1**.

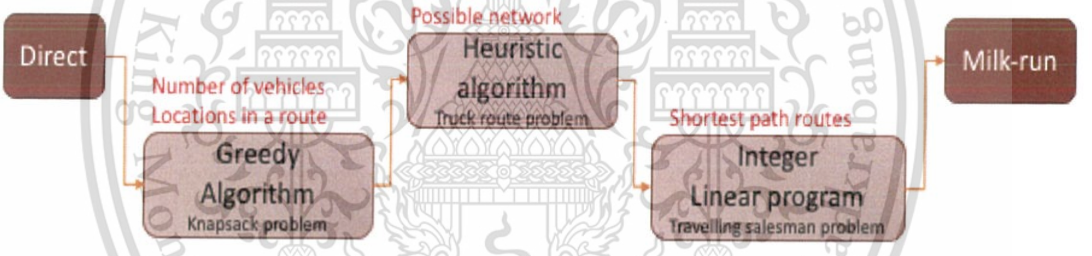

Figure 3.1 The Flow of the Study

3.3 Methodology and Procedure

3.3.1 Greedy Algorithm

It is to find where to go and how many vehicles based on its capacity. This algorithm is the heuristic method which is simple and efficient. The result is not optimal solution but it could provide good enough solutions in reasonable time.

Knapsack problem (KP) is considered with the greedy algorithm as a combinatorial optimization. In this problem, it is about to pretend as a thief who want to steal and fit things in a bag. Ivica and Golub (2006) also described the Knapsack as a maximization problem of choosing as much as possible items that can fit into a bag with maximization weight (Ivica and Golub, 2006). Therefore, with many value items, the thief has to select things to get the highest total value within the limited capacity of a bag. There are three strategies for the selection:

- Greedy by profit: with the highest profit.
- Greedy by weight: with the lowest weight.
- Greedy by profit density: with the highest profit density.

$$x_i \begin{cases} 1; & \text{if object } i \text{ is selected to be in a sack} \\ 0; & \text{if object } i \text{ is not selected to be in a sack} \end{cases}$$

Objective function:

$$Maximize \sum_{i=1}^{n} v_i x_i$$

Subject to

$$\sum_{i=1}^{n} w_i x_i \leq W$$

$$x_i \in \{0,1\}; \quad \forall i$$

$$\text{Profit density} = (d_i) = \frac{v_i}{w_i}$$

w_i = weight of item i

v_i = value of item i

W = capacity of the bag

Source: Williams (2009), Logic and Integer Programming

In this study, the knapsack problem is applied to solve on loading problem for milk run delivery. It means that all items have to be delivered no need for the highest value selection. Therefore, Knapsack will be solved in another way to carry as much as possible with the total lowest cost. The capacity of vehicle is more complicated as involving too many constraints such as the size of package, the size of vehicles, the available payload of vehicles, and the available cubic meter inside the vehicles which all of the selected items are not over than these capacity constraints. Moreover, the type of vehicles will be considered in this study up to three types: 1) pick up, 2) 6-wheel truck, and 3) 10-wheel truck. The greedy strategies also have to change for the selection: greedy by cost, greedy by weight, and greedy by cost density.

- Greedy by cost: with the lowest cost
- Greedy by weight: with the lightest weight.
- Greedy by cost density: with the lowest density.

$$x_i \begin{cases} 1; & \text{if object } i \text{ is selected to be in a sack} \\ 0; & \text{if object } i \text{ is not selected to be in a sack} \end{cases}$$

Objective function:

$$Minimize \sum_{i=1}^{n} c_i x_i$$

Subject to

$$\sum_{i=1}^{n} w_i x_i \leq W$$

$$x_i \in \{0,1\}; \quad \forall i$$

Profit density = $(d_i) = \frac{c_i}{w_i}$

$w_i =$ weight of item i

$c_i =$ cost of item i

$W =$ capacity of the bag

The expected result is to find the proper type of vehicles with the possible number of vehicles and specify which nodes in the transportation route by the capacity of selected type of vehicles. Then, the result is developed in the next process for the truck routing problem.

3.3.2 Heuristic Algorithm

It is to find how to connect nodes to be a route. Heuristic method is designed for the specific purpose or problem. In this study, it is designed for a truck route problem. It is how to solve a problem with experience-based technique, so the answer is not guaranteed to be optimal but good enough, quick, easy in practical use.

Customer	Demand (Density)
1	0.3
2	0.4
3	0.6
4	0.8
5	0.1
6	0.2
7	0.3
8	0.5
9	0.3

Figure 3.2 Customer Demand

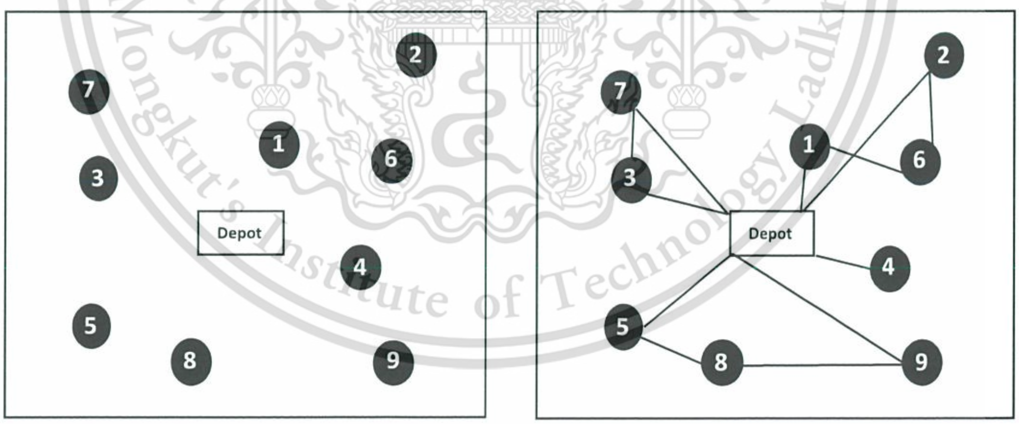

Figure 3.3 Customer Locations and Heuristic Route

Data requirement includes the customer demand as sample in **Figure 3.2** which showed demand in ratio, and customer locations as total 20 locations in **Figure 3.3.**

Step 1: Consider which the customer is located at the farthermost from depot and then selects the location including in a route.

