DISTRIBUTION NETWORK DESIGN: A CASE OF A BOTTLED DRINKING WATER COMPANY

By
SIRINTORN KUEKKONG

A Final Report of the Six-Credit Course
SCM 2202 Graduate Project

Submitted in Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN SUPPLY CHAIN MANAGEMENT

Martin de Tours School of Management and Economics
Assumption University
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Declaration of Authorship Form

I, Sirintorn Kuekkon

declare that this thesis/project and the work presented in it are my own and has been generated by me as the result of my own original research.

Distribution Network Design: A Case of a Bottled Drinking Water Company

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ADVISOR'S STATEMENT

I confirm that this thesis/project has been carried out under my supervision and it represents the original work of the candidate.

Signed ____________

(Dr. Vatcharapol Sukhotu)

Date 9 Dec 2011

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Sirintorn Kuekkong
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November 2011

ABSTRACT

The role of business logistics for a company has become a major concern as the competition in the market increases every day. The company has to focus on the efficiency of the supply chain management operations by improving customer service levels and minimizing logistics cost.

This study presents the location decision in distribution network design to enable answer the questions of the company when they intend to increase capacity of facilities such as how many distribution centers should be located, where the distribution centers should be located and what size each distribution center should be. The conceptual framework of the location decision for the distribution centers is worked out through three sections.

In the first section, a current distribution network is evaluated for the performance that results in total logistics cost. In the second section, alternative distribution network models of single facility location and multiple facility locations are determined by Center-of-Gravity (COG) method. In the last section, optimal location of distribution centers is determined with lowest total logistic cost and customer service level improvement.

The implementing of this new distribution network illustrates the total logistics cost saving of almost 20.5 Million-THB per year or 5.7% compared to the baseline network and can answer the question of the company and enable them achieve the objectives in terms of cost and customer service levels.

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and she hereby certifies that the verbiage, spelling and format is commensurate with the quality of internationally acceptable writing standards for a Master Degree in Supply Chain Management.

Signed

Asst Prof Dr. June Bernadette D'Souza

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Date:

CHAPTER I

GENERALITIES OF THE STUDY

1.1 Background of the Research

With high competition of bottled drinking water business in the market, companies are required to focus on the efficiency of their supply chain management by improving customer service levels and increasing the profitability to the business. The worldwide market increases the competition from local and overseas competitors which forces the company to look at their business more critically to improve supply chain performances to be competitive in the market. In a world of shrinking margins, controlling the cost of doing business is the key factor that puts the supply chain network optimization goals ahead of the competitor.

The company in this study which hereafter is called "NW Company", is a manufacturer and leader of bottled drinking water worldwide. It presents the strongest brands in many countries and also in the Thai market. There are two product categories which are as follows:

- Bottled drinking water, small size: 0.33 liters, 0.5 liters, 0.6 liters, 1.5 liters and 6.0 liters
- Bottled drinking water, big size: 18.9 liters (Home and Office Delivery)

NW Company supplies the purified water enriched with an adequate mineral balance under the international brand. The location of natural underground water is researched and qualified by water resource specialist of NW corporate worldwide and International Bottled Water Association which warrants a good quality of water with sufficient essential nutrients. The plant is located in Ayutthaya province; the plant location is selected based on a qualified water resource (well) location which is independent from the demand points.

Recently consumers have gradually changed the behavior of water consumption from simple source for example rain and tap water to be bottled drinking water which is of good quality and good for health. The bottled drinking water business has high growth of demand rapidly in the Thai market. The competition is also increasing from local and international brands. Since the consumer's considering point is price and availability of the products more than brands, the competitive advantage of bottled drinking water business is logistics issues like transportation cost, distribution networks and customer response time.

Facility location decision in distribution network is not only a key strategy to determine the distribution network to minimize the distribution cost but also to improve customer service level. Therefore the appropriate facility location decision is very important and challenge to a company to improve their distribution efficiency to get the most benefit for the business in terms of costs and customer service levels.

1.2 Statement of the Problem

There are three problems which are focused in this study;

1.2.1 Distribution Center Capacity

The plant is located in Ayutthaya province and there is one central distribution center (DC) at the plant. All the products are stored at central DC and distributed to retailers in the country by using truck service of the third-party logistics (3PL). There is one access road width 8 meters go to the plant and three dock stations are operated at central DC.

A characteristic of bottled drinking water is a seasonal product. It has high sales volume in summer and at the end of the year. The peak factor is 1.15 of baseline demand that requires the company to keep the average inventory 7 days to ensure the stock availability and satisfy customer demands and serve uncertainty demand during the seasonal period.

The demand of bottled drinking water foresees high growth in next few years as shown in Figure 1.1. In the year 2012, the DC requires an average inventory over 9,700 pallets while the existing capacity is 10,000 pallets positions as shown in Figure 1.2. The loading capacity at DC is 1,360 pallets per day against shipment 1,380 pallets per day. That means the DC capacity will be full and limited from the year 2012 onwards.

Figure 1.1: Sales Volume and Growth Projection

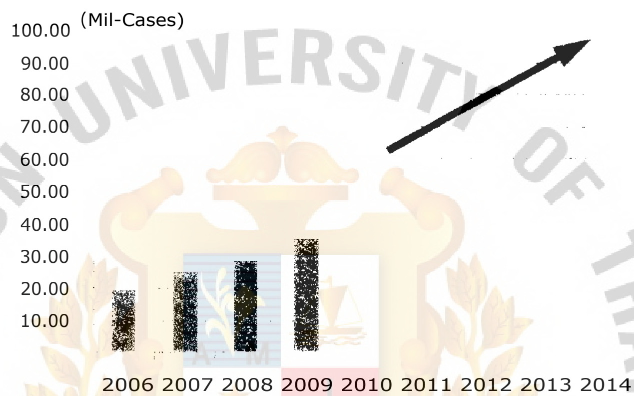
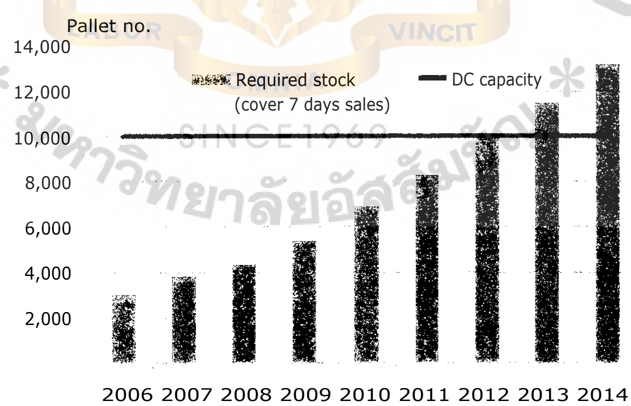
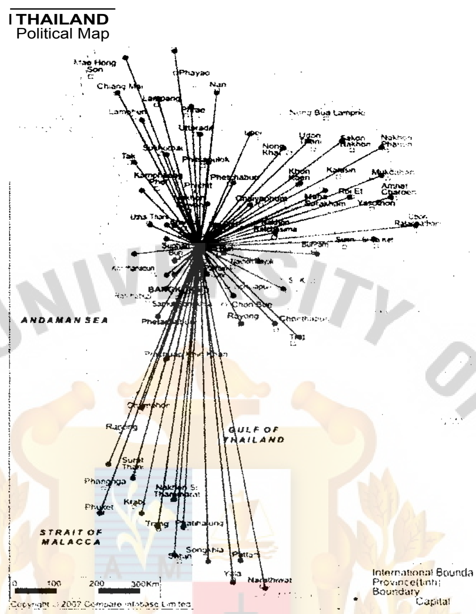


Figure 1.2: Current Distribution Center Capacity and Inventory



The current distribution network is a simple network design as shown in Figure 1.3. One central DC is located in Ayutthaya province and distributes the products to retailers across the country. There are two main customer groups which are retailers called Modern Trade and Traditional Trade or Distributors.

Figure 1.3: Current Distribution Network



The company needs to increase the capacity of DC, potentially at the same location or even at new locations with lowest cost and be able to serve the growing demand in the future.

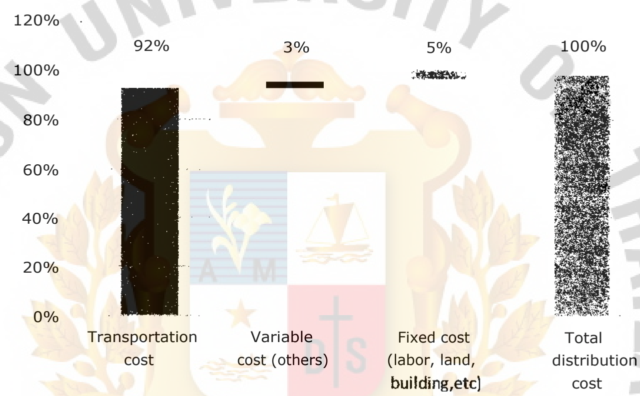
1.2.2 Transportation Cost Issue

Bottled drinking water is a weight-gaining processes and the final product weighs more than the sum of inbound raw material which causes the outbound freight to be heavier than the inbound freight. Since the drinking water products are heavy and have low margin compared to other consumer products, the business strategy is defined as high volume low margin product. Consequently the product weight is key factor which impact transportation cost.

Even through the current central DC is located in plant and the transportation cost from plant to DC is zero, the transportation cost from DC to retailers is still extremely high. The transportation cost is represented as 92% of total distribution cost as shown in Figure 1.4 because almost 50 % of total shipments to retailers is small shipment size which affects the unit of transportation cost increase.

As the transportation cost is the biggest portion in total distribution cost, the company focuses on reducing the transportation cost, possibly to improve the routing of shipments (through a consolidation center or direct) between plant and DCs.

Figure 1.4: Total Distribution Cost- Break Down by Cost Components



1.2.3 Customer Service Levels (Customer Response Time))

Bottled drinking water is a fast moving consumer good (FMCG) where retailers require a quick response time, starting from the order received to the product delivered. The requirement is meeting their demands, 95% of deliveries should be made within 24 hours. Currently NW Company can service 92% of deliveries separated by region as below.

- 66% 1 day (24 hours) for Central, East and West region
- 16% 2 day (48 hours) for North and North East region
- 18% 3-4 day (72-96 hours) for South region

The problem is the North, North East and Southern regions because of the long distance between central DC and retailer locations. The radius from DC to retailers is different in each region and is as follows:

- DC to Central Min. 30 km and Max. 302 km
- DC to East Min. 157 km and Max. 321 km
- DC to West Min. 176 km and Max. 357 km
- DC to North Min. 172 km and Max. 714 km
- DC to North East Min. 215 km and Max. 603 km
- DC to South Min. 539 km and Max. 1553 km

Thus the retailers foresee NW Company improve the service level in terms of response time to support fast movement of bottled drinking water products within 24 hours and also help them to reduce the holding inventory consequently.

The NW Company is now thinking about DC capacity expansion together with distribution network redesigning to determine the facility location decisions that minimize the distribution cost including facility cost, transportation costs and inventory holding cost and improve customer service levels.

1.3 Research Question

As the statement problem, the research question of study is how to improve the distribution network of a company by using mathematical approach to minimize total logistics cost and reduce customer response time.

1.4 Research Objectives

This project attempts to attain two objectives as follows:

1.4.1 To study the distribution network redesigning to improve the logistics cost and customer service level that results in ;

(1) Number of distribution center (DCs)

(2) Location of DCs

(3) Size of DCs

(4) Allocation of customers to DCs

(5) Transportation methods between plant to DCs and DCs to customer

(6) Inventory level at the DCs

(7) Customer response time

1.4.2 To provide the quantitative measurement of calculation costing model of total distribution cost from distribution network design which are minimized in area of ;

(1) Facility cost (fixed and variable cost)

(2) Transportation cost

(3) Inventory holding cost

1.5 Scope of the Research

This study focus on distribution network design of bottled drinking water product and the scope of study as follows:

1.5.1 Distribution network in the study includes product flow from the plant to DCs and DCs to the customer (retailer), excluding the product flow from retailer's DCs to store or consumers.

1.5.2 Products in the study are the bottled drinking water small format excluding the big format (home-office-delivery water) because they are different distribution strategies and marketplaces.

1.5.3 Customer in the study focus on big retailers, modern trades and traditional trades which are high sales contribution to business. 99% of total sales volumes are big retailers while the small retailers as 1% and are not included in the scope of study.

The data of customer demand for the year 2011 is used as the baseline and database for analysis. The methodology is a case study. *"Location Allocation"* scenario analysis based methodology by the LOGWARE program and the excel spreadsheet.

The result of the Location Allocation scenario analysis is to find the most suitable distribution network. Four factors are be used as criteria for analysis which are facility cost, transportation cost saving, inventory holding cost and on-time delivery in response time to retailers.

At the end of the study, conclusions from the result and analysis are discussed. After that, recommendations for the company are addressed as a proposal for further implementation.

1.6 Significance of the Research

This study aims to study the distribution network redesigning of the bottled drinking water products for the NW Company. The results obtained from the study can be used as a guideline for the company in considering the new distribution networks that can help minimize the total logistics cost and satisfy customer service levels. In this study, the knowledge of distribution network concepts and mathematical model approach is Center-of-Gravity (COG) method which is significantly used in the study. The potential benefits, supporting factors and limitation relating to the distribution network implementation are analyzed and considered. This can be useful for further study and can be applied by other manufacturers who are considering the new distribution network design strategy.

1.7 Limitations of the Research

The limitations of the study are described as follows:

1.7.1 Plant location is fixed according to the selection of a qualified water resource (well) location which cannot be moved to other source.

1.7.2 Plant capacity is known and enough, so the supply capacity is not considered in the case study.

1.7.3 The regional distribution center of NW Company can be rented only in order to keep the flexibility in the future to serve the demand area change.

1.8 Definition of Terms

COG (Center-of-Gravity): means the basic assumption of mathematical method that the transportation costs are proportional to the distance and volume carried along the route (Meidan, 1978).

MULTICOG *(Multiply-Center-of-Gravity):* means that the exact Center-of-Gravity method approach in a multiple location format to find the minimum transportation cost among origin and destination points (Ballou, 2004).

DC (Distribution Center): means the facility that accumulates and consolidates products from various points of manufacture within a single firm, or from several firms, for combined shipment to common customers (Frazelle, 2002).

Location Allocation: means the algorithms used primarily in a geographic information system to determine an optimal location for one or more facilities that will demand service from a given set of points (http://en.wikipedia.org/wiki/Location-allocation)

FTL *(Full Truck Load):* means transportation of large shipment to fully utilize the vehicle capacity. (Wisner et al, 2009)

LTL *(Less than Truck Load):* means transportation of relatively small freight, not using the full capacity of the vehicle. (Wisner et al, 2009).

Peak Factor: means the ratio of a maximum flow to the average flow, such as maximum monthly sales volume to the average monthly sales volume (http://ascelibrary.org/proceedings/resource/2/ascecp/173/40792/51 1)

CHAPTER II

REVIEW OF RELATED LITERATURE AND RESEARCH FRAMEWORKS

This chapter reviews the relevant literature in four key areas. The first section describes about supply chain and facility location decision. The second section discusses the factors influencing network design that consist of facility location decision, transportation decision, inventory decision, customer service level and the interdependence between them. The third section presents the model approaches for distribution network design, Center-of-Gravity (COG) mathematical method. In the study, the LOGWARE program is selected as a tool to find COG location for both single and multiple DC locations. The concept instruction LOGWARE is also described in this section. Lastly the criteria of supply chain performance evaluation are presented in the forth section.