D → 2 → D

then $w_2 = 0.4$

Step 2: After selection, if there is available space in a truck, nearby customer will be considered next to visit and pick up parts until the truck is full. Regarding the previous step, the location number 8 will be selected as a next location.

D → 2 → 6 → 1→ D

then total $w_2 + w_6 + w_1 = 0.9$

While combing these locations, these constraints will be considered carefully as following.

- Total weight do not exceed vehicle capacity
- Distance of each route do not maximum length or time (e.g. per day)
- Customers on each route do not exceed maximum stops (e.g. per day)

Step 3: Start Steps 1 and 2 again for the remaining customers. For example,

D→ 7→ 3→ D

then total $w_7 + w_3 = 0.9$

According to the result from the previous greedy algorithm, it provided which locations or nodes that one truck can deliver the parts to. In this study, heuristic algorithm will help to solve the vehicle routing problem by finding how to connect each destination in order to build the possible routes. Then, the result will be developed in the next process for an optimization.

3.3.3 Integer Linear Programming (ILP)

It is to find how to optimize vehicle routing. This algorithm is broadly applied to solve the vehicle routing problem which is to optimize the milk run route. Network routing problems can be formulated as linear programing problems which can be easily reformulated as a travelling salesman problem (Gerard and Diptesh, 2010).

This study will show a formulation for the traveling salesman problem. In the formulation, there are several abbreviations in the formulation, where D_{ij} standing for distance between *i* to *j*, *N* standing for set of nodes, *A* standing for set of arcs, *S* standing for number of nodes in a route.

The decision variable x_{ij} is for each arc *i* to *j* and also assumes a value of 1, if arc is included in the optimal solution or selected to be on the tour, and 0 otherwise. It consists of two main elements in this formulation, namely objective function and constraints.

The objective function aims to minimize the total selected of arc with the minimum distances which will run relating to decision variables under three constraints. Each node will be visited exactly once.

$$x_{ij} \begin{cases} 1; & \text{if arc } (i,j) \text{ is selected to be on a tour} \\ 0; & \text{if arc } (i,j) \text{ is not selected to be on a tour} \end{cases}$$

Objective function:

$$Minimize \sum_{(i,j)\in A} D_{ij} x_{ij}$$

Subject to

$$\sum_{(i,j)\in A} x_{ij} = 1; \quad \forall i \in N \tag{3.1}$$

$$\sum_{(j,i)\in A} x_{ji} = 1; \quad \forall i \in N \tag{3.2}$$

$$\sum_{(i,j)\in A: i\in S, j\in S} x_{ij} \leq |S| - 1; \quad \forall S \subset N, 2 < |S| < N - 2 \tag{3.3}$$

$$x_{ij} \in \{0,1\}; \quad \forall (i,j) \in A$$

Source: Gerard and Diptesh (2010), Networks in Action: Text and Computer Exercises in Network Optimization.

The first constrain (3.1) will control that only one arc of the network departing from *i* with the sum of total arcs equal to 1. The second constraint (3.2) will also limit that only one arc of the network arriving to *i* with the sum of total arcs equal to 1. It seems that these two constraints adequate formulations but they are not. The subtour elimination constraint (3.3) is needed to eliminate all solutions that are not tours. If a set of nodes forms one of the subtours, the result would fail to satisfy the optimized solution. In other words, the number of arc, *A* should be less or equal to the number of nodes set $|S|$-*1* which the condition all of S is a subset of *N*, and number of node set *S* is greater than 2 nodes but less than to N-2 nodes (Gerard and Diptesh, 2010).

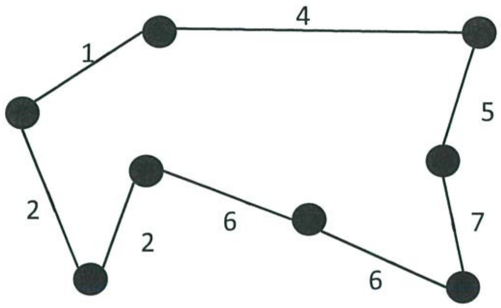

Figure 3.2 Sample of a Traveling Salesman Problem

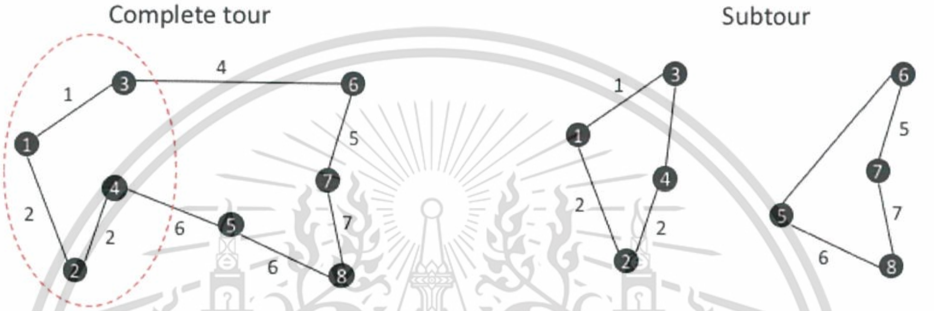

Figure 3.3 Comparison of Completed Tour and Sub Tours

As the result, the previous process is a heuristic method, so the result is showed only possible or good enough routes, according to the heuristic algorithm. It is possible that the total of distance can be developed more in this process. Integer linear programming is an exact method; therefore, the result will be an optimization. The expected result is to reduce the total distance greater than the previous process.

CHAPTER 4

RESULTS AND DISCUSSIONS

Currently, there are four suppliers of Tier 2 (location 1-4) and two customers of Tier 1 (location 5 and 6) in **Figure 4.1**. They are all direct delivery from Tier 2 to Tier 1. Therefore, the number of vehicles is equal to number of supplier Tier 2 which is four of 6-wheel trucks. Moreover, the capacity of truck is also not full comparing with the current daily delivery as only 30%-40% of the truck filling ratio. However, it is not only the weight is considered, but also the size of package is to fit inside a vehicle. There are two types of packages: steel rack and plastic box.

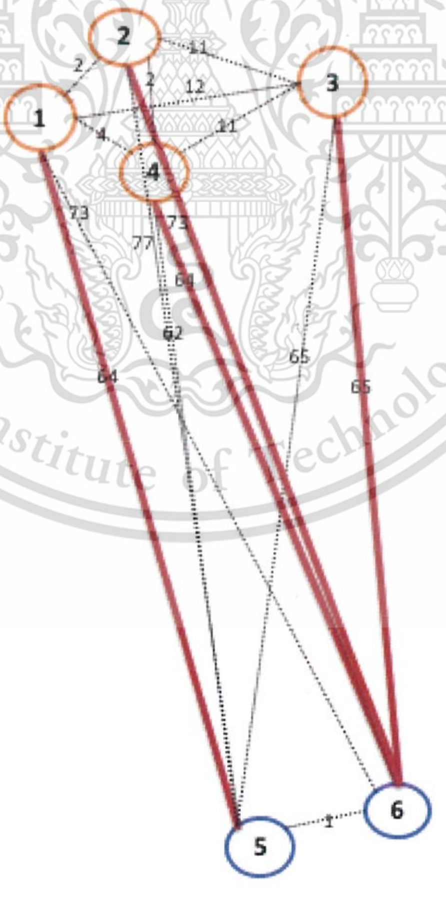

Figure 4.1 Current Delivery Route

Table 4.1 Current Condition with Number of Vehicles and Total Distances

Topic	Vehicle	Location	Route	Distance(km)
Current	1	5,1,5	5-1-5	128
	1	6,2,6	6-2-6	146
	1	6,3,6	6-3-6	120
	1	6,4,6	6-4-6	128
Total	**4**			**522**

This study aims to increase the truck filling ratio which leads to reduce number of vehicles and also the total distances in the meantime. It begins with the greedy algorithm to solve the knapsack problem.

4.1 Greedy Algorithm Results

With this approach, it assumes a vehicle as a bag of thief. The capacity of truck is the first priority of a constraint to consider the selected modes of transport. The candidate modes in this study are pick-up, 6-wheel truck, and 10-wheel truck. The capacity would be validated as following: limited available payload weight, dimension of truck, and volume, according to **Table 4.2**. Therefore, it is required to know the dimension of package and gross weight to match with the capacity.

Table 4.2 The Capacity Matrix

Mode	Available Payload Weight (kg)	W(m.)	L(m.)	H(m.)	CBM/truck	CBM (80%)	Steel Rack	Plastic Box
Pick up	1000	1.5	2.3	2.0	6.7	5.4	2	60
6-Wheel	6000	2.4	7.5	2.4	42.3	33.8	24	420
10-Wheel	13000	2.4	7.5	2.4	42.3	38.1	24	420

First step, the definition of each variables has to be clarified, referring to the formulation below. Then, a matrix is created to validate by inputting the information from supplier's survey for each mode of transportation with the detail of parts, from/to destination, package type, gross weight, number of package per day, vehicle operating cost by weight, volume of delivery per day, weight per day and cost density.

$$x_i \begin{cases} 1; & \text{if object } i \text{ is selected to be in a sack} \\ 0; & \text{if object } i \text{ is not selected to be in a sack} \end{cases}$$

Objective function:

$$Minimize \sum_{i=1}^{n} c_i x_i$$

Subject to

$$\sum_{i=1}^{n} w_i x_i \leq W$$

$$x_i \in \{0,1\}; \quad \forall i$$

$c_i = Vehicle\ operating\ cost\ (Thai\ Baht\ per\ kilometer\ per\ ton)$

$w_i = Volume\ of\ a\ container\ (\ cubic\ meter\ per\ day)$

$W = Capacity\ of\ truck, according\ to\ Figure\ 4.2$

$d_i = Cost\ density\ equal\ to\ \frac{c_i}{w_i}$

Third step, validator is set what to be greedy. In this study, the greedy strategy is separated into 3 categories: greedy by cost, greedy by weight, and greedy by cost density.

- Greedy by cost: with the lowest vehicle operation cost by weight
- Greedy by weight: with the lightest weight.
- Greedy by cost density: with the lowest density.

Fourth step, it is to combine information from second step and third step into one matrix and then solve the knapsack problem with binary number 1-0, for 1 as selected, 0 as otherwise, with each greedy strategy. While solving, it is important to consider the selection less or equal to the capacity.

Table 4.3 Demonstration of Logical Thinking Process of Knapsack Problem

Tier 2	Tier1	i	c_i	w_i	c_i / w_i	Greedy by Cost	Greedy by Volume weight	Greedy by Density	Optmal solution
1	5	item 1	10	3	3.3	0	1	0	1
2	6	item 2	5	5	1.0	0	0	0	0
3	6	item 3	15	3	5.0	0	1	0	0
4	6	item 4	2	6	0.3	1	0	1	1
If capacity = 10 kg, Total weight (W)						6	6	6	9
Total cost (c_i)						2	25	2	12

1) Greedy by cost, the selection starts with the lowest cost as item 4. Then, it cannot go further for selection as the next low cost item is item 2 which the sum of total weight is 11 kilograms over the capacity of truck at 10 kilograms. Therefore, the selection is only item 4 with the weight as 6 kilograms and the total cost is 2 Baht.