2.1 Supply Chain and Facility Location Decision

Supply chain is the integration of activities taking place among a network of facilities, suppliers, manufacturers, warehouses, distribution centers, retailers and consumers that procure the raw materials, transform them to work-in-process and finished goods and deliver finished goods to consumers through a physical distribution (Wisner, Leong & Tan, 2009). The physical distribution is one part of the supply chain which comprises of those activities that are integrated into business logistics, as a wide range of activities taking place after the production of products such as products to the warehouse, distribution centers to retailers and before delivery to consumers (Thai & Grewal, 2005)

Supply chain is also referred to distribution network design which has a significant impact on supply chain performances and plays a key role in controlling cost of business (Chopra & Meindl, 2001). The distribution network optimization is intelligently designed to minimize costs by providing the customer with the right goods, in the right quantity, at the right time, and at the right place. In addition it is necessary to enhance the efficiency and effectiveness of a distribution operation Coyle, Bardi and Langley (2003), Ashayeri and Rongen (1997) describe that the distribution network decision should take into account both quantitative and qualitative factors.

Facility location, also known as location analysis, is a branch of operations research and computational geometry concerning itself with mathematical modeling and solution of problems concerning optimal placement of facilities in order to minimize transportation costs. Khumawala and Whybark (1976) describe the location problem is as a set of potential locations including any existing ones and select those which should be used to satisfy the customer demands at minimum distribution costs. These costs include inbound and outbound transportation costs, warehouse operating costs including all relevant fixed and variable costs.

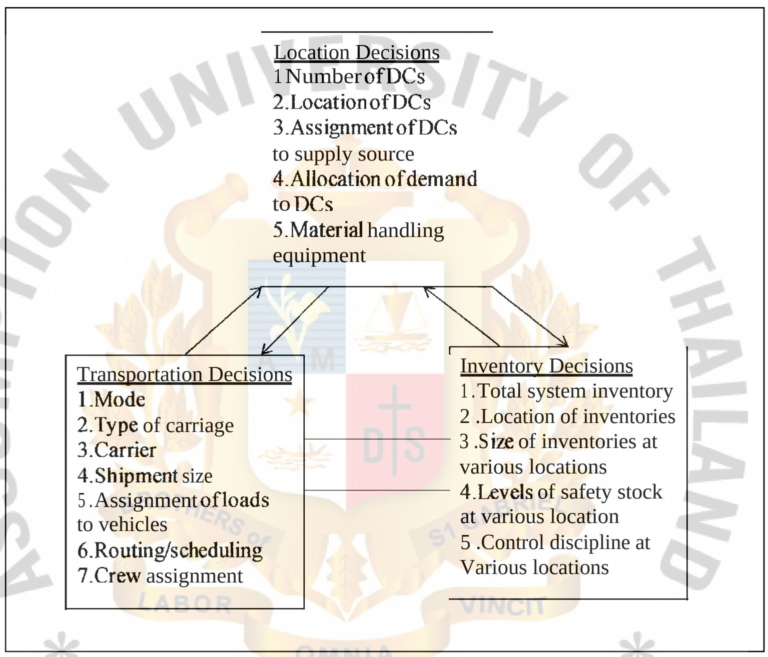
Perl and Sirisoponsilp (1989), Jayaraman (1998) and Meidan (1978) consider the design of a distribution network as the process which consists of determining the following elements:

(1) Number and locations of distribution centers (DCs)
(2) Size of each DCs location
(3) Allocation of customers (markets) to DCs
(4) Flow pattern from supply sources (plants) to DCs
(5) Transportation service between plants to DCs and DCs to customer
(6) Levels of inventories at the DCs

The number and locations of warehouses are keys to reducing total distribution costs so the business problem of logistics network design involves several decisions such as inventory policy is to be determined, customer service levels which are to be set, transport modes which are to be selected, stocking points which are to be located and sized. The proper aggregate location planning problem is one of minimizing the sum of that relevant cost (Ballou, 1995).

Pen and Sirisoponsilp (1989) studied that the facility location decisions related to the design of a distribution network can be classified into three basic components, facility location, transportation and inventory decisions. In the context of distribution network design there is interdependence among these three sets of decision as shown in Figure 2.1

Figure 2.1: Interdependence between Facility Location, Transportation and Inventory Decision



The objective of the distribution network design process can be described as that of finding the optimal balance between distribution cost and customer service. Wisner et al. (2009) mention that customer desires and competition levels play the important roles in network design decision which typically results in trade-off between the cost of building, operating facilities cost, transportation cost, inventory cost and customer service.

2.2 Factors Influencing Network Design Decision

Chopra and Meindl (2001) describe the various strategic factors that have an impact on network design decision within the supply chain. The logistical and operational factors are key factors in consideration.

2.2.1 Facility Costs (Setup and Operating Cost)

The facility costs can be divided into fixed and variable cost. Fixed cost is cost such as rental, leasing or construction cost. They do not vary with the demand quantity. Variable costs are costs associated with production or warehouse operation that do vary with quantity. Facility costs increase as the number of facilities increase as shown in Figure 2.2

Figure 2.2: Relation between Number of Facilities and Facility Costs

2.2.2 Transportation Costs

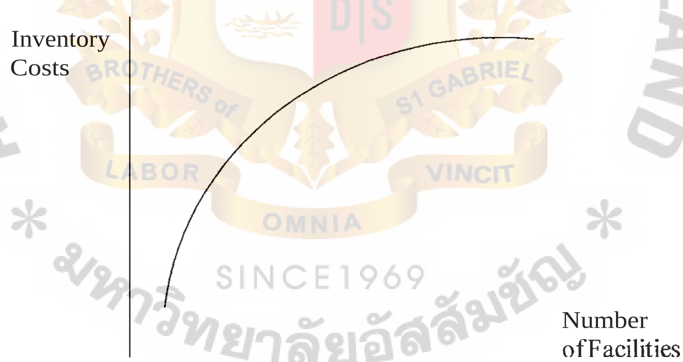
The transportation cost includes inbound and outbound transportation cost. Normally outbound transportation costs per unit tend to be higher than inbound cost because inbound lot sizes are typically larger. Thus number of facilities that increase affect the transportation cost which decreases as shown in Figure 2.3

Figure 2.3: Relation between Number of Facilities and Transportation Cost

2.2.3 Inventory Costs

As the number of facilities in a supply chain increases, resulting inventory costs also increase as shown in Figure 2.4. The firms try to consolidate and limit the number of facilities in their supply chain network to decrease inventory cost.

Figure 2.4: Relation between number of facilities and inventory costs



As the objective of inventory is to satisfy customer demand when uncertain demand incurring, each location may face uncertain demand so some safety inventory should be carried out. In this case study, the inventory both *Centralized* and *Decentralized Systems* and increasing inventory costs as a result of higher safety stock requirements is considered (Anupindi, Chopra, Deshmush, Mieghem & Zemel, 2003)

Anupindi et al. (2003) also describes a principle of *Square Root Law* states that total safety inventory required to provide a specified level of service which increases by the square root of the number of locations. A similar N location of decentralized networks requires a safety inventory investment of N times the safety inventory in each warehouses by comparing the safety inventory carried by centralized (I^{c}_{safety}) and decentralized (I^{d}_{safety}) systems Anupindi et al.(2003) also observe that when both systems provide the same service level, the total safety inventory required by centralized operation is 1/4 times the required total safety inventory in the decentralized operation. That is the safety inventory in a centralized system is less than N location in a decentralized system by a factor of $1/\sqrt{N}$ in a centralized system. This is less than in the decentralized system and are equal to

$$_{safety}\ z \times \sqrt{N}\ \sigma_{LTD}$$

$$I'_{safety} \quad N \times z \times \sigma_{LTD}$$

Where:

z = desired service level

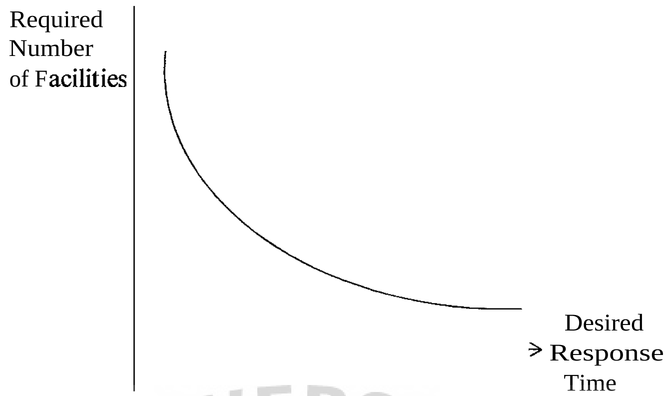
N = number of locations

σ_{LTD} = standard deviation of lead time demand at centralized

2.2.4 Customer Service Levels (Customer Response Time)

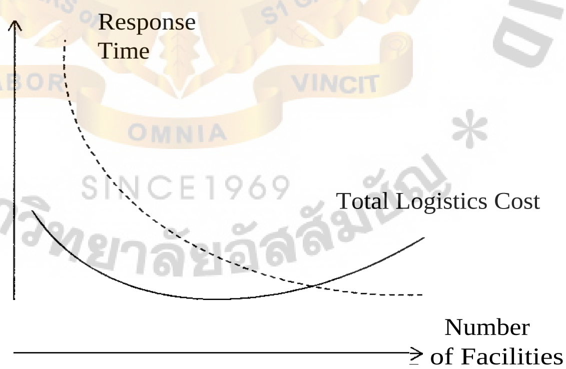
Chopra and Meindl (2001) have mentioned that the firms should consider the response time customers desire when designing their distribution network. A decrease in the response time that a customer desire determines the number of facilities required in the network, as shown in Figure 2.5

Figure 2.5: Relation between Desired Response Time and Number of Facilities



Total logistics costs are the sum of facility cost, transportation cost, and inventory holding cost for a distribution network. As the number of facilities increases, total logistics costs decrease and then increase as shown in Figure 2.6 As a firm wants to reduce the response time for their customers. It may have to increase the number of facilities beyond the point that minimizes logistics costs.

Figure 2.6: Variation in Logistics Cost and Response Time with Number of Facilities



2.3 Method Approached for Facility Location Decision

The technique approach in the case is *Center-of-Gravity or COG* the exact Center-of-Gravity method to find the single facility location. The *Multiple-Center-of-Gravity or MULTICOG* to find the multiple facility locations is used as well. The LOGWARE program and excel spreadsheet are used to complete the calculation costing model of total distribution cost. The approaches are classified for single and multiple facility locations (Bozarth & Handfield, 2006)

2.3.1 Single Facility Location by Center-of-Gravity Method (COG)

The center of gravity method looks at the single strategic location decision (Bozarth & Handfield, 2006). This can be especially important when a firm is developing its logistics network and must decide where to place plants or warehouses. Ballou (2004) state that the approach is simple, since the transportation rate and the point volume are the only location weight factors. The total transportation cost is calculated as follows:

$$\text{Minimize } TC = \sum_{i=1} V_i R_i d_i$$

Where:

TC = total transportation cost

N = the number of origin/destination point i

V_i = volume of an origin/destination point i

R_i = transportation rate between the facility and origin/destination points, such as THB/unit/kilometer

d_i = distance between points

Center-of-Gravity Method

The Center-of-Gravity is a basic assumption method in which the transportation costs are proportional to the distance and volume carried along the route (Meidan, 1978). This technique attempts to identify the best location for a single facility location of a warehouse, a store, or a plant, given multiple demand points that differ in location and importance. Location is typically expressed in (X Y) coordinate term, where the X and Y values represent relative position on a map. The center of gravity works by calculating the weighted average (X, Y) values of the demand locations which is the total transportation cost.

The approximate Center-of-Gravity is coordinate as the initial location from Center-of-Gravity formula by omitting the distance term d_i and is as follows:

$$X \text{ coordinate} = X = \frac{{}_{i=1} V_i R_i X_i}{V_i R_i}$$

$$Y \text{ coordinate} = Y \quad \frac{{}_{i=1} V_i R_i Y_i}{V_i R_i}$$

The distance d_i is estimated by

$$= K \quad (\quad - X)^2 + (Y_i - Y)^2$$

Where:

= position of demand point i

K = a scaling factor to convert coordinate distances to kilometers

The resulting (X_i, Y_i) values represent the *ideal location*, given the relative weight (that is, importance) placed on each demand point.

2.3.2 Multiple Facility Location by Multiple Center-of-Gravity Method (MULTICOG)

The problem is to locate one or more facilities (source point), such as warehouses, to serve a number of demand points of known locations, volumes, and transportation rates. The number of facility locations is specified. The objective is the find the coordinates of the facilities such that the following expression minimizes the total transportation cost and is as follows:

$$\text{Minimize } TC = \sum_{j=}^{M} \sum^{N} V_{ij} R_{ij} d_{ij}$$

Where:

TC = total transportation cost

i = demand point number up to a total of N

j = facility number (source point) up to a total of M

= volume of an origin/destination points

$R,$ = transportation rate between the facility and origin/destination points, such as THB/unit/kilometer

$d,$ = distance between points

Multiple Center-of-Gravity Method

Ballou (2004) suggests the exact Center-of-Gravity method approach in a multiple location format to find the minimum transportation cost among origin and destination points. It is necessary to assign the origin and destination points to arbitrary locations. One approach is to form the clusters by grouping the points that are closest to each other and then the center-of gravity is found. The points are reassigned to these locations, new Center-of-Gravity locations are found and this process will be continued until nothing change. It can be repeated for different numbers of facilities. The facility location is found by solving two equations for the coordinates of the location.