2) Greedy by volume weight, the selection begins with the lightest one which is item 1 and item 3 with the sum of total weight as 6 kilograms and then stop the selection because the next light one is item 2 as 5 kilograms. The total three items will over than the capacity. Therefore, item 1 and item 3 will be selected with weight as 6 kilograms and the total cost is 25 Baht.

3) Greedy by density, the selection will consider the lowest cost density first, so it will start with item 4 as 0.3. The result is similar to the greedy by cost because of the limited capacity. Therefore, the item 4 is selected as the total weight as 6 kilograms and the total cost as 2 Baht.

Then, the optimal solution runs to pick up item as much as possible with the conditions as the total lowest cost but still keeping weight less or equal to the capacity. The final result is shown on **Table 4.3** by selecting item 1 and 4 for the first vehicle with the total weight as 9 kilograms and the lowest total cost as only 12 Baht. The rest items will be loaded to next vehicle under each capacity condition until picking all items completely.

In this study, it is more complicated solving the knapsack problem which will applied to run with all three types of transport: pick up, 6-wheel truck, and 10-wheel truck. In each type, it has different capacity, according to **Table 4.2**. Therefore, the matrix has to be validated carefully.

Another complicated issue is to consider the capacity constraints. For instance, with the 6-wheel truck, the total gross weight is not over 6,000 kilograms but the space sometimes is not enough inside the truck with the dimension of package. The number of packages are limited by stimulating the size of package matching with the size of truck. For example, steel rack can be fitted total 24 of them with 2 layers in one truck. For plastic box will be placed on pallet as 15 boxes per pallet and the pallet can fit in one truck as total 28 pallets of them or 420 boxes per truck. In case of mixed type, it also has to consider case by case to know the number of packages.

The results is shown on **Table 4.4** with three scenarios including the selected types of transportation and the locations in each route.

Table 4.4 Results of Knapsack Problem

Topic	Vehicle	Route	Location
Current (Direct Delivery)	6-wheel	Route 1	5,1,5
	6-wheel	Route 2	6,2,6
	6-wheel	Route 3	6,3,6
	6-wheel	Route 4	6,4,6
Scenario 1	**Pick up**	Route 1	5,1,5
	6-wheel	Route 2	5,1,3,2,4,6,5
	Pick up	Route 3	5,1,5
Scenario 2	**6-wheel**	Route 1	5,1,3,2,6,5
	6-wheel	Route 2	6,4,6
Scenario 3	**10-wheel**	Route 1	5,1,3,4,6,5
	Pick up	Route 2	6,2,6
	Pick up	Route 3	6,2,6

Current delivery scheme, there are four of 6-wheel with all direct and exclusive truck from and to locations.

- Scenario 1, pick-up is the first priority to consider type of vehicle loading until full capacity and then to the next vehicles until finishing all items.
- Scenario 2, 6-wheel truck is the first priority to consider type of vehicle loading until full capacity and then to the next vehicles until finishing all items.
- Scenario 3, 10-wheel truck is the first priority to consider type of vehicle loading until full capacity and then to the next vehicles until finishing all items. It may notice why two of pick-up using in the condition 3 but 6-wheel truck. The reason is the rest items for picking as only 3 steel rack which two of pick-up are lower cost than one of 6-wheel truck.

Regarding these three conditions, they obviously reduce number of vehicles after running the greedy algorithm because the algorithm mainly considers the capacity of truck to be loading fully fulfilled. Moreover, the result of this algorithm can show what kind of the suitable types of vehicles based on the vehicles capacity and locations but there is no idea where to go from the first location to the next and until returning back to the first location. The network has to be created, so all three scenarios will be run in the next algorithm as heuristic algorithm to find possible milk run route.

4.2 Heuristic Algorithm Results

This algorithm is a heuristic method which is designed to solve a truck route problem. It will solve and find how to connect each nodes or locations to be a network. With the result from previous process in **Table 4.4**, there are specific locations on each route. Therefore, those locations are run with this algorithm to find possible routes departing from the Tier 1 locations and return to Tier 1 locations after visiting all Tier 2 locations.

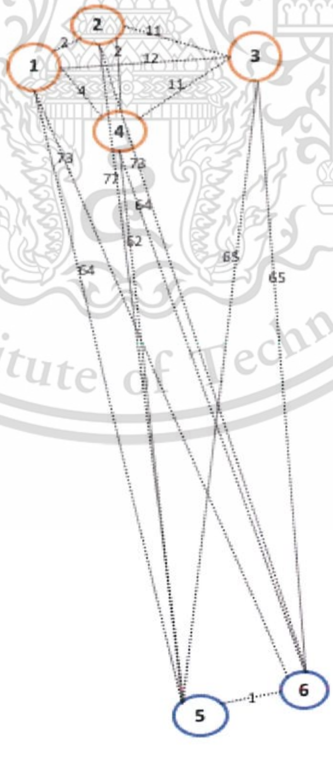

Figure 4.2 Mapping Location of Tier 2 (1-4) and Tier 2 (5,6) with Distances

Firstly, all of locations have to be located and draw with all possible arcs or route between each nodes or locations. After that, each location is defined distances by Google digital mapping. For example, the distance between location 1 and location 5 is 64 kilometers. The result is shown below on **Figure 4.2**. All of locations are needed to be connected in order to find possible routes as much as possible. Then, this approach will start with three main steps.

Secondly, each location is connected by heuristic algorithm. According to **Table 4.4**, it starts with route 2 from scenario 1 as following location 5,1,3,2,4,6,5.

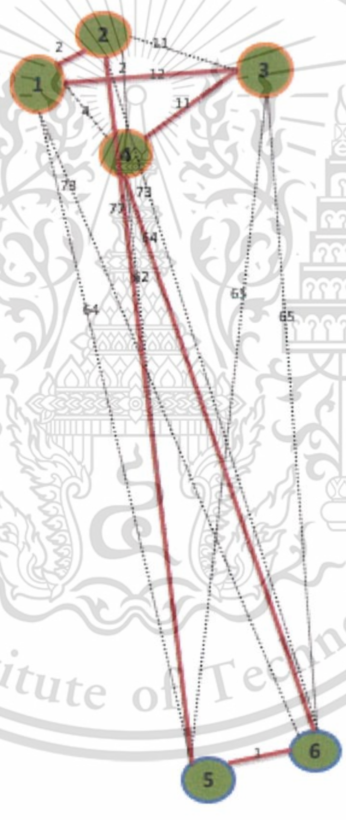

Figure 4.3 Heuristic Result of the Route 2 of the Scenario 1

Step 1: Start from location 5 as a Tier 1 to the farthest Tier 2 location which is location 2.

5 → 2 → , total distance = 62 kilometers

Step 2: Other locations are 1,3,4,6. The next drop would be nearby location 2 which is location 1 and then go to location 3, to location 4, to location 6 and return to location 5.

5 → 2 → 1 → 3 → 4 → 6 → 5, total distance = 167 kilometers

Step 3: Start steps 1 and step 2 again for the remaining routes on **Table 4.4** until completing all.

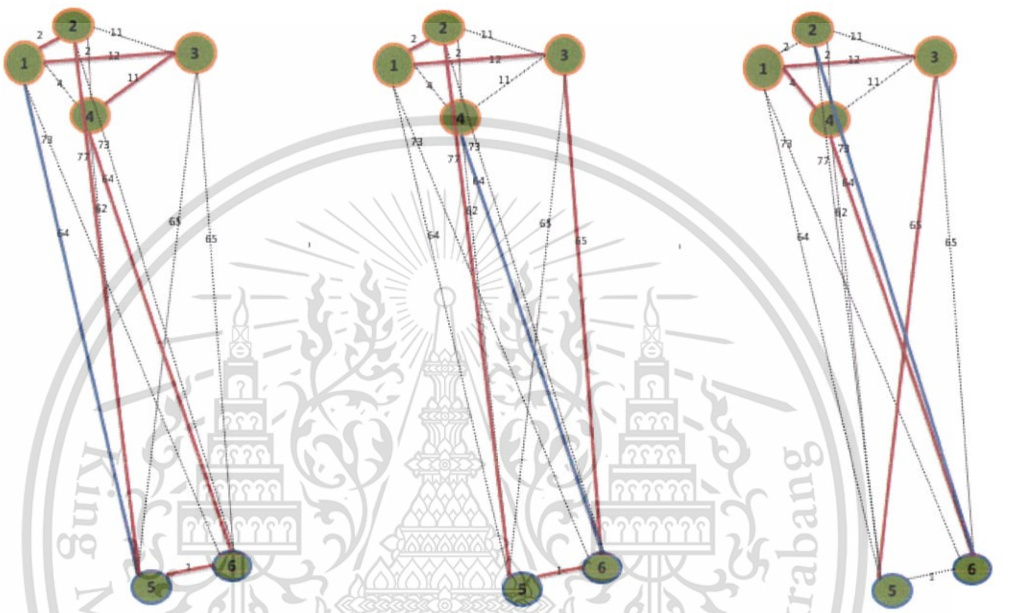

Figure 4.4 Results of Heuristic

Table 4.5 Results of Heuristic

Topic	Vehicles Type	Route	Location	Sequence	Distance (kilometer)
Current (Direct delivery)	6-wheel	Route 1	5,1,5	5--1--5	128
	6-wheel	Route 2	6,2,6	6--2--6	146
	6-wheel	Route 3	6,3,6	6--3--6	120
	6-wheel	Route 4	6,4,6	6--4--6	128
	Total				522
Scenario 1	Pick up	Route 1	5,1,5	5--1--5	128
	6-wheel	Route 2	5,1,3,2,4,6,5	5-2-1-3-4-6-5	167
	Pick up	Route 3	5,1,5	5-1-5	128
	Total				423
Scenario 2	6-wheel	Route 1	5,1,3,2,6,5	5-2-1-3-6-5	157
	6-wheel	Route 2	6,4,6	6-4-6	128
	Total				285
Scenario 3	10-wheel	Route 1	5,1,3,4,6,5	5-3-1-4-6-5	146
	Pick up	Route 2	6,2,6	6-2-6	146
	Pick up	Route 3	6,2,6	6-2-6	146
	Total				438

Finally, according to **Table 4.5**, it showed that the total distance can be reduced comparing between current and the results of all three scenarios. Especially, the scenario 2 can be reduced up to 45%. Only scenario 2 is selected to run in the last algorithm with the shortest total distances comparing with other conditions. Other scenarios contain more than one direct delivery which cause long distances, so they are unnecessary to consider for the next process.

4.3 Integer Linear Programming Result

This approach is the exact method, so the result was an optimization which is the expected final result for this study. The initial solution from the heuristic result was run in this algorithm to solve a travelling salesman problem. The objective function aims to minimize total distances for this milk run route with three constraints: 1) each location departs only once, 2) each location arrives only once, and 3) sub tours have to be eliminate in the condition that the number of route is less or equal to the number of locations in the route minus one.