The exact Center-of-Gravity coordinates is:

$$X \quad \frac{/}{V_i R_i / d_i}$$

$$Y - \frac{V_i R_l Yi /}{\sum V_j R, /}$$

Where:

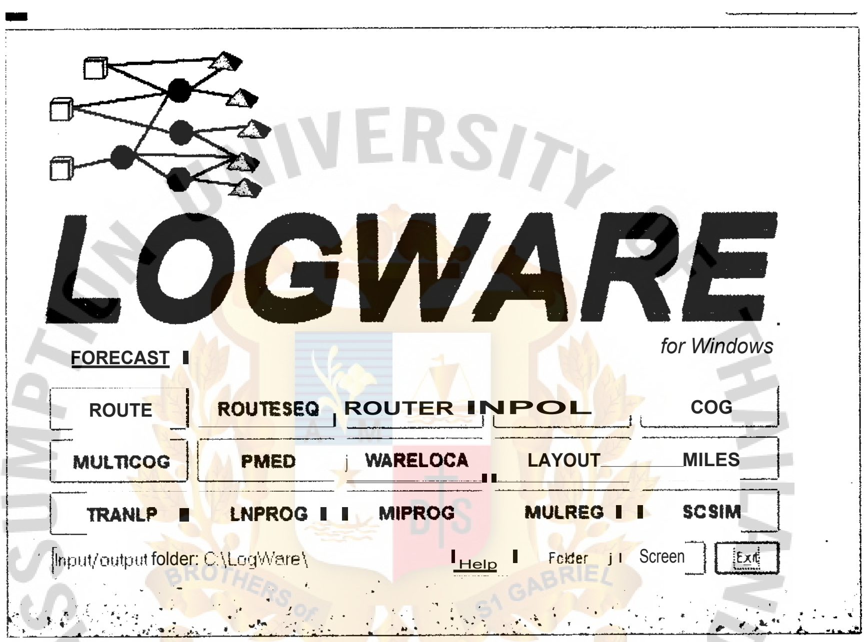
X, Y = coordinate points of the located facility

= coordinate points of source and demand points

LOGWARE *Program*

Ballou (2004) has introduced LOGWARE program version 5.0 Copyright 1992-2004 that is a collection of selected computer software programs that is useful for analyzing a variety of logistics/supply chain problems and case studies. Each module is selected from the following master screen as shown in Figure 2.7

Figure 2.7: LOGWARE Program Master Screen



There are sixteen modules existing in LOGWARE program as follows:

FORECAST : Forecasts time series data by means of exponential smoothing and time series decomposition methods

ROUTE : Determines the shortest path through a network of routes

ROUTESEQ : Determines the best sequence to visit stops on a route

ROUTER : Develops routes and schedules for multiple trucks serving multiple stops

INPOL : Finds optimal inventory ordering policies based on economic order quantity principles

COG : Finds the location of a single facility by the exact Center-of-Gravity method

MULTICOG : Locates a selected number of facilities by the exact Center-of-Gravity method

PMED : Locates a selected number of facilities by the P-median method

WARELOCA : A warehouse location program for specifically analyzing the problem

LAYOUT : Positions products in warehouses and other facilities

MILES : Computes approximate distance between two points using latitude-longitude or linear-grid coordinate points

TRANLP : Solves the transportation method of linear programming

LNPROG : Solves general linear programming problems by means of the simplex method

MIPROG : Solves the mixed integer linear programming problem by means of branch and bound

MULREG : Finds linear regression equations by means of the stepwise procedure of regression/correlation analysis

SCSIM : Simulates the flow of a product through five echelons of a supply channel

2.4 Distribution Network Performance Evaluation

To understand the real impact of distribution network design in supply chain management, Bozarth and Handfield (2006) indicated that performance should be evaluated in terms of effective logistics which serves the customer, such as on time delivery and efficient logistics which provides the service, such as total logistics cost.

Coyle et al. (2003) describe two principle categories that provide a useful way to evaluate the supply chain performance:

2.4.1 *Time* has traditionally been an important barometer of logistics performance with regard to measuring effectiveness such as on-time delivery, order cycle time, response time.

2.4.2 *Cost* has been indicated as the measurement for efficiency such as inventory turn, total distribution cost which consist of cost of goods, transportation cost, inventory carrying cost, handling cost.

2.5 Summary

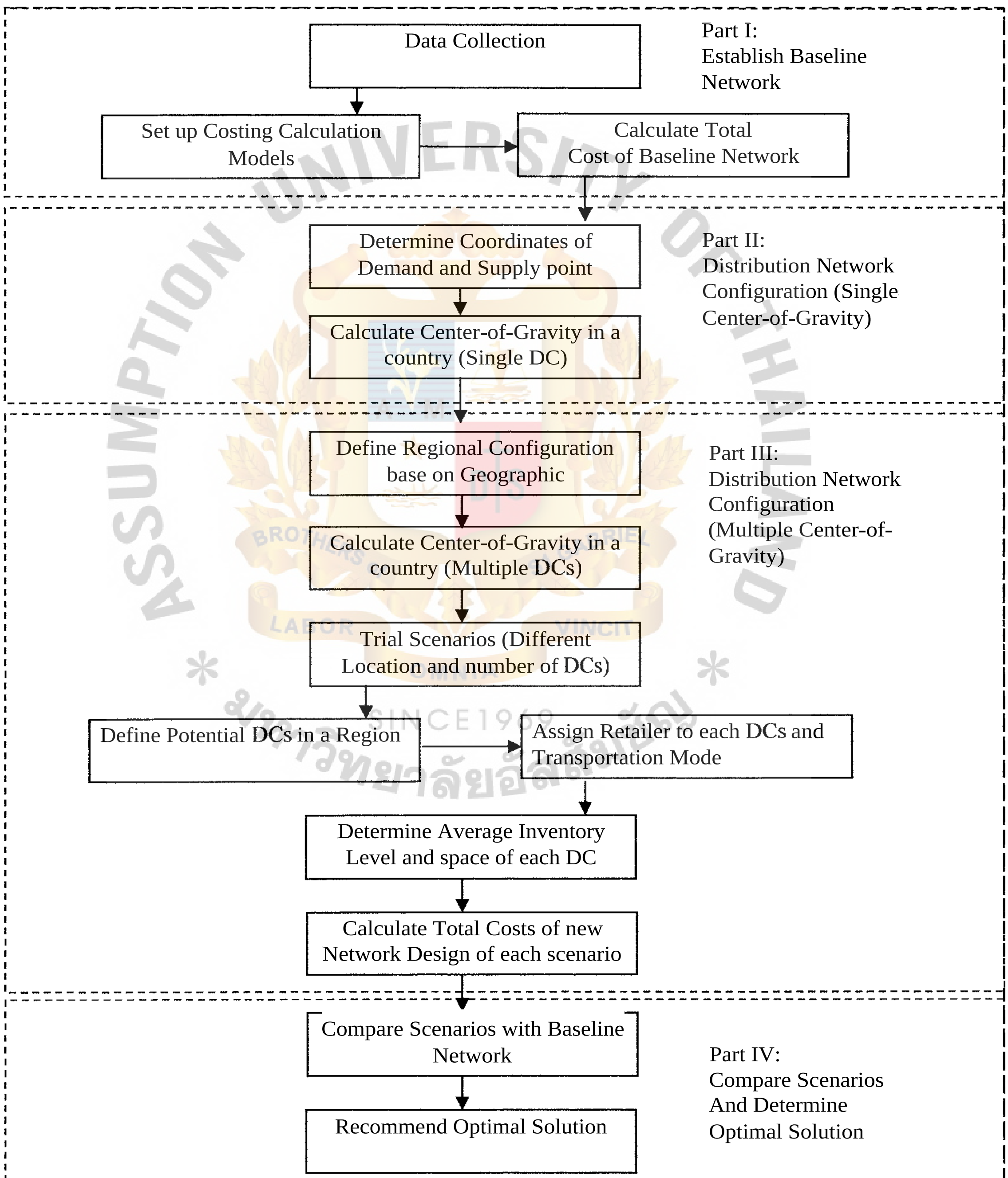
Location decision is important process in distribution network design that can minimize the total logistics cost and improve the service levels to the business. There are mainly three criteria related to total logistics cost which are facility costs (fixed and variable cost), transportation costs and inventory holding cost. Moreover the interdependence between facility location, transportation, inventory, and customer service level should be considered and trade-off in distribution network to get most benefit to company in terms of effective logistics serve to customer and efficient cost is important. The exact Center-of-Gravity is a model approach for facility location decision for both of single and multiple facility location decision by calculating the weighted average of demand locations with distance between source and demand points as it results in total transportation cost. The distribution network performance should be evaluated in terms of total logistics cost and customer service levels such as on time delivery.

CHAPTER III

RESEARCH METHODOLOGY

The flowchart of the proposed method in this study is shown in Figure 3.1

Figure 3.1 Flow Chart of Research Methodology



Part I: Establish Baseline Network

3.1 Data Collection

The required data can be generalized and includes:

3.1.1 Location of plant, distribution center and retailers

3.1.2 Coordinates (X, Y) of demand and source points

3.1.3 Demand volume by customer locations

3.1.4 Facility cost, including fixed cost and variable cost

3.1.5 Transportation costs

3.1.6 Transportation mode and shipment size by customer locations

The data of customer demand for the year 2011 is used as the baseline and database for analysis as shown in Table 3.1 and used in calculation of total logistics cost of existing network and new distribution network design.

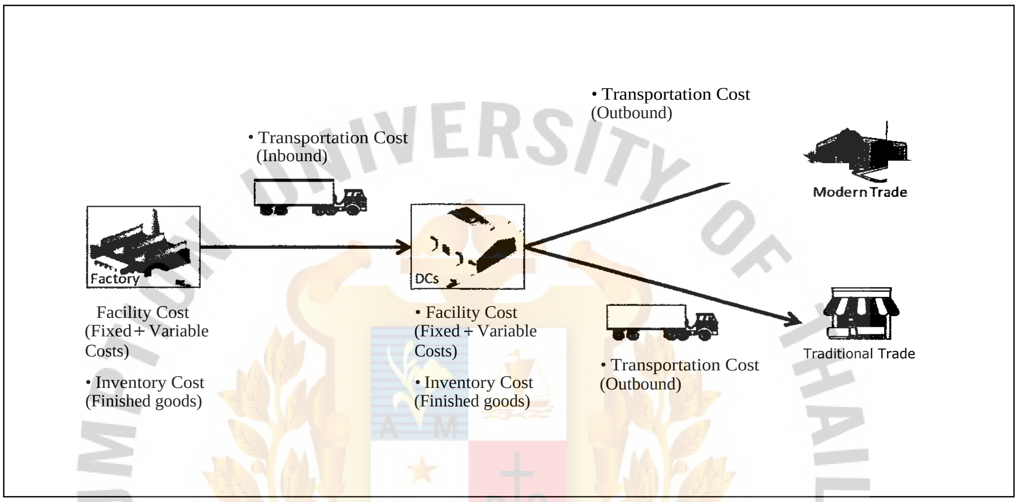
Table 3.1: Customer Demand and Facility Cost

Province	Volume per year		Modern Trade	Traditional Trade	Fixed Warehouse Cost	Variable Warehouse Cost
	Cases	Pallets	%of Volume	%of Volume	THB per Month	THB per Sqm per Month
Ayutthaya	10,754,154	84,017	94%	6%	500,000.00	110.00
Bangkok	10,997,810	85,920	78%	22%	800,000.00	120.00
Lopburi	344,112	2,688	0%	100%	400,000.00	100.00
Nakhon Nayok	183,203	1,431	0%	100%	400,000.00	100.00
Nontha Buri	7,048,856	55,069	83%	17%	400,000.00	100.00
Phetcha Bun	183,948	1,437	0%	100%	400,000.00	100.00
Phichit	40,620	317	0%	100%	400,000.00	100.00
Phitsanu Lok	373,387	2,917	0%	100%	400,000.00	100.00
Samut Prakan	1,233,148	9,634	0%	100%	400,000.00	100.00
Saraburi	460,697	3,599	0%	100%	400,000.00	100.00
Suphan Buri	318,708	2,490	0%	100%	400,000.00	100.00
Uthai Thani	23,263	182	0%	100%	400,000.00	100.00
Chantha Buri	424,726	3,318	0%	100%	400,000.00	100.00
Phuket	3,394,303	26,518	0%	100%	500,000.00	110.00
Satun	46,601	364	0%	100%	400,000.00	100.00
Songkhla	1,617,048	12,633	0%	100%	400,000.00	100.00
Surat Thani	3,677,488	28,730	73%	27%	400,000.00	100.00
Trang	43,774	342	0%	100%	400,000.00	100.00
Yala	56,374	440	0%	100%	400,000.00	100.00
Total	**55,166,148**	**430,986**				

3.2 Establish Performance Evaluation Costing Model

The component of total logistics cost is set up the formulation in order to evaluate network performance. There are three main cost components which are facility cost, transportation cost and inventory holding cost as shown in Figure 3.2

Figure 3.2: Components of Total Logistics Cost in Distribution Network



3.2.1 Facility Cost

The facility cost is includes fixed cost which is not related to sales volume while variable cost is related to the volume. The formulation is shown as follows:

Facility cost = Fixed cost + Variable cost

Fixed cost = (include labor, building, forklifts and other equipments)	Fixed cost per month of each DCs x 12 months
Variable cost = (include warehouse space cost, pallet rental, fuel cost, etc)	(Required warehouse space (sqm) x Variable cost per sqm) x 12 months
Required warehouse space (sqm) =	(Annual demand / Inventory turnover ratio) x Peak factor x Average pallet space 1.33 sqm per pallet
Inventory turnover ratio =	Annual demand / Average inventory level
Peak factor	Maximum of (Actual demand of each month - Average demand per month) / Average demand per month

3.2.2 Transportation Cost

The transportation cost is includes inbound transportation from plant to DCs and outbound transportation from DCs to retailers.

- Modern Trade uses 18 wheel semi-trailer and Traditional Trade uses 10 wheel truck as shown in Figure 3.3.
- Distance (km) from plant to DCs is a round trip as shown in Table 3.2
- Transportation rate is the trip rate which related to truck type and distance between locations so the conversion rate of transport cost in THB per km are used in the calculation.

Figure 3.3: Current Transportation Mode from DC to Retailers

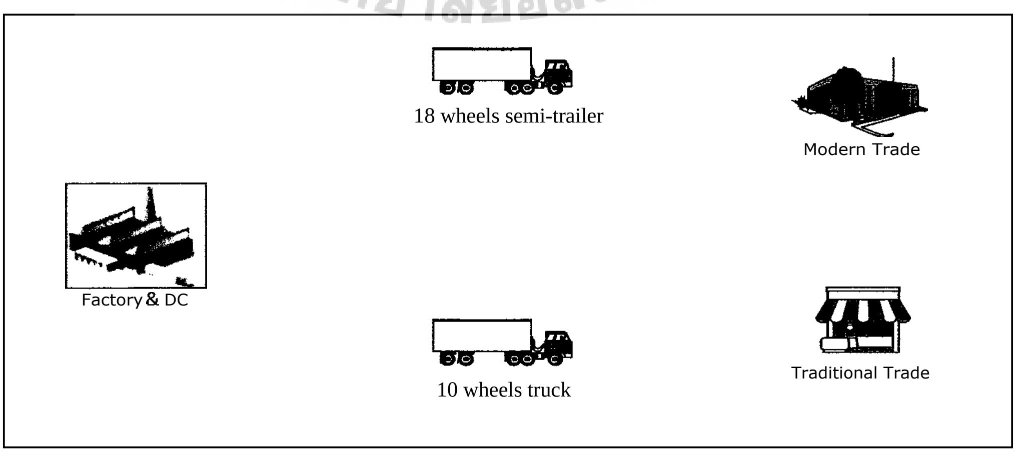


Table 3.2: Distance between Provinces in Country (kilometer: km)

Province	Chaiya Phum	Loei	Nongbua Lampoo	Nong Kai	Udon Thani	Khonkaen	Mahasarakam	Roiet	Karasin	Sakon Nakhon	…	Songkhla	Pattani	Yala	Narathiwat	Satun
Chaiya Phum	30	228	195	288	251	128	166	205	204	339		1343	1405	1459	1494	1340
Loei	228	30	92	192	141	207	289	329	293	318		1542	1604	1658	1693	1539
Nongbua Lampoo	195	92	30	104	51	117	205	244	187	227		1538	1600	1654	1689	1535
Nong Kai	288	192	104	30	52	173	267	306	240	209		1638	1700	1754	1789	1635
Udon Thani	251	141	51	52	30	121	186	214	174	177		1585	1647	1701	1736	1582
Khonkaen	128	207	117	173	121	30	76	115	80	208		1459	1521	1575	1610	1456
Mahasarakam	166	289	205	267	186	76	30	40	52	180		1481	1543	1597	1632	1478
Roiet	205	329	244	306	214	115	40	30	49	161		1517	1579	1633	1668	1514
Karasin	204	293	187	240	174	80	52	49	30	130		1527	1589	1643	1678	1524
Sakon Nakhon	339	318	227	209	177	208	180	161	130	30		1655	1717	1771	1806	1652
Nakhon Panom	428	425	321	318	253	297	269	249	219	94		1745	1807	1861	1896	1742
Mukdahan	372	454	373	432	292	231	188	149	159	114		1687	1749	1803	1838	1684
Amnat Charoen	324	450	371	428	391	246	170	129	168	199		1601	1663	1717	1752	1598
Yasothon	274	389	309	367	313	185	109	68	116	178		1539	1601	1655	1690	1536
Ubon Ratchathani	369	495	413	473	436	290	215	174	222	280		1611	1673	1727	1762	1608
Sisaket	286	466	384	444	390	262	187	146	199	314		1545	1607	1661	1696	1542
Surin	227	447	368	426	375	230	168	146	199	325		1441	1503	1557	1592	1438
Buriram	181	402	321	380	328	187	148	149	200	340		1394	1456	1510	1545	1391
Nakhon Ratchasima	120	348	317	373	320	193	217	233	262	390		1267	1329	1383	1418	1264
Saraburi	225	422	421	522	469	342	365	383	411	539		1100	1162	1216	1251	1097

The total transportation cost formulation is shown as follows:

Transportation cost = Inbound + Outbound transportation cost

Plant to DCs = (Inbound)	Number of trips x Transport cost per km. of 18 wheel x Distance between plant to each DCs
DCs to Retailers = (Outbound) 18 wheel semi-trailer	Number of trips x Transport cost per km. of 18 wheel x Distance between DCs to each Retailers x 2 (round trip)
DCs to Retailers = (Outbound) 10 wheel truck	Number of trips x Transport cost per km. of 10 wheel x distance between DCs to each Retailers x 2 (round trip)

3.2.3 Inventory Holding Cost

The inventory holding cost and safety inventory for decentralized DCs is shown as follows:

Decentralized safety inventory	=	Safety inventory of centralized system x Square root of number of DCs
Inventory holding cost	=	Average inventory level in pallet x Product cost per pallet

The additional information is summarized as below.