First step, the definition of each variables has to be clarified, referring to the formulation.

$$x_{ij} \begin{cases} 1; & \text{if arc } (i,j) \text{ is selected to be on a tour} \\ 0; & \text{if arc } (i,j) \text{ is not selected to be on a tour} \end{cases}$$

Objective function:

$$Minimize \sum_{(i,j)\in A} D_{ij}x_{ij}$$

Subject to

$$\sum_{(i,j)\in A} x_{ij} = 1; \quad \forall i \in N$$

$$\sum_{(j,i)\in A} x_{ji} = 1; \quad \forall i \in N$$

$$\sum_{(i,j)\in A: i\in S, j\in S} x_{ij} \leq |S| - 1; \quad \forall S \subset N, 2 < |S| < N - 2$$

$$x_{ij} \in \{0,1\}; \quad \forall (i,j) \in A$$

Source: Gerard and Diptesh (2010), Networks in Action: Text and Computer Exercises in Network Optimization.

$x_{ij} = 1$ *is the path/tour from location i to location j, 0 otherwise*

D_{ij} = *the total distance from location i to location j*

S = *the number of locations in a route*

N = *the number of all locations*

A = *the number of all routes*

Table 4.6 Distance Matrix in Kilometer

From/To	1	2	3	4	5	6
1	0	2	12	4	64	73
2	2	0	11	2	77	73
3	12	11	0	11	65	65
4	4	2	11	0	62	64
5	64	77	65	62	0	1
6	73	73	65	64	1	0

Second step, it is to clarify distance in the data matrix, according to **Table 4.6**. This data is used to generate the formulation. According to the route 1 of the scenario 2 in **Table 4.5**, the objective function aims minimize this route, 5-2-1-3-6-5, total distance as 157 kilometers, according to the generated formulation below

Objective function

Min Z = $12x_{13}+2x_{12}+64x_{15}+73x_{16}+12x_{31}+11x_{32}+65x_{35}+$

$65x_{36}+2x_{21}+11x_{23}+77x_{25+}+73x_{26}+64x_{51}+65x_{53}+$

$77x_{52}+1x_{56}+73x_{61}+65x_{63}+73x_{62}+1x_{65}$

Subject to

1. Depart only once

$x_{12}+x_{13}+x_{15}+x_{16}=1$ $\quad x_{51}+x_{52}+x_{53}+x_{56}=1$

$x_{21}+x_{23}+x_{25}+x_{26}=1$ $\quad x_{61}+x_{62}+x_{63}+x_{65}=1$

$x_{31}+x_{32}+x_{35}+x_{36}=1$

2. Arrive only once

$x_{21}+x_{31}+x_{51}+x_{61}=1$ $\quad x_{15}+x_{25}+x_{35}+x_{65}=1$

$x_{12}+x_{32}+x_{52}+x_{62}=1$ $\quad x_{16}+x_{26}+x_{36}+x_{56}=1$

$x_{13}+x_{23}+x_{53}+x_{63}=1$

3. Sub tour constrains elimination

$x_{12}+x_{21} <= 1$ $x_{26}+x_{62} <= 1$

$x_{14}+x_{41} <= 1$ $x_{32}+x_{23} <= 1$

$x_{15}+x_{51} <= 1$ $x_{35}+x_{53} <= 1$

$x_{16}+x_{61} <= 1$ $x_{36}+x_{63} <= 1$

$x_{25}+x_{52} <= 1$ $x_{56}+x_{65} <= 1$ $etc ...$

Table 4.7 Result of Decision Value

From Location	To Location	Distance (km)	Decision Variable
1	3	12	0
1	2	2	0
1	5	64	1
1	6	73	0
3	1	12	0
3	2	11	1
3	5	65	0
3	6	65	0
2	1	2	1
2	3	11	0
2	5	77	0
2	6	73	0
5	1	64	0
5	3	65	0
5	2	77	0
5	6	1	1
6	1	73	0
6	3	65	1
6	2	73	0
6	5	1	0
			143

Thirdly, the formulation is run in the excel solver. The result is shown in the **Table 4.7**. The selected to be on tour will be 1, otherwise is 0.

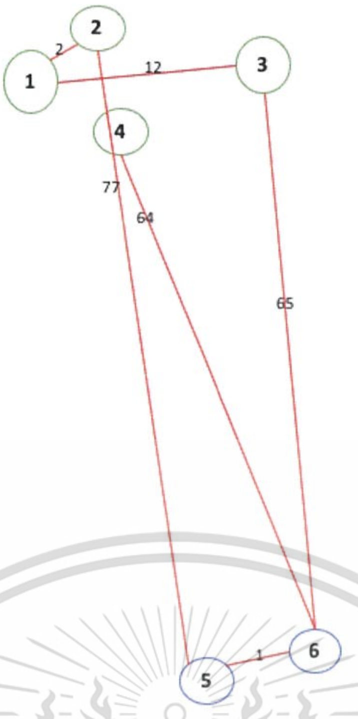

Figure 4.5 The Network of Heuristic Method

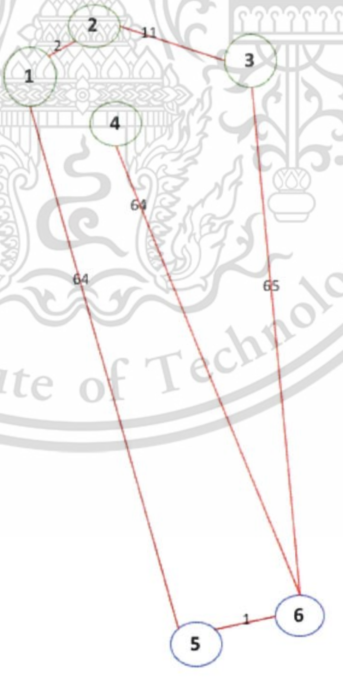

Figure 4.6 The Network of Integer Linear Programming

Table 4.8 Comparison Results of Heuristic and Integer Linear Programming

Initial	Route		km	After	Route		km	Saving
Heuristic algorithm	1	5-2-1-3-6-5	157	Integer linear programming	1	5-6-3-2-1-5	143	-9%
	2	6-4-6	128		2	6-4-6	128	0%
	Total		**285**		**Total**		**271**	**-5%**

According to the **Table 4.8,** after running an optimization model, the distance in the route 1 can be reduced 9% and the total distance is reduced 5%. This result is linked to other researchers who apply the integer linear programming to develop the result from other algorithms. According to Chawanat and Anirut (2016), they studied to improve milk run transport cost in an automotive spare part company in Thailand (Chawanat and Anirut, 2016). The result of initial solution of saving algorithm developed and reduced distance 9.97% of individual route and 4.7% for total distance with this optimization model. Apichit et al. (2013) also applied this model to develop the initial solution from heuristic result and the transport cost can be reduced 9.7% in a case study of concrete block distribution in Bangkok Metropolitan Region (Apichit et al., 2013).

Table 4.9 Results of Comparison between Original Route and Revised Routes

Approach	Route	Total Transport Distance(km)	Number of Vehicles	Transport Cost (THB/yr)
Current condition (direct delivery)	5-1-5, 6-2-6, 6-3-6, 6-4-6	522	4	1,338,115.68
Heuristic algorithm (milk run delivery)	5-2-1-3-6-5, 6-4-6	285	2	730,580.40
Integer linear programming (milk run delivery)	5-1-2-3-6-5, 6-4-6	271	2	694,692.24

Final result is shown in **Table 4.9**. The Integer Linear Programming (ILP) can develop the heuristic result with totally 5% of the reduced distance. However, ILP result has to be developed on the sequence of the route 1 for practical use from 5-**6**-3-2-1-5 in **Table 4.8** to 5-1-2-3-**6**-5 in **Table 4.9** for suitable sequence of supply. A truck has to depart from location 5 to pick part from location 1-3 and then come back to supply at the location 6 and 5 respectively for completing supply in one cycle as same total 143 kilometer as the original ILP result.

Milk run with optimization model can totally improve the direct delivery up to 48% of transport cost reduction. Therefore, the final result proves that the selected methodologies are useful for solving the vehicle routing problems. With transport resource management, it is improved by the reduced number of vehicle and drivers. Social and environmental impact can get benefit in term of reducing accident events, traffic congestion, and Greenhouse Gases (GHGs) emissions consistent with the reduced number of vehicles.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study aims to find the optimal solution for transport resource management and cost reduction. As mentioned earlier, there are three levels of scenario: strategical, tactical and operational view. Therefore, this section concludes each scenario and also the top view of a combination of all scenarios.

In strategical scenario, it is a vision of CEO in a company who has a management philosophy in mind and then converts and cascades as a mindset to employees in an organization. The frugal mindset is a representative of the strategical scenario in this study which focus on improving transport management between Tier 1 and Tier 2. Frugal engineering firstly uses to develop product with the resource constraints which serve to the poorest citizens within emerging markets such as India and China. However, with the rapid economic growth in these markets, people can gain more power of purchasing as new middle class. They would prefer to affordable and simple technology solutions and products to meet their tight budget (Mokter, 2017). Affordability is a key to serve low-income customers with frugal innovation. This study is to improve the price to be more affordable by managing transport resources and applying one of frugal principles as "*do more with less*". It is how to maximize results with minimum resources; in other words, it is to maximize loading capacity of vehicles with the minimum number of vehicles but still keep a service level of customer satisfaction. The frugal mindset enhances a value creation: 1) the economic value, offering the greater values to customer with the lowest cost, 2) the environmental value, optimizing resource utilization, and 3) the social value, accessing of products with affordable price to mass population which can lift up their quality of life to own products with low cost, especially in an emerging market. Nano, a car product from frugal development is one of the best examples which allow millions of people to reliably drive their own cars (Vikas et al., 2010). Therefore, its benefit of frugal mindset is not only to make an affordable price solely, but also can appreciate with higher revenue and profits on mass populations in these emerging markets.

In tactical scenario, in order to support the frugal mindset, logistics and supply chain management has to be reviewed where is the cost that the customers are not willing to pay (Eugenia and Julia, 2016). Supply chain is a network of value creators along a pipeline of value to the end customers. However, it requires logistics management as activities managing a flow of value to offer the better value to end customers, according to supply chain thinking as collaboration (co-planning), communication (information sharing), connection (flow of value) (Suharitdamrong, 2014). The synchronization with customers is a key in this study to know the demand for planning and then lead to operate logistics activities for supply effectively. The goals of synchronization are to achieve better quality, cheaper cost, and shorter lead time supported by the supply chain thinking.

In operational scenario, milk run is selected as a logistic management scheme which integrates process with transportation management. With the logistics system, this scheme serves the transportation quality collaboratively with strong information sharing for communication with suppliers to solve any issues of shipments (i.e. wrong delivery, transportation damage) through the material flow of channel connectively with the shorter lead time. Milk run is an operational scheme to support how to maximize loading capacity of vehicle with the minimum number of vehicles. There are three main procedures developing the optimize solution for this milk run study. Firstly, it is to find the minimum number of vehicles and locations in a route subjected to the capacity of vehicle itself by a greedy algorithm solving knapsack problems. Then, it is to create networks for each route by heuristic algorithm solving truck route problem. Finally, the optimization model will develop the network from heuristic result with integer linear programming solving traveling salesman problem. After completing all study processes, the selected algorithms could improve the current condition with interesting potential on transport cost reduction of 48% or 643, 423 THB/ year. Therefore, the selected algorithms are the useful methods for solving vehicle routing problems offering the milk run optimization.