- Average product cost is 5,000 THB per pallet
- Average 128 case per pallet
- Full Truck Load (FTL) is 99% of total sales which consists of Modern Trade 51% and Traditional Trade 48%
- Less Truck Load (LTL) is 1% of total sales which is not in the scope of study
- Transportation costs per km by truck type is shown in Table 3.3
- Loading capacity of 18 wheel semi-trailer is 24 pallets per trailer and 10 wheel is 12 pallets per truck
- Assume the distance in same province is 30 km one way

Table 3.3: Transportation Cost by Retailers and Truck Type

Retailers	Modern Trade	Traditional Trade
10 wheel truck	22 THB per km	12 THB per km
18 wheel semi-trailer	35 THB per km	16 THB per km

3.3 Evaluate Baseline Network Model

To understand the current total logistics cost of baseline network which is measured by three criteria, facility costs, transportation costs and inventory holding costs.

3.3.1 Facility Cost (Central DC at plant in Ayutthaya province)

The facility cost is consisted as fixed cost and variable cost that are calculated with using the formula below:

Fixed cost (DC Ayutthaya) = 500,000 THB per month x 12 months

= 6,000,000 THB per year

For variable cost is related to the average inventory level and storage space requirement. The sample of calculation is shown as below;

Average inventory level (retailer in Ayutthaya) = 84,017 pallet per year / 12 month / 26 sale day per month x 7 day
= 1,885 pallets

The peak factor is used in storage space calculation to ensure the storage space is enough during the peak season. The calculation is shown in Table 3.4

Table 3.4: Peak Factor Calculation

Month	Average demand/month	Dif. from Average demand	% Dif. (peak factor)
Jan	5,800,679	- 1,046,563	**-15.3%**
Feb	6,560,900	286,342	**-4.2%**
Mar	7,119,914	272,672	**4.0%**
Apr	6,469,735	377,507	**-5.5%**
May	6,871,085	23,843	**0.3%**
Jun	7,032,568	185,326	**2.7%**
Jul	7,211,557	364,315	**5.3%**
Aug	6,860,073	12,831	**0.2%**
Sep	6,652,981	194,261	**-2.8%**
Oct	6,766,388	- 80,854	**-1.2%**
Nov	6,947,322	100,080	**1.5%**
Dec	7,873,706	1,026,464	**15.0%**
Total	**82,016,908**		
Ave rage	**6,847,242**		

Peak factor calculation = Maximum of ((5,800,679 - 6,847,242), (6,560,900 - 6,847,242), (7,119,914 - 6,847,242),........(7,873,706 - 6,847,242)) / 6,847,242
= 15% or 1.15

Table 3.5: Inventory Level and Storage Space Requirement of Baseline Network

Province	Volume		Avg. Inventory Level (Sales volume/ Inventory turnover ratio)		Required Storage Space (sqm) (Peak factor = 1 15)		
	Case	Pallets	Case	Pallets	Case	Pallets	Sqm
Ayutthaya	10,754,154	84,017	241,279	1,885	277,471	2,168	2,890
Bangkok	10,997,810	85,920	246,746	1,928	283,758	2,217	2,956
Lopburi	344,112	2,688	7,720	60	8,879	69	92
Nakhon Nayok	183,203	1,431	4,110	32	4,727	37	49
Nontha Buri	7,048,856	55,069	158,147	1,236	181,870	1,421	1,894
Phetcha Bun	183,948	1,437	4,127	32	4,746	37	49
Phichit	40,620	317	911	7	1,048	8	11
Phitsanu Lok	373,387	2,917	8,377	65	9,634	75	100
Samut Prakan	1,233,148	9,634	27,667	216	31,817	249	331
Saraburi	460,697	3,599	10,336	81	11,887	93	124
Suphan Bud	318,708	2,490	7,151	56	8,223	64	86
Uthai Thani	23,263	182	522	4	600	5	6
Chantha Bud	424,726	3,318	9,529	74	10,958	86	114
Chon Buri	2,047,938	16,000	45,947	359	52,839	413	550
Prachin Buri	341,184	2,666	7,655	60	8,803	69	92
Rayong	699,562	5,465	15,695	123	18,050	141	188
Khanchana Buri	190,985	1,492	4,285	33	4,928	38	51
Phetcha Burl	359,796	2,811	8,072	63	9,283	73	97
Phrachuap Khirikhan	71,489	559	1,604	13	1,845	14	19
Ratcha Buri	367,970	2,875	8,256	64	9,494	74	99
Chiang Mai	2,000,125	15,626	44,875	351	51,606	403	538
Chiang Rai	514,392	4,019	11,541	90	13,272	104	138
Kamphaeng Phet	526,366	4,112	11,809	92	13,581	106	141
Lampang	119,953	937	2,691	21	3,095	24	32
Nakhon Sawan	214,589	1,676	4,814	38	5,537	43	58
Nan	140,887	1,101	3,161	25	3,635	28	38
Phare	266,119	2,079	5,971	47	6,866	54	72
Amnat Charoen	81,708	638	1,833	14	2,108	16	22
Buriram	395,910	3,093	8,883	69	10,215	80	106
Chaiya Phum	170,662	1,333	3,829	30	4,403	34	46
Khonkaen	1,577,861	12,327	35,401	277	40,711	318	424
Loei	221,549	1,731	4,971	39	5,716	45	60
Mukdahan	184,606	1,442	4,142	32	4,763	37	50
Nakhon Ratchasima	670,171	5,236	15,036	117	17,291	135	180
Roiet	62,851.20	491	1,410	11	1,622	13	17
Sakon Nakhon	336,504.00	2,629	7,550	59	8,682	68	90
Sisaket	92,786.40	725	2,082	16	2,394	19	25
Ubon Ratchathani	474,194.40	3,705	10,639	83	12,235	96	127
Udon Thani	671,736.00	5,248	15,071	118	17,332	135	181
Chumphon	246,945.60	1,929	5,540	43	6,372	50	66
Nakhon Sithammarat	598,876.80	4,679	13,436	105	15,452	121	161
Narathiwat	77,930.40	609	1,748	14	2,011	16	21
Pattani	87,309.60	682	1,959	15	2,253	18	23
Phang Nga	21,453.60	168	481	4	554	4	6
Phatthalung	109,520.40	856	2,457	19	2,826	22	29
Phuket	3,394,303.20	26,518	76,154	595	87,577	684	912
Satun	46,600.80	364	1,046	8	1,202	9	13
Songkhla	1,617,048.00	12,633	36,280	283	41,722	326	435
Surat Thani	3,677,487.60	28,730	82,508	645	94,884	741	988
Trang	43,773.60	342	982	8	1,129	9	12
Yala	56,373.60	440	1,265	10	1,455	11	15
Total	**55,166,148**	**430,986**	**1,237,702**	**9,670**	**1,423,357**	**11,120**	**14,827**

The sample of storage space requirement of retailer's demand in Ayutthaya is calculated as below;

Required storage space (retailer in Ayutthaya) = 1,885 pallets x 1.33 sqm per pallet x 1.15 peak factor
= 2,890 sqm

The overall results of average inventory level and storage space requirement by demand point are shown in Table 3.5. The average inventory level is 9,670 pallets and space requirement is 14,827 sqm.

Then the variable cost is calculated as below.

Variable cost (DC Ayutthaya) = 14,827 sqm x 110 THB per sqm per month x 12 months
= 19,571,163 THB

After that the facility cost of baseline network is calculated as below.

Facility cost (DC Ayutthaya) = Fixed cost + Variable cost
= 6,000,000 THB + 19,571,163 THB
= 25,571,163 THB

3.3.2 Transportation Cost (Central DC to Retailers)

The transportation cost is calculated separately between Modern Trade and Traditional Trade as shown in Table 3.7

The example of transportation cost calculation from central DC to retailers in Bangkok is shown as follows:

Number of trips of Modern Trade (Bangkok) = 85,920 pallets x 78% / 24 pallets per trailer
= 2,801 trips

Number of trips of Traditional Trade (Bangkok) = 85,920 pallets x 22% / 12 pallets per truck
= 1,560 trips

Transportation cost (DC to retailer Bangkok) = (2,801 trips x 156 km x 35 THB per km) + (1,560 trips x 156 km x 12 THB per km)
= 15,293,460 THB

From the calculation the transportation cost of Modern Trade is 96,962,880 THB per year while Traditional Trade is 186,352,344 THB per year and total transportation cost of baseline network is 283,315,224 THB per year as shown in Table 3.7

3.3.3 Inventory Holding Cost (Average Inventory in Central DC)

Inventory holding cost = 9,670 pallets x 5,000 THB per pallet
= 48,347,736 THB

3.3.4 Total Logistics Cost

Total logistics cost consist of facility cost of current distribution center, transportation cost and inventory holding cost. The cost for inbound transportation cost is zero so only outbound transportation cost are calculated and inventory holding cost of central DC at the plant is shown in Table 3.6

Table 3.6: Annual Total Logistics Cost of Baseline Network

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	55,166,148	430,986	6,000,000	19,571,163		283,315,224	48,347,736	**357,234,123**
(%)			*2%*	5%		79%	*14%*	*100%*

The total logistics cost is 357,234,123 THB per year, facility cost (fixed + variable) is 7%, transportation cost is 79% and inventory holding cost is 14% of total logistics cost. This total logistics cost of baseline network is benchmarked with the alternative distribution network design in Part IV.

Table 3.7: Transportation Cost of Modern Trade and Traditional Trade

Province	Volume	Modern Trade	Traditional Trade	Distance (DC to retailers)	Modem Trade		Traditional Trade		Total Transportation Cost (THB/year)
	Pallets	%of Volume	%of Volume	Round trip (km)	No. of trip 18 w (24 pallets/trip)	Transportation cost (35 THB/km)	No. of trip 10 w (12 pallets/trip)	Transportation cost (12 THB/km)	
Ayutthaya	84,017	94%	6%	60	3,295	6,919,500.00	412	296,640.00	7,216,140.00
Bangkok	85,920	78%	22%	156	2,801	15,293,460.00	1,560	2,920,320.00	18,213,780.00
Lopburi	2,688	0%	100%	148		-	225	399,600.00	399,600.00
Nakhon Nayok	1,431	0%	100%	220			120	316,800.00	316,800.00
Nontha Bud	55,069	83%	17%	150	1,899	9,969,750.00	792	1,425,600.00	11,395,350.00
Phetcha Bun	1,437	0%	100%	610		-	120	878,400.00	878,400.00
Phichit	317	0%	100%	558			27	180,792.00	180,792.00
Phitsanu Lok	2,917	0%	100%	618			244	1,809,504.00	1,809,504.00
Samut Prakan	9,634	0%	100%	210			803	2,023,560.00	2,023,560.00
Saraburi	3,599	0%	100%	138			300	496,800.00	496,800.00
Suphan Bud	2,490	0%	100%	154			208	384,384.00	384,384.00
Uthai Thani	182	0%	100%	292			16	56,064.00	56,064.00
Chantha Buri	3,318	0%	100%	640		-	277	2,127,360.00	2,127,360.00
Chon Bud	16,000	0%	100%	350			1,334	5,602,800.00	5,602,800.00
Prachin Bud	2,666	0%	100%	288		-	223	770,688.00	770,688.00
Rayong	5,465	0%	100%	546			456	2,987,712.00	2,987,712.00
Khanchana Buri	1,492	0%	100%	398			125	597,000.00	597,000.00
Phetcha Bud	2,811	0%	100%	410			235	1,156,200.00	1,156,200.00
Phrachuap Khirikhan	559	0%	100%	724			47	408,336.00	408,336.00
Ratcha Buri	2,875	0%	100%	360			240	1,036,800.00	1,036,800.00
Chiang Mai	15,626	45%	55%	1272	290	12,910,800.00	723	11,035,872.00	23,946,672.00
Chiang Rai	4,019	0%	100%	1536	-		335	6,174,720.00	6,174,720.00
Kamphaeng Phet	4,112	0%	100%	608			343	2,502,528.00	2,502,528.00
Lampang	937	0%	100%	1086			79	1,029,528.00	1,029,528.00
Nakhon Sawan	1,676	0%	100%	344			140	577,920.00	577,920.00
Nan	1,101	0%	100%	1210			92	1,335,840.00	1,335,840.00
Phare	2,079	0%	100%	974			174	2,033,712.00	2,033,712.00
Amnat Charoen	638	0%	100%	1094			54	708,91200	708,912.00
Buriram	3,093	0%	100%	680			258	2,105,280.00	2,105,280.00
Chaiya Phum	1,333	0%	100%	578			112	776,832.00	776,832.00
Khonkaen	12,327	56%	44%	810	290	8,221,500.00	448	4,354,560.00	12,576,060.00
Loei	1,731	0%	100%	976		-	145	1,698,240.00	1,698,240.00
Mukdahan	1,442	0%	100%	1266			121	1,838,232.00	1,838,232.00
Nakhon Ratchasima	5,236	3%	97%	426	7	104370.00	423	2162,376.00	2,266,746.00
Roiet	491	0%	100%	926			41	455,592.00	455,592.00
Sakon Nakhon	2,629	0%	100%	1202			220	3,173,280.00	3,173,280.00
Sisaket	725	0%	100%	982			61	718,824.00	718,824.00
Ubon Ratchathani	3,705	0%	100%	1114			309	4,130,712.00	4,130,712.00
Udon Thani	5,248	0%	100%	1062			438	5,581,872.00	5,581,872.00
Chumphon	1,929	0%	100%	1068		-	161	2,063,376.00	2,063,376.00
Nakhon Sithammarat	4,679	0%	100%	1754			390	8,208,720.00	8,208,720.00
Narathiwat	609	0%	100%	2426			51	1,484,712.00	1,484,712.00
Pattani	682	0%	100%	2248			57	1,537,632.00	1,537,632.00
Phang Nga	168	0%	100%	1760			14	295680.00	295,680.00
Phatthalung	856	0%	100%	1892			72	1,634,688.00	1,634,688.00
Phuket	26,518	0%	100%	1972			2,210	52,297,44060	52,297,440.00
Satun	364	0%	100%	2118			31	787,896.00	787,896.00
Songkhla	12,633	0%	100%	2124	-		1,053	26,838,864.00	26,838,864.00
Surat Thani	28,730	73%	27%	1430	870	43,543,500.00	655	11,239,800.00	54,783,300.00
Trang	342	0%	100%	1860			29	647,280.00	647,280.00
Yala	440	0%	100%	2356			37	1,046,064.00	1,046,064.00
Total	**430,986**			**48,184**	**9,452**	**96,962,880.00**	**17,040**	**186,352,344.00**	**283,315,224.00**

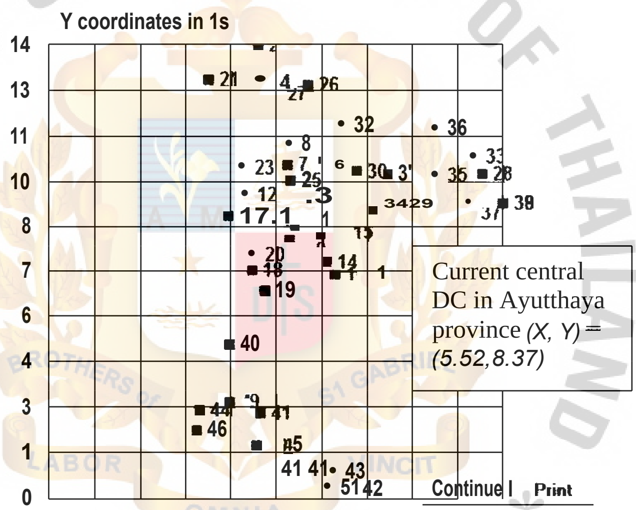
Part II: Distribution Network Configuration (Single Center-of-Gravity)

3.4 Find Potential Location of Single Facility Location Model

3.4.1 Determine Coordinates of Demand and Supply Point

The next step is to redesign the distribution network by using Center-of-Gravity method to find the best location with lowest transportation cost. Firstly, we have to determine coordinates (X,Y) of demand (retailers) and source points (plant and DCs). The coordination of each location are shown in Figure 3.4

Figure 3.4: Coordinate (X,Y) of Demand and Source Points



There are 52 markets to be served from a single DC location which include source points or plants. The total volume of product shipped by the plant is the sum of the volume demanded by the markets *(P 1)*. The annual volume of the markets and the transportation rates are shown in Table 3.8

Table 3.8: Coordinates (X, Y) of Demand and Source Points

Demand point number	Point (I)	Province	Region	Coordinates		Volume (pallet)	Transport Rate (THB/PL/km)
				x	y		
1	C1	Ayutthaya	Central	5.52	8.37	84,017	2.86
2	C2	Bangkok	Central	5.48	7.73	85,920	2.72
3	C3	Lopburi	Central	5.89	9.08	2,688	2.01
4	C4	Nakhon Nayok	Central	6.06	8.14	1,431	2.01
5	C5	Nontha Bud	Central	5.39	7.94	55,069	2.76
6	C6	Phetcha Bun	Central	6.16	10.44	1,437	2.00
7	C7	Phichit	Central	5.35	10.24	317	2.04
8	C8	Phitsanu Lok	Central	5.43	10.85	2,917	2.01
9	C9	Samut Prakan	Central	5.76	7.64	9,634	2.00
10	C10	Saraburi	Central	5.88	8.54	3,599	2.00
11	C11	Suphan Buri	Central	4.99	8.55	2,490	2.00
12	C12	Uthai Thani	Central	4.43	9.35	182	2.11
13	C13	Kamphaeng Phet	Central	4.37	10.16	4,112	2.00
14	C14	Nakhon Sawan	Central	5.43	9.76	1,676	2.00
47	S8	Satun	South	4.98	0.93	364	2.04
48	S9	Songkhla	South	5.55	0.90	12,633	2.00
49	S10	Surat Thani	South	4.05	2.97	28,730	2.67
50	511	Trang	South	4.65	1.60	342	2.04
51	S12	Yala	South	6.29	0.29	440	2.02
52	P1	Plant (source point)	Central	5.52	8.37	430,986	2.86

3.4.2 Calculate Approximate Center-of Gravity Coordinate

After the coordinates (X, Y) are defined in each source point and demand points, the next step is finding the best location of single DC (ideal location) with the lowest transportation cost. The *approximate Center-of-Gravity* coordinate is the initial location from Center-of-Gravity and the formula is as follows:

$$X \text{ coordinate} = X = \frac{\sum_{i=1} V_i R_i X_i}{\sum_{i=1}^{I} V_i R_i}$$

$$Y \text{ coordinate} = Y = \frac{\sum_{i=1}^{I} V_i R_i Y_i}{V_i R_i}$$

Where:

(X_i, Y_i) = position of demand point i

V = volume of demand point i

R = transportation cost (THB per pallet per km)

The approximate Center-of-Gravity method can be calculated as shown in Table 3.9

Table 3.9: Approximate Center-of-Gravity Method

Province	Volume	Coordinates		Distance (DC to retailers)	Transportation cost (THB/PL/km)	Center of gravity (X,Y) (Approx. Method)		
	Pallets	(X)	(Y)	Round trip (km)	(R)	V x R x X	V x R x Y	V x R
Ayutthaya	84,017	5.52	8.37	60	2.86	1,328,949	2,013,504	240,538
Bangkok	85,920	5.48	7.73	156	2.72	1,278,576	1,804,109	233,510
Lopburi	2,688	5.89	9.08	148	2.01	31,822	49,018	5,400
Nakhon Nayok	1,431	6.06	8.14	220	2.01	17,462	23,449	2,880
Nontha Buri	55,069	5.39	7.94	150	2.76	819,412	1,207,106	151,938
Phetcha Bun	1,437	6.16	10.44	610	2.00	17,747	30,056	2,880
Phichit	317	5.35	10.24	558	2.04	3,466	6,633	648
Phitsanu Lok	2,917	5.43	10.85	618	2.01	31,807	63,518	5,856
Samut Prakan	9,634	5.76	7.64	210	2.00	110,922	147,148	19,272
Saraburi	3,599	5.88	8.54	138	2.00	42,311	61,496	7,200
Suphan Buri	2,490	4.99	8.55	154	2.00	24,920	42,690	4,992
Uthai Thani	182	4.43	9.35	292	2.11	1,700	3,590	384
Chantha Bud	3,318	7.13	6.85	640	2.00	47,393	45,570	6,648
Chon Bud	16,000	6.23	7.24	350	2.00	199,397	231,794	32,016
Prachin Bud	2,666	6.58	8.16	288	2.01	35,214	43,661	5,352
Rayong	5,465	6.43	6.88	546	2.00	70,324	75,252	10,944
Khanchana Buri	1,492	4.02	8.70	398	2.01	12,059	26,102	3,000
Phetcha Bud	2,811	4.58	6.98	410	2.01	25,832	39,385	5,640
Phrachuap Khirikhan	559	4.87	6.34	724	2.02	5,489	7,152	1,128
Ratcha Buri	2,875	4.60	7.48	360	2.00	26,508	43,057	5,760
Chiang Mai	15,626	3.59	12.88	1272	2.41	135,220	484,773	37,652
Chiang Rai	4,019	4.71	13.91	1536	2.00	37,884	111,848	8,040
Kamphaeng Phet	4,112	4.37	10.16	608	2.00	35,985	83,653	8,232
Lampang	937	4.72	12.80	1086	2.02	8,955	24,273	1,896
Nakhon Sawan	1,676	5.43	9.76	344	2.00	18,231	32,795	3,360
Phuket	26,518	3.33	2.10	1972	2.00	176,498	111,529	53,040
Satun	364	4.98	0.93	2118	2.04	3,702	689	744
Songkhla	12,633	5.55	0.90	2124	2.00	140,181	22,861	25,272
Surat Thani	28,730	4.05	2.97	1430	2.67	310,520	227,707	76,620
Trang	342	4.65	1.60	1860	2.04	3,234	1,115	696
Yala	440	6.29	0.29	2356	2.02	5,589	261	888
Total	**430,986**					**5,825,371**	**8,010,207**	**1,070,600**
					Approximate Method -->	**5.44**	**7.48**	

The calculation is as given below:

$$X = 5{,}825{,}371 \,/\, 1{,}070{,}600 = 5.44$$

And $$Y = 8{,}010{,}207 \,/\, 1{,}070{,}600 = 7.48$$

After that the exact Center-of-Gravity is computed by the LOGWARE program with COG module. The data inputs shown in Table 3.10 and the results are given in Table 3.11

Table 3.10: Data Input in LOGWARE Program (Single Facility Location)

Problem label: COG_Single Facility Location

Power factor (T): 5

Map scaling factor (K): 111

Point no_	Point label	X coor-dinate	Y coor-dinate	Volume	Transport rate
1	C1	5.52	8.37	84017	2.86
2	C2	5.48	7.73	85920	2.72
3	C3	5.89	9.08	2688	2.01
4	C4	6.06	8.14	1431	2.01
5	C5	5.39	7.94	55069	2.76
6	C6	6.16	10.44	1437	2
7	C7	5.35	10.24	317	2.04
8	C8	5.43	10.85	2917	2.01
9	C9	5.78	7.64	9634	2
10	C10	5.88	8.54	3599	2
11	C11	4.99	8.55	2490	2
12	C12	4.43	9.35	182	2.11
13	EI	7.13	6_85	3318	2
14	E2	6.23	7.24	16000	2
15	E3	6.58	8.16	2666	2.01
16	E4	6.43	6.88	5465	2
17	W1	4.02	8.7	1492	2.01
18	W2	4.58	6.98	2811	2.01
19	W3	4.87	6.34	559	2.02

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K value is a scaling factor to convert coordinate distances to kilometers. One latitudinal degree is 110.6 kilometers and one longitudinal degree is 111.3 kilometers (http://en.wikipedia.org/wiki/Geographic coordinate system) so K is used 111 in every scenario.

Table 3.11: Forty Four Computational Cycles of Location Coordinates and Total Transportation Costs as Generated from COG Software Module

EXACT CENTER-OF-GRAVITY METHOD RESULTS

Title: COG Single Facility Location

Iteration	X coordinate	Y coordinate	Cost	
0	5.453	7.957	270,993,396.71	<-- COG
	5.498	5.131	250,947,975.47	
2	5.511	8.261	236,439,232.04	
3	5.515	2.325	229,091,775.44	
4	5.519	2.355	226,179,915.62	
	5.520	2.365	225,134,022.34	
6	5.520	5.365	224,771,539.22	
7	5.520	5.369	224,647,452.96	
2	5.520	2.370	224,605,166.95	
9	5.520	5.370	224,590,772.93	
10	5.520	2.370	224,595,876.37	
11	5.520	2.370	224,554,210.94	
12	5.520	5.370	224,523,644.52	
13	5.520	2.370	224,553,451.99	
14	5.520	2.370	224,523,356.37	
15	5.520	2.370	224,523,364.09	
16	5.520	2.370	224,553,356.51	
	5.520	2.370	224,553,353.93	
18	5.520	2.370	224,523,353.06	
19	5.520	2.370	224,523,352.76	
44	5.520	8.370	224,583,352.60	< Exact solution

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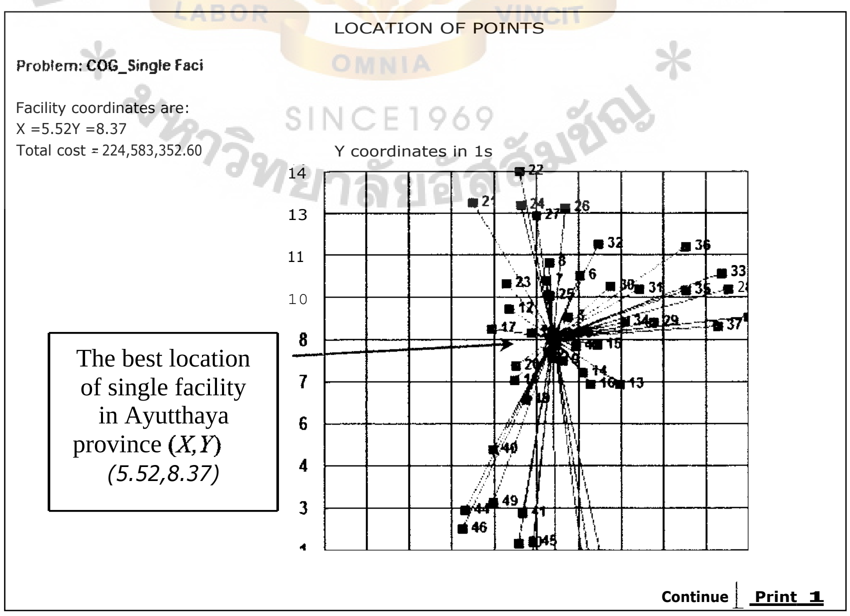
The exact Center-of-Gravity from LOGWARE is coordinates *(5.52, 8.37)* which is in the Ayutthaya province. The location points are plotted in Figure 3.5.

Figure 3.5: Exact Center-of -Gravity of Single Facility Location



From the LOGWARE program using straight line of distance between DC and demand points so it generates the estimated transportation cost at 224,583,352 THB per year. Anyhow the exact transportation cost must be recalculated by using the actual distance between DC and demand points in the excel spread sheet to verify the actual transportation cost in the step of performance evaluation.

3.5 Evaluate Performance of Single Facility Location Model

The total logistics cost is determined by using the steps of calculation as given below:

$$\text{Minimize } TC = \mathbf{V}_i R_i d_i$$

Where:

TC = total transportation cost

- = volume at point i
- = transportation rate to point i

d_1 = distance to point i from the facility to be located

The total logistics cost is shown in Table 3.12

Table 3.12: Total Logistics Cost of Single Facility Location

Single COG (Excel sheet) - Ideal Facility Location

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(THB)	(THB)
Ayutthaya (5.52,8.37)	55,166,148	430.986	6.000,000	19,571.163		283.315,224	48,347,736	**357,234,123**

From this scenario it suggests that the Center-of-Gravity of single DC location in Ayutthaya province is in the same area with the existing DC. That means the current DC is in the best location with the lowest total logistics cost at 357,234,123 THB per year.