Consequently, three levels of scenario are supported each other through the study. Frugal mindset is conducted as a company goals with the concept to maximize to profits with minimum transport resources in term of logistics. In order to develop the mindset, logistics and supply chain management is the next scenario to review current condition with supply chain thinking as collaboration, communication, and connective by logistics management for offering value to the end customers (Suharitdamrong, 2014). Therefore, a key focus is to synchronized logistics activities with the customer needs for achieving customer satisfaction at the right place in the right time with the right cost. The last scenario is the milk run optimization which is performed as a logistics management supporting the supply chain thinking while enhances the optimized solution, according to the purpose of the frugal mindset.

5.2 Recommendations

This study is considered only low truck utilization for developing milk run scheme. However, milk run can also develop inventory management with sequence and small lot of delivery, so it would be interesting to consider for the full truck utilization with big lot of delivery with low frequency of delivery as twice a month. Moreover, it is important to determine trade-off analysis for inventory costs and transportation cost. If the inventory cost (holding cost) is higher than the transport cost (moving cost), it had better increase frequency of delivery and manage loading to be smaller lot applying to milk run concept with nearby suppliers.

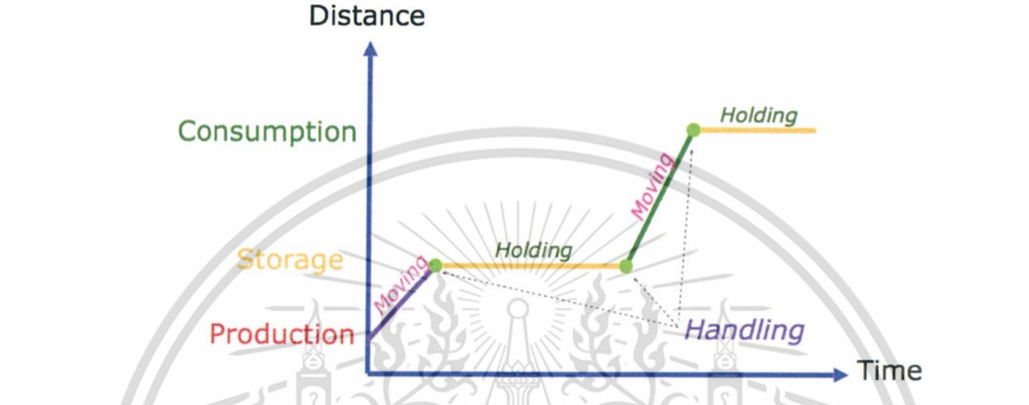

Figure 5.2.1 Logistics Cost Diagram

In the future work, it aims to expand the model with the time interval study to manage time schedule to control the total delivery time not over the required cycle time per day or number of hours per day with cycle time management. Besides, originally vehicle operating cost is economic value which is converted to finance value for calculating transport cost in this study. Therefore, in practical work it had better apply the market transport rate for the calculation. However, it would be interesting to try this logical thinking process to other manufacturing network studies.

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APPENDIX A

EXPENDITURES FOR VEHICLE OPERATING COST

Table A.1.1 Approximate Prices of Representative Vehicles

No.	Types of vehicles	Representative vehicles		
		Brand	Vehicle model	Price (baht/Unit)
1	Light Truck (LT)	Toyota	Vigo champ 2.5G (VNT)	714,000
2	Medium Truck (MT)	Isuzu	NPR	1,050,000
3	Heavy Truck (HT)	Hino	FM 1 JNRD 260HP	2,200,000
4	Articulated Truck (AT)	Hino	FM 1 JNRD 260HP	2,200,000

Source: Reference price in October 2015

Table A.1.2 Economic Prices of Various Types of Car Tires

No.	Types of vehicles	Prices of truck tires	
		Size of wheels and tires	Price (baht /tire)
1	Light Truck (LT)	215/70 R16C	3,900
2	Medium Truck (MT)	7.50-16-14PR	4,400
3	Heavy Truck (HT)	9.00-20-14PR	6,800
4	Articulated Truck (AT)	10.00-20-16PR	8,000

Source: Reference price in October 2015

Table A.1.3 Fuel Prices for Trucks

Fuel groups	Types	Retail prices
Fuel gas	NGV	13.55/kg.
Diesel fuel	B5	23.44

Source: Reference price in October 2015

Table A.1.4 Economic Prices of Lubricants

Brand	Prices of lubricants for diesel engines (baht/liter)	
	Synthetic Blends	Full-Synthetic
PTT	110	278.57
Shell	108.33	-
Castrol	124.29	300
Valvoline	117.14	242.86
Bangchak	88.57	278.57
Mobil	113.33	316.67
Financial average price	110.28	283.73
Market share (%)	50	50
Weighted average price	197	

Source: Reference price in October 2015

APPENDIX B

CONVERSION FACTORS

Table A.2.1 Summary of Country Parameters for Thailand (1980)

Efficiency Pricing Parameters	Central value	Sensitivity range
Standard Conversion Factor (SCF)	0.92	0.91 - 0.94
Consumption Goods Conversion Factor (CGCF)	0.95	0.77 - 0.98
Intermediate Goods Conversion Factor (IGCF)	0.94	0.90 - 1.09
Capital Goods Conversion Factor (KGCF)	0.84	0.83 - 0.96
Construction Conversion Factor (CCF)	0.88	0.86 - 0.92
Electricity Conversion Factor (ECF)	0.90	0.88 - 0.93
Transportation Conversion Factor (TCF)	0.87	0.85 - 0.90
Labor Conversion Factor (LCF)	0.92	0.91 - 0.94
Marginal Productivity of Capital (q)	0.16	0.12 - 0.20
Rice Conversion Factor (RCF)	1.11	0.92 - 1.49

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