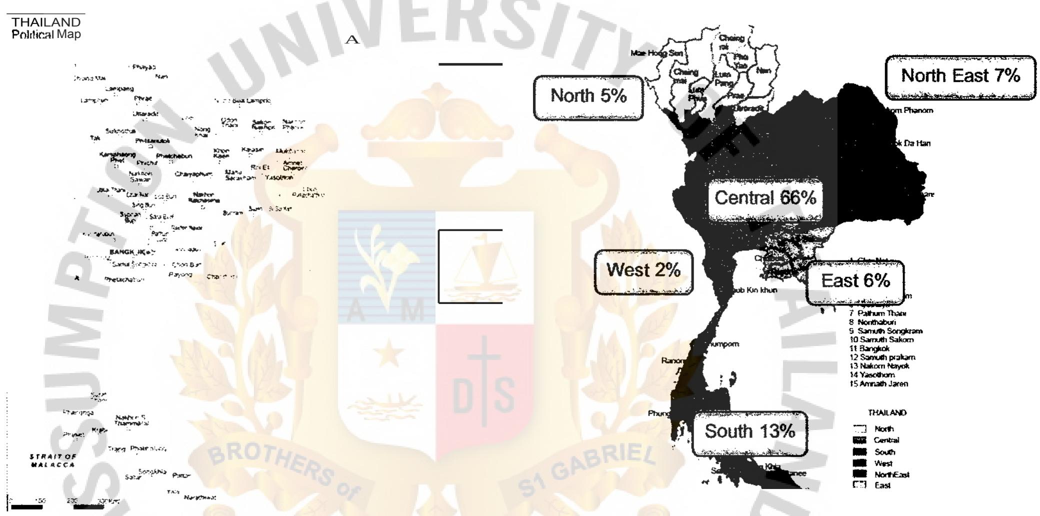
Part III: Distribution Network Configuration (Multiple Center-of-Gravity)

3.6 Find Potential Location of Multiple Facility Location Models

3.6.1 Define Sales Region by Geographical Locations

There are 6 regions in a country which are Central, East, West, North, North East and South as shown in Figure 3.6

Figure 3.6: Define Region by Geographic and Sales Contribution by Regions



3.6.2 Generate Distribution Network Scenarios

The network scenarios are generated in different locations and the number of DCs by using two methods is MULTICOG method and COG method.

MULICOG Method

There are nine scenarios (Scenario no.1-9) with different number of DCs to run in the LOGWARE program to compute the exact Center-of-Gravity by using MULTICOG module. The input data is shown in Table 3.13. The sample of scenario no.1 (2 DCs) is shown in Table 3.14 and the overall results are shown in Figure 3.7

Table 3.13: Data Input in LOGWARE Program (Multiple Facility Location)

Problem label: [illegible]tiple Facility Location

Map scaling facto, (K): 111

Point no.	Point label	X coor-dinate	Y coor-dinate	Volume	Transport rate
1	[illegible]	5.52	8.37	84017	2.86
2	C2	5.48	7.73	85920	232
3	C3	5.89	9.08	2688	2.01
4	C4	6.06	8.14	1431	2.01
5	105	5.39	7.94	55069	2.76
6	C6	6.16	10.44	1437	2
		5.35	10_24	317	2.04
8	C8	5.43	10.85	2917	2.01
9	1C9	5.76	7.64	9634	2
10	IC10	5.88	8.54	3599	2
11	C11	4.99	8.55	2490	2
12	C12	4.43	9.35	182	2.11
13	E1	7.13	6.85	3318	2
14	E2	6.23	7.24	16000	2
1	E3	6.58	8.16	2666	2.01
16	1E4	6.43	6.88	5465	2
17	W1	4.02	8.7	1492	2.01
18	W2	4.58	6.98	2811	2.01
19	W3	4.87	6.34	559	2.02

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Table 3.14: Location Coordinates, Transportation Costs and Assignment Customer to DCs as Generated from MULTICOG Software Module (Scenario no.!)

[MULTIPLE CENTER OF GRAVITY SOLUTION RESULTS

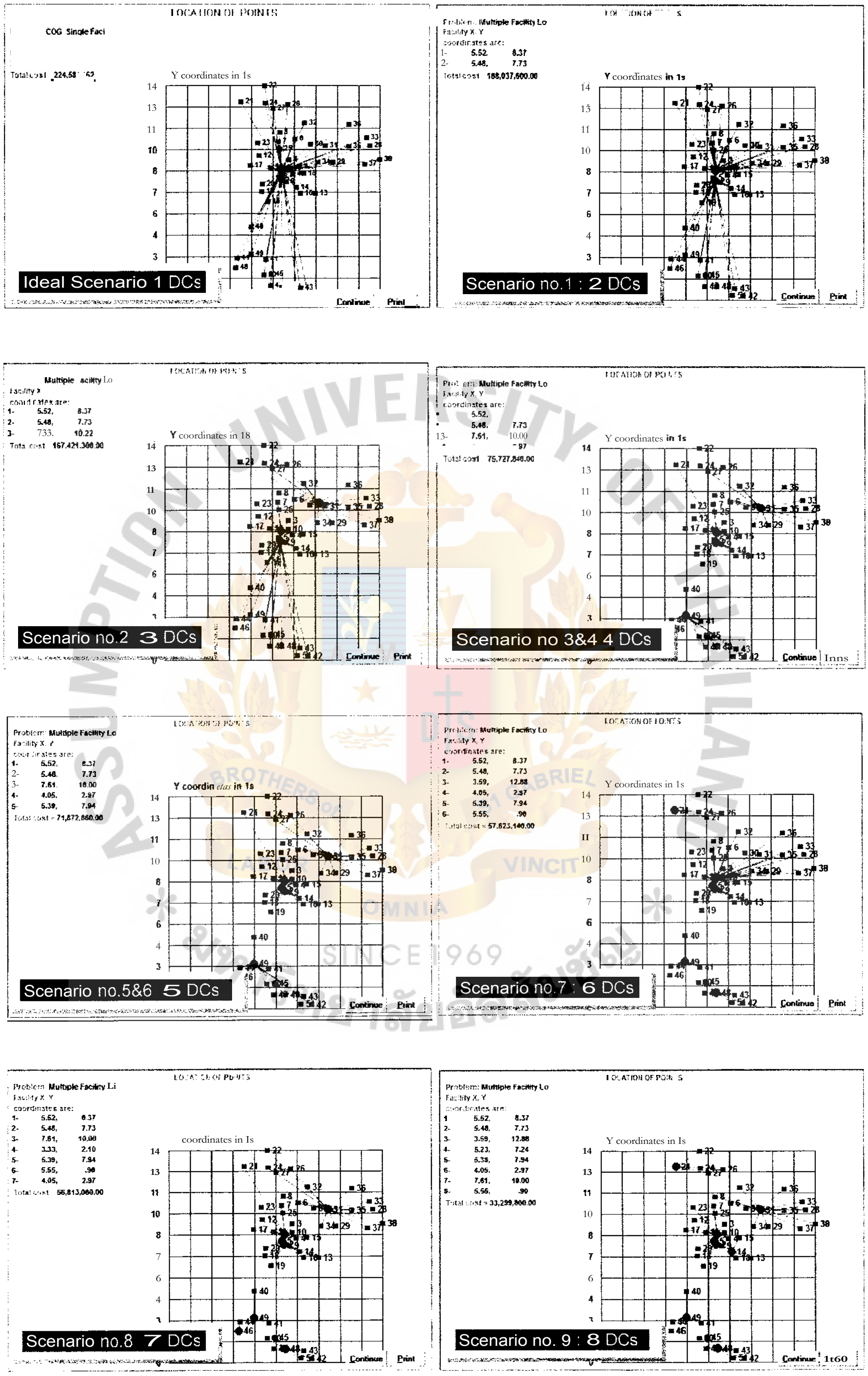
Problem label: Multiple Facility Location

Source	X coor-dinate	Y coor-dinate	Volume	Cost
1	5.52	8.37	171,384	66,938,708.12
2	5.48	7.73	259,601	121,098,922.88

Total cost 188,037,600.00

Source	Allocated demand points to source points
1	1,3,4,6,7,8,10,11,12,15,17.21,22,23,24,25,26,27,28,29.30, 31,32,33,34,35,36,37,38,39
2	2,5,9,13,14,16,18.19,20,40,41.42,43,44,45,46,47,48,49,50, 51

Figure 3.7: Number of DCs and Coordinates (*X,Y*) of Scenario no. 1-9



COG Method

Scenario no.10 represents this method. There are six regions in a country that are defined by geographic locations and the next step is to calculate the exact Center-of-Gravity COG by region by using COG module in LOGWARE. The sample of input data to Northern region is shown in Table 3.15 and 3.16. The result of COG in Northern region and overall results of all regions are shown in Figure 3.8 and 3.9

Point label *P1* represents a source point or plant which supplies products to the new DC location. The volume of P1 is equal to sum of the volume in each demand point.

Table 3.15: Data Input in LOGWARE Program of the Northern Region

Problem label: COG_Single Facility Location (North)

Power factor (T): [illegible]

Map scaling factor (K): [111

Point no.	Point label	X coordinate	Y coordinate	Volume	Transport rate
1	N1	3.59	12.88	15626	2.41
2	N2	4.71	13.91	4019	2
3	N3	4.72	12.8	937	2.02
4	N4	5.8	1211	1101	2.01
5	N5	5.12	12.42	2079	2.01
6	P1	5.52	8.37	23762	1.33

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Table 3.16: Five Hundred Computational Cycles of Location Coordinates and Total Transportation Costs as Generated from COG Software Module (North Region)

EXACT CENTER-OF-GRAVITY METHOD RESULTS

Title: COG_Single Facility Location (North)

Iteration	X coordinate	Y coordinate	Cost	
0	4.565	11.283	22,293,920.55	<-- COG
	4.416	11.729	21,398,626.87	
2	4.293	12.042	20,870,583.65	
3	4.199	12.243	20,593,623.17	
4	4.101	12.368	25,442,679.11	
5	4.029	12.452	20,352,048.91	
6	3.972	12.513	20,293,057.53	
	3.925	12.559	20,252,438.18	
	3.888	12.596	20,223,159.22	
9	3.557	12.626	20,201,329.88	
10	3.231	12.651	20,124,592.39	
1	3.509	12.672	20,171,45[illegible].52	
12	3.795	12.690	20,160,946.04	
13	3.774	12.706	20,152,392.11	
14	3.759	12.719	20,145,329.24	
15	3.747	12.731	20,139,425.11	
16	3.735	12.742	20,134,433.14	
17	3.725	12.752	20,130,171.14	
18	3.716	12.765	20,126,500.33	
19	3.708	12.762	20,123,313.77	
500	3.590	12.880	20,089,950.02	< -- Exact solution

Continue Print

Figure 3.8: Coordinates (X,19 of DC Location in Northern Region

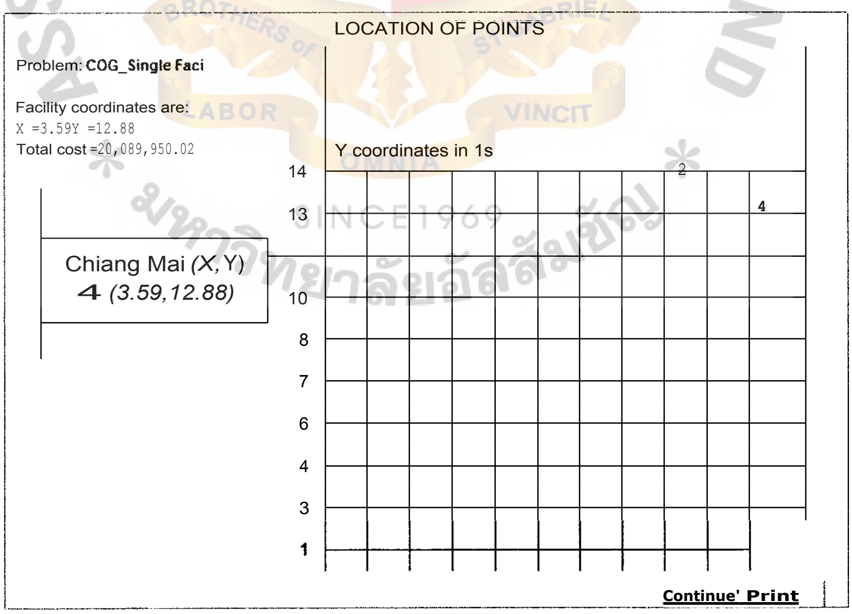
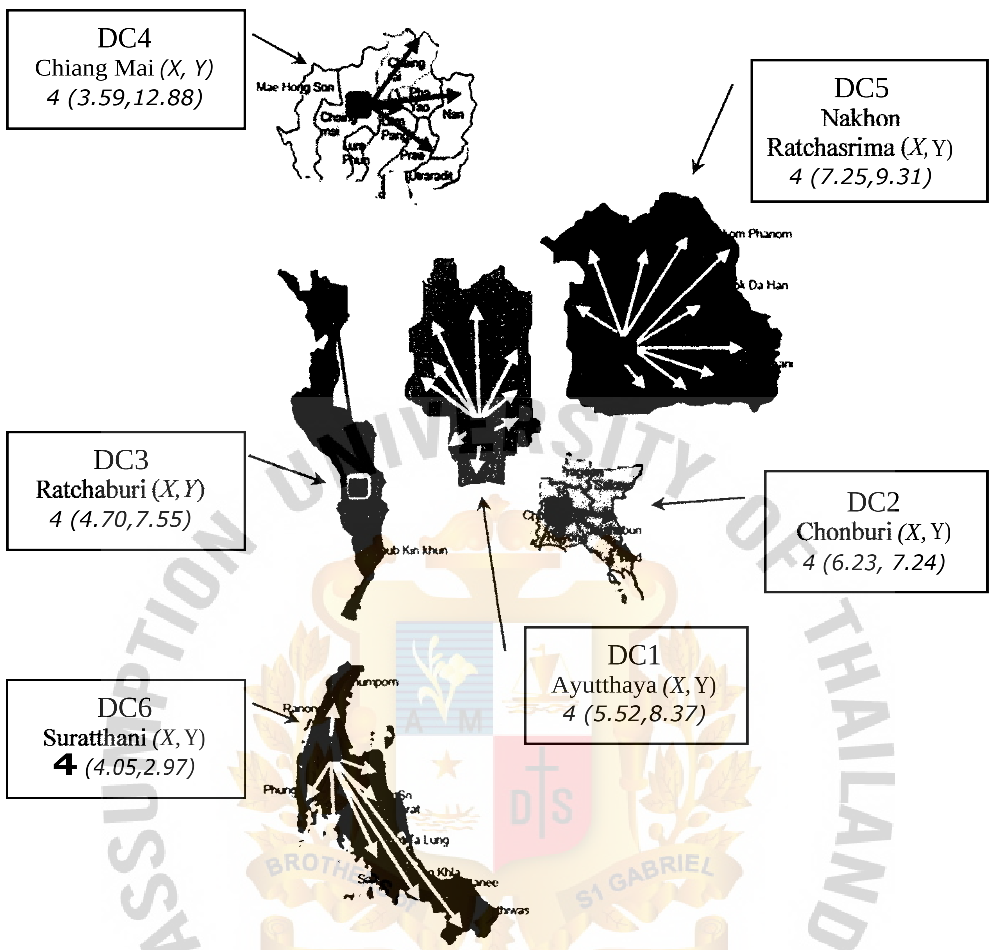


Figure 3.9: Coordinates ***(X,Y)*** of DC Location in Each Region (Scenario **no.10)**



There are 6 DCs in 6 regions as a result of scenario no.10 as given below DC location and coordinates *(X*, Y)

DC 1:	Ayutthaya	*(5.52,8.37)*
DC 2:	Chonburi	*(6.23,7.24)*
DC 3:	Ratchaburi	*(4.70,7.55)*
DC 4:	Chiang Mai	*(3.59,12.88)*
DC 5:	Nakhon Ratchasrima	*(7.25,9.31)*
DC 6:	Suratthani	*(4.05,2.97)*

3.6.4 Define Potential DCs in Each Region

There are potential DCs in each region as shown in Table 3.17

Table 3.17: Potential DCs and Volume Allocation for Each DC Location

Scenario	DC	Region	DC Location	Coordinates		Volume
				(X)	(Y)	(cases)
Baseline	1 DC	Central	Ayutthaya	5.52	8.37	430,986
Ideal	1 DC	Central	Ayutthaya	5.52	8.37	430,986
1	2 DCs	Central	Ayutthaya	5.52	8.37	171,384
			Bangkok	5.48	7.73	259,601
2	3 DCs	Central	Ayutthaya	5.52	8.37	104,670
			Bangkok	5.48	7.73	259,601
		North East	Khonkaen	7.33	10.22	66,714
3	4 Dcs	Central	Ayutthaya	5.52	8.37	120,296
			Bangkok	5.48	7.73	181,651
		North East	Khonkaen	7.33	10.22	51,088
		South	Suratthani	4.05	2.97	77,950
4	4 Dcs	Central	Ayutthaya	5.52	8.37	131,350
			Bangkok	5.48	7.73	181,651
		North East	Khonkaen	733	10.22	40,035
		South	Suratthani	4.05	2.97	77,950
5	5 DCs	Central	Ayutthaya	5.52	8.37	120,296
			Bangkok	5.48	7.73	123,707
			Nonthaburi	5.39	7.94	57,944
		North East	Khonkaen	7.33	10.22	51,088
		South	Suratthani	4.05	2.97	77,950
6	5 DCs	Central	Ayutthaya	5.52	8.37	131,350
			Bangkok	5.48	7.73	123,707
			Nonthaburi	539	7.94	57,944
		North East	Khonkaen	7.33	10.22	40,035
		South	Suratthani	4.05	2.97	77,950
7	6 DCs	Central	Ayutthaya	5.52	8.37	147,622
			Bangkok	5.48	7.73	123,707
			Nonthaburi	5.39	7.94	57,944
		North	Chiang Mai	3.59	12.88	23,762
		South	Suratthani	4.05	2.97	62,024
			Songkla	5.55	0.90	15,926
8	7 DCs	Central	Ayutthaya	5.52	8.37	120,296
			Bangkok	5.48	7.73	123,707
			Nonthaburi	5.39	7.94	57,944
		North East	Khonkaen	7.33	10.22	51,088
		South	Phuket	323	2.1	26,686
			Songkla	5.55	0.90	15,926
			Suratthani	4.05	2.97	35,338
9	8 DCs	Central	Ayutthaya	5.52	8.37	102,004
			Bangkok	5.48	7.73	98,924
			Nonthaburi	5.39	7.94	57,944
		East	Chon Burl	6.23	7.24	27,449
		North	Chiang Mai	3.59	12.88	23,762
		North East	Khonkaen	7.33	10.22	42,952
		South	Suratthani	4.05	2.97	62,024
			Songkla	5.55	0.90	15,926
10	6 DCs	Central	Ayutthaya	5.52	8.37	255491
		East	Chon Bun	6.23	7.24	27,449
		West	Ratchaburi	4.7	7.55	7,736
		North	Chiang Mai	3.59	12.88	23,762
		North East	Nakhon Ratchasima	725	9.31	38,598
		South	Suratthani	4.05	2.97	77,950

3.7 Assign Retailers, Transportation Mode and Inventory Level to DCs

3.7.1 Assign Retailers to Each DC

LOGWARE provides the assignment of retailers to DC as summarized in Table 3.18

Table 3.18: Assignment of Retailers to DC of Each Scenario

Scenario	Number of DC	DC Location	Ohai a P	oei	on T an	ho aen	oiet	Sako Nak on	ukdanan	Amnat Charoen	U n R ich hani	Sisaket	Burriram	Na on Ra chasima	g Nburi	Chi 5b ai	Chiang Rai	Nan	P re	3 ,ang	mph en Ph2	g hla	Pa an		N rat	co
Baseline	1 Dcs	Ayutthaya	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	2 DCs	Ayutthaya	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
		Bangkok																				1	1	1	1	1
2	3 DCs	Ayutthaya													1						1					
		Bangkok																				1	1	1	1	1
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1						
3	4 Dcs	Ayutthaya													1						1					
		Bangkok																								
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1						
		Surat Thani																				1	1	1	1	1
4	4 Dcs	Ayutthaya													1	1	1	1	1	1	1					
		Bangkok																								
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1												
		Surat Thani																				1	1	1	1	1
5	5 Dcs	Ayutthaya													1						1					
		Bangkok																								
		Nonthaburi																								
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1						
		Suratthani																				1	1	1	1	1
6	5 Dcs	Ayutthaya													1	1	1	1	1	1	1					
		Bangkok																								
		Nonthaburi																								
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1												
		Suratthani																				1	1	1	1	1
7	6 Dcs	Ayutthaya	1	1	1	1	1	1	1	1	1	1	1	1	1						1					
		Bangkok																								
		Nonthaburi																								
		Chiang Mai														1	1	1	1	1						
		Suratthani																								
		Songkla																				1	1	1	1	1
8	7 Des	Ayutthaya													1	1					1					
		Bangkok																								
		Nonthaburi																								
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1			1	1	1	1						
		Phuket																								
		Songkla																				1	1	1	1	1
		Suratthani																								
9	8 Dcs	Ayutthaya													1						1					
		Bangkok																								
		Nonthaburi																								
		Chon Bud																								
		Chiang Mai														1	1	1	1	1						
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1												
		Suratthani																								
		Songkla																								
10	6 Dcs (Region)	Ayutthaya													1						1					
		Chon Buri																								
		Ratcha Bud																								
		Chiang Mai														1	1	1	1	1						
		Nakhon Ratchasima	1	1	1	1	1	1	1	1	1	1	1	1												
		Surat Thani																								

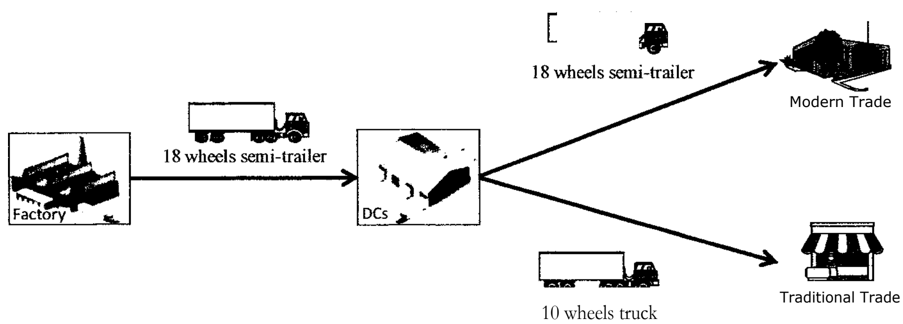
3.7.2 Assign Transportation Mode to Each Location

To maximize the shipment size of inbound transportation from plant to DCs, a network of DCs allow larger shipments from the plant to the DCs that help decreasing the unit transportation cost as a result of the *economies-of-scale* in transportation. The single product or group of product destined for multiple DCs can be aggregated to each DC. Since the transportation of 18 wheel semi-trailer is lower than the 10 wheel truck as shown in Figure 3.10, the 18 wheel semi-trailer is proposed to be used instead of 10 wheel truck for inbound transportation, plant to DCs. The outbound transportation maintains a current shipment size because it is related to customer order size.

Figure 3.10: Comparison of Transportation Cost between 18 Wheel Semi-Trailer and 10 Wheel Truck (THB per pallet per km)

The transportation cost of 18 wheel semi-trailer (24 pallets per trailer) is 16 THB per km or 0.67 THB per pallet per km while 10 wheel truck (12 pallets per truck) is 12 THB per km or 1.00 THB per pallet per km. Therefore there is a 35% of transportation cost saved by using the new approach. The shipment size assignment is shown in Figure 3.11

Figure 3.11: Assigned Transportation Mode for Each Location



3.7.3 Determine Average Inventory Level and Space Requirement of Each Scenario

The safety inventory of decentralized system is equal to;

$$I^{d}_{safety} = N \times z \times \sigma_{LTD}$$

Where:

z = desired service level 95%

N = number of locations

σ_{LTD} = standard deviation of lead time demand at centralized system

For example:

$I^{d}_{safety\ (N=1)}$ = 1 x 1.65 x 414 pallets
= 684 pallets

$I^{d}_{safety\ (N=2)}$ = 2 x 1.65 x 414 pallets
= 1,368 pallets

Cycle inventory (N = 1) = Average inventory (N = 1) - $I^{d}_{safety\ (N=1)}$
= 9,670 pallets – 684 pallets
= 8,986 pallets

Average inventory (N = 2) = $I^{d}_{safety\ (N=2)}$ + Cycle inventory (N = 1)
= 1,368 pallets + 8,986 pallets
= 10,353 pallets

Inventory holding cost = 10,353 pallets x 5,000 THB per pallet

= 51,766,611 THB

Required storage space (DC size) = 10,353 pallets x 1.33 sqm per pallet

x 1.15 peak factor

= 14,827 sqm

The result of average inventory, inventory cost and space requirement of baseline, single DC and each scenario of multiple DCs are shown in Table 3.19

Table 3.19: Average Inventory Cost and Space Requirements

Scenario	DC number	*N*	Service Level	*Z*	*a LTD*	Safety Inventory (pallet)	Cycle Inventory (pallet)	Avg. Inventory (pallet)	Inventory cost **(THB)**	DC size (x peak 1.15) **(Sqm)**
Baseline	Baseline	1	95.0%	1.65	414	684	8,986	9,670	48,347,736	14,827
Ideal	(Ideal)	1	95.0%	1.65	414	684	8,986	9,670	48,347,736	14,827
1	2 DCs	2	95.0%	1.65	414	1,368	8,986	10,353	51,766,611	15,875
2	3 DCs	3	95.0%	1.65	414	2,051	8,986	11,037	55,185,487	16,924
3	4 DCs	4	95.0%	1.65	414	2,735	8,986	11721	58,604,363	17,972
4	(Reallocate)	4	95.0%	1.65	414	2,735	8,986	11,721	58,604,363	17,972
5	5 DCs	5	95.0%	1.65	414	3,419	8,986	12,405	62,023,238	19,020
6	(Reallocate)	5	95.0%	1.65	414	3,419	8,986	12,405	62,023,238	19,020
7	6 DCs	6	95.0%	1.65	414	4,103	8,986	13,088	65,442,114	20,069
8	7 Dcs	7	95.0%	1.65	414	4,786	8,986	13,772	68,860,990	21,117
9	8 DCs	8	95.0%	1.65	414	5,470	8,986	14,456	72,279,865	22,166
10	(Regional DCs)	6	95.0%	1.65	414	4,103	8,986	13,088	65,442,114	20,069

Table 3.19 shows that the increasing number of DCs causes increasing inventory holding cost as well as the space requirement consequently.

3.8 Evaluate Alternative Network Models

As the LOGWARE program use straight lines of distance between DC and demand points, it generates the estimated transportation cost. Then the exact transportation cost must be calculated by using the actual distance between DC and demand points in the excel spread sheet to determine the actual transportation cost in the steps of performance evaluation.

3.8.1 Total Logistics Cost

The total logistics cost of multiple DCs each scenario are summarized in Table 3.20

Table 3.20: Total Logistics Cost of Each Scenario

Multi COG (Excel) - 2 DCs as Regional DC

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	21,937,152	171,384	6,000,000	6,201,165		86,737,674	4,117	20,584,932	119,523,771
Bangkok *(5.48,7.73)*	33,228,928	259,601	9,600,000	10,246,989	26,998,504	158,590,116	6,236	31,180,555	236,616,165
Total	**55,166,080**	**430,985**	**15,600,000**	**16,448,155**	**26,998,504**	**245,327,790**	**10,353**	**51,765,487**	356,139,936

Multi COG (Excel) - 3 DCs as Regional DC

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	13,397,760	104,670	6,000,000	4,997,641		13,498,716	2,680	13,402,304	37,898,661
Bangkok **(5.48,7.73)**	33,228,928	259,601	9,600,000	13,521,776	26,998,504	158,590,116	6,648	33,239,889	241,950,285
Khonkaen *(7.33,10.22)*	8,539,392	66,714	6,000,000	3,185,325	36,025,560	48,707,274	1,708	8,542,170	102,460,329
Total	**55,166,080**	**430,985**	**21,600,000**	**21,704,742**	**63,024,064**	**220,796,106**	**11,037**	**55,184,363**	382,309,275

Multi COG (Excel) - 4 DCs as Regional DC

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	15,397,888	120,296	6,000,000	5,314,063		13,498,716	2,847	14,232,626	39,045,405
Bangkok *(5.48,7.73)*	23,251,328	181,651	9,600,000	10,060,656	18,891,704	20,625,384	4,940	24,699,951	83,877,696
Khonkaen *(7.33,10.22)*	6,539,264	51,088	6,000,000	3,387,002	27,587,520	48,707,274	1,814	9,071,389	94,753,184
Surat *(4.05,2.97)*	9,977,600	77,950	4,800,000	3,597,701	74,312,333	29,568,912	2,120	10,599,272	122,878,218
Total	**55,166,080**	**430,985**	**26,400,000**	**22,359,422**	**120,791,557**	**112,400,286**	**11,721**	**58,603,238**	340,554,504

Multi COG (Excel) **- 4 DCs as Regional DC (Allocate North to AY)**

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	16,812,744	131,350	6,000,000	6,668,516		49,828,692	3,572	17,860,251	80,357,459
Bangkok **(5.48,7.73)**	23,251,295	181,651	9,600,000	7,274,745	18,891,677	20,625,384	4,940	24,699,951	81,091,757
Khonkaen *(7.33,10.22)*	5,124,486	40,035	6,000,000	9,222,268	21,618,925	11,906,194	1,089	5,443,764	54,191,151
Surat *(4.05,2.97)*	9,977,623	77,950	4,800,000	1,847,771	74,312,506	29,568,912	2,120	10,599,272	121,128,462
Total	**55,166,148**	**430,986**	**26,400,000**	**25,013,301**	**114,823,108**	**111,929,182**	**11,721**	**58,603,238**	336,768,830

Multi COG Excel) - 5 DCs as Regional DC

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	15,397,888	120,296	6,000,000	6,427,772		37,445,388	3,462	17,311,646	**67,184,807**
Bangkok *(5.48,7.73)*	15,834,496	123,707	9,600,000	7,210,877	12,865,528	15,479,724	3,560	17,802,352	**62,958,480**
Nonthaburi *(5.39,7.94)*	7,416,832	57,944	4,800,000	2,814,631	5,794,400	5,318,460	1,470	7,351,910	**26,079,401**
Khonkaen *(7.33,10.22)*	6,539,264	51,088	6,000,000	2,729,746	27,587,520	24,158,170	2,244	11,217,627	**71,693,064**
Surat *(4.05,2.97)*	9,977,600	77,950	4,800,000	3,786,434	74,312,333	29,568,912	1,668	8,338,579	**120,806,259**
Total	**55,166,080**	**430,985**	**31,200,000**	**22,969,461**	**120,559,781**	**111,970,654**	**12,404**	**62,022,114**	**348,722,010**

Multi COG (Excel) - 5 DCs as Regional DC (Allocate North to AY)

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	16,812,744	131,350	6,000,000	7,018,344		49,828,692	3,780	18,902,207	**81,749,242**
Bangkok *(5.48,7.73)*	15,834,468	123,707	9,600,000	7,210,877	12,865,505	15,479,724	3,560	17,802,352	**62,958,458**
Nonthaburi *(5.39,7.94)*	7,416,827	57,944	4,800,000	2,814,631	5,794,396	5,318,460	1,152	5,761,349	**24,488,836**
Khonkaen *(7.33,10.22)*	5,124,486	40,035	6,000,000	2,139,175	21,618,925	11,906,194	2,244	11,217,627	**52,881,922**
Surat *(4.05,2.97)*	9,977,623	77,950	4,800,000	3,786,434	74,312,506	29,568,912	1,668	8,338,579	**120,806,431**
Total	**55,166,148**	**430,986**	**31,200,000**	**22,969,461**	**114,591,333**	**112,101,982**	**12,404**	**62,022,114**	**342,884,889**

Multi COG (Excel) - 6 DCs as Regional DC

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	18,895,616	147,622	6,000,000	8,243,331		52,217,202	4,483	22,415,137	**88,875,670**
Bangkok **(5.48,7.73)**	15,834,496	123,707	9,600,000	7,535,821	12,865,528	15,479,724	3,757	18,783,680	**64,264,753**
Nonthaburi *(5.39,7.94)*	7,416,832	57,944	4,800,000	2,941,467	5,794,400	5,318,460	722	3,607,960	**22,462,287**
Chiang Mai *(3.59,12.88)*	3,041,536	23,762	6,000,000	1,326,854	20,150,176	4,505,400	1,884	9,417,739	**41,400,169**
Surat *(4.05,2.97)*	7,939,072	62,024	4,800,000	3,148,584	59,129,547	18,525,720	1,760	8,798,230	**94,402,081**
Songkhla *(5.55,0.90)*	2,038,528	15,926	4,800,000	808,479	22,551,216	1,684,704	484	2,418,243	**32,262,642**
Total	**55,166,080**	**430,985**	**36,000,000**	**24,004,535**	**120,490,867**	**97,731,210**	**13,088**	65,440,990	**343,667,601**

Multi COG (Excel) - 7 DCs as Regional DC

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	15,397,888	120,296	6,000,000	6,983,793		37,445,388	3,844	19,220,203	**69,649,384**
Bangkok *(5.48,7.73)*	15,834,496	123,707	9,600,000	7,834,638	12,865,528	15,479,724	3,953	19,765,008	**65,544,897**
Nonthaburi *(5.39,7.94)*	7,416,832	57,944	4,800,000	3,058,105	5,794,400	5,318,460	1,632	8,162,436	**27,133,400**
Khonkaen *(7.61,10.00)*	6,539,264	51,088	6,000,000	2,965,877	27,587,520	24,158,170	853	4,263,639	**64,975,206**
Phuket **(3.33,2.10)**	3,415,808	26,686	6,000,000	1,549,223	35,083,195	1,620,432	1,852	9,257,882	**53,510,731**
Songkhla *(5.55,0.90)*	2,038,528	15,926	4,800,000	840,537	22,551,216	1,684,704	509	2,544,581	**32,421,038**
Surat *(4.05,2.97)*	4,523,264	35,338	4,800,000	1,865,050	33,688,893	4,469,736	1,129	5,646,117	**50,469,797**
Total	**55,166,080**	**430,985**	**37,200,000**	**23,232,173**	**137,570,752**	**90,176,614**	**13,772**	**68,859,865**	**363,704,454**

Multi COG (Excel) - 8 **DCs** as Regional DC

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	13,056,512	102,004	6,000,000	6,132,117		12,728,028	3,421	17,106,896	41,967,041
Bangkok *(5.48,7.73)*	12,662,272	98,924	9,600,000	6,487,484	10,288,096	8,543,004	3,318	16,590,083	51,508,667
Nonthaburi *(5.39,7.94)*	7,416,832	57,944	4,800,000	3,166,668	5,794,400	5,318,460	797	3,984,946	23,064,474
Chon Buri *(6.23,7.24)*	3,513,472	27,449	4,800,000	1,500,076	6,404,767	3,822,912	921	4,603,272	21,131,027
Chiang Mai *(3.59,12.88)*	3,041,536	23,762	6,000,000	1,428,439	20,181,859	4,505,400	1,944	9,717,534	41,833,231
Khonkaen *(7.61,10.00)*	5,497,856	42,952	6,000,000	2,582,093	23,194,080	13,774,258	2,080	10,401,773	55,952,204
Surat *(4.05,2.97)*	7,939,072	62,024	4,800,000	3,389,643	59,129,547	18,525,720	1,441	7,203,319	93,048,228
Songkhla *(5.55,0.90)*	2,038,528	15,926	4,800,000	870,377	22,551,216	1,684,704	534	2,670,919	32,577,215
Total	**55,166,080**	**430,985**	**42,000,000**	**24,686,520**	**147,543,964**	**68,902,486**	**14,456**	**72,278,741**	361,082,087

10 COG (Excel) - Regional DC

DC	Annual Volume		Facility cost (THB)		Transportation cost (THB)		Avg. Inventory	Inventory holding cost	Total logistics cost
	(Cases)	(Pallets)	Fixed	Variable	DC-Plant-DC	DC-Cus-DC	(Pallets)	(THB)	(THB)
Ayutthaya *(5.52,8.37)*	32,702,861	255,491	6,000,000	14,266,724	-	43,371,174	7,759	38,793,855	102,431,754
Chon Buri *(6.23,7.24)*	3,513,409	27,449	4,800,000	1,393,396	6,404,652	3,822,912	834	4,167,791	20,588,751
Ratchaburi ***(4.70,7.55)***	990,240	7,736	4,800,000	392,723	1,856,700	985,440	235	1,174,675	9,209,538
Chiang Mai *(3.59,12.88)*	3,041,477	23,762	6,000,000	1,326,854	20,181,466	7,585,848	722	3,607,960	38,702,127
Nakhon Ratchasima	4,940,538	38,598	4,800,000	1,959,386	10,961,819	18,843,704	1,172	5,860,726	42,425,635
Surat *(4.05,2.97)*	9,977,623	77,950	4,800,000	3,957,063	74,312,506	29,568,912	2,367	11,835,982	124,474,463
Total	**55,166,148**	**430,986**	**31,200,000**	**23,296,146**	**113,717,143**	**104,177,990**	**13,088**	**65,440,990**	337,832,269

Scenario no.3 (4 DCs) and no.5 (5 DCs) re-allocates the demand of Northern region (Chiang Mai, Chiang Rai, Nan, Phare, Lampang, Kamphaeng and Phitsanu Lok) from DC Khonkaen to DC Ayutthaya as shown in scenario no.4 and 5 which generates the lower transportation cost than the prior scenario.

3.8.2 Customer Service Levels (Customer Response Time)

The next step is to evaluate the performance of customer service levels related to on-time delivery or response time of each scenario. Normally delivery lead time from central DC to retailers is a minimum of 1 day and a maximum of 4 day; the longest distance is going to the Southern region. From the ten scenarios it shows that increasing number of DCs affect the customer service levels decrease. The details as shown in Table 3.21

Table 3.21: Distance and Maximum Delivery Lead Time from DC to Retailers

Scenario	DC	Region	DC Location	Volume (cases)	Min. Distance (one way km)	Max Distance (one way km)	Min Delivery Lead lime (Baseline)	Max Delivery Lead Time (Baseline)	Min Delivery Lead lime (Scenario)	MaxDelivery Lead Time (Scenario)	
Baseline	1 DC	Central	Ayutthaya	430,986	30	1213	1	4	1	4	-
Ideal	1 DC	Central	Ayutthaya	430,986	30	1,213	1	4	1	4	-
1	2 DCs	Central	Ayutthaya	171,384	30	768	1	4	1	3	4
			Bangkok	259,601	26	1,135			1	4	
2	3 DCs	Central	Ayutthaya	104,670	30	304	1	4	1	1	4
			Bangkok	259,601	26	1,135			1	4	
		North East	Khonkaen	66,714	30	732			1	3	
3	4 Dcs	Central	Ayutthaya	120,296	30	304	1	4	1	1	3
			Bangkok	181,651	26	284			1	1	
		North East	Khonkaen	51,088	30	732			1	3	
		South	Suratthani	77,950	30	525			1	2	
4	4 Dcs	Central	Ayutthaya	131,350	30	768	1	4	1	3	3
			Bangkok	181,651	26	284			1	1	
		North East	Khonkaen	40,035	30	290			1	1	
		South	Suratthani	77,950	30	525			1	2	
5	5 DCs	Central	Ayutthaya	120,296	30	636	1	4	1	2	3
			Bangkok	123,707	26	284			1	1	
			Nonthaburi	57,944	30	132			1	1	
		North East	Khonkaen	51,088	30	732			1	3	
		South	SuratMani	77,950	30	525			1	2	
6	5 DCs	Central	Ayutthaya	131,350	30	768	1	4	1	3	3
			Bangkok	123,707	26	284			1	1	
			Nonthaburi	57,944	30	132			1	1	
		North East	Khonkaen	40,035	30	290			1	1	
		South	Suratthani	77,950	30	525			1	2	
7	6 DCs	Central	Ayutthaya	147,622	30	633	1	4	1	2	2
			Bangkok	123,707	26	284			1	1	
			Nonthaburi	57,944	30	132			1	1	
		North	Chiang Mai	23,762	30	342			1	1	
		South	Suratthani	62,024	30	264			1	1	
			Songkla	15,926	30	198			1	1	
8	7 DCs	Central	Ayutthaya	120,296	30	304	1	4	1	1	1
			Bangkok	123,707	26	284			1	1	
			Nonthaburi	57,944	30	132			1	1	
		North East	Khonkaen	51,088	30	290			1	1	
		South	Phuket	26,686	30	87			1	1	
			Songkla	15,926	30	198			1	1	
			Suratthani	35,338	30	184			1	1	
9	8 DCs	Central	Ayutthaya	102,004	30	304	1	4	1	1	1
			Bangkok	98,924	26	284			1	1	
			Nonthaburi	57,944	30	132			1	1	
		East	Chon Buri	27,449	30	167			1	1	
		North	Chiang Mai	23,762	30	342			1	1	
		North East	Khonkaen	42,952	30	319			1	1	
		South	Suratthani	62,024	30	264			1	1	
			Songkla	15,926	30	198			1	1	
10	6 DCs	Central	Ayutthaya	255,491	30	309	1	4	1	1	2
		East	Chon Buri	27,449	30	167			1	1	
		West	Ratchaburi	7,736	30	215			1	1	
		North	Chiang Mai	23,762	30	342			1	1	
		North East	Nakhon Ratchasima	38,598	30	407			1	2	
		South	Suratthani	77,950	30	525			1	2	

The sample of calculation of response time in baseline network from Ayutthaya to Narathiwat is given below and is as follows:

Response time = Maximum distance (km) of DC to retailer one way / 350 km per day per driver per route

= 1213 / 350

= 3.5 day or 4 days

Scenario no. 8 (7 DCs) and no. 9 (8 DCs) provides the best response time with the maximum delivery lead time of 1 day compared to 4 days of the baseline network.

Part IV: Compare Scenarios and Recommend Optimal Solution

3.9 Benchmark Models with Baseline Network

From the previous part, there is one scenario for single DC location and ten scenarios for multiple DC locations. Therefore the next step is to benchmark those generated alternative network models with baseline network. The last step is to recommend the optimal network model.

The alternative network models compared with baseline network resulted in total logistics cost which consist of facility cost (fixed and variable cost), transportation cost and inventory holding cost as shown in Table 3.22

Table 3.22: Comparison of Scenarios with Baseline Network (unit: million-THB)

Unit . Million-THB per year

Scenario	Number of DC	Fixed cost	Variable cost	Transportation cost	Inventory holding cost	Total logistics cost	Cost saving from baseline	% Dif. From baseline
Baseline	Baseline	6.0	19.6	2833	48.3	357.2		0.0%
Ideal	Single DC	6.0	19.6	283.3	483	357.2		0.0%
1	2 DCs	15.6	16.4	272.3	51.8	356.1	1.1	0.3%
2	3 DCs	21.6	21.7	283.8	55.2	382.3	- 25.1	-7.0%
3	4 DCs	26.4	22.4	233.2	58.6	340.6	16.7	4.7%
4	(Reallocate)	26.4	25.0	226.8	58.6	336.8	20.5	5.7%
5	5 DCs	31.2	23.0	232.5	62.0	348.7	8.5	2.4%
6	(Reallocate)	31.2	23.0	226.7	62.0	342.9	14.3	4.0%
7	6 DCs	36.0	24.0	218.2	65.4	343.7	13.6	3.8%
8	7 Des	42.0	25.1	227.7	68.9	363.7	- 6.5	-1.8%
9	8 DCs	46.8	25.6	216.4	72.3	361.1	- 3.8	-1.1%
10	6 DCs (Regional DCs)	31.2	23.3	217.9	65.4	337.8	19.4	5.4%

3.10 Recommendation for the Optimal Network Model

The last step is to recommend the optimal network model. The selection criteria of making decisions is to minimize the total logistics cost. The customer service level is also a part to be considered where making decision by benchmarking between scenarios, the optimal network model is scenario no.4 with 4 DCs location which are located in Ayutthaya, Bangkok, Khonkaen and Suratthani. The optimal network model generates the lowest logistics cost of 336,769,954 THB per year while the baseline network generates a total logistics cost of 357,234,123 THB per year.

3.11 Summary

The Center-of-Gravity (CO) method is used in the study to determine the distribution network model for both single and multiple DC models. There is one scenario for single DC location and ten scenarios for multiple DC location..

From the comparison between scenarios of both single and multiple DC with baseline network, the optimal solution is scenarios no.4 that is to locate 4 DCs location as follows:

- Central region : DC1 Ayutthaya and DC2 Bangkok
- North East : DC3 Khonkaen
- South : DC4 Suratthani

The optimal distribution network generates the total logistics cost of 336,768,830 THB per year while baseline network generates the total logistics cost of 357,234,123 THB per year.

NW Company must do the trade-off between facility cost, transportation cost, inventory holding cost and customer service levels to get the most benefit for the company before making decisions. The result of scenarios are analyzed and discussed in Chapter 4.

CHAPTER IV

PRESENTATION AND CRITICAL DISCUSSION OF RESULTS

Chapter 4 discusses and analyzes the result of scenarios and covers the analysis of distribution center locations and the analysis of distribution network performance evaluation or total logistics cost saving.

4.1 Analysis of Distribution Center Location

4.1.1 DC Location and Center-of-Gravity Method

In the study, Center-of-Gravity (COG) method is used to calculate the optimal location of DC in a country for both of single and multiple DC location models. In the scenario, central DC at plant in Ayutthaya province *(P1)* is a source point that is also taken into account in COG calculation because the product should be transported from plant to DC before delivery to the retailers. As the principle of COG method, it provides the optimal location by minimizing the transportation costs which are proportional to the distance and volume carried along the route, plant to DC (inbound transportation) and DC to retailers (outbound transportation).

In single DC location model by COG method, Ayutthaya province is suggested as the best DC location (ideal location) to distribute the product to retailers across the country. It can be analyzed that the existing central DC is in the best location that generates the lowest total logistics cost of 357,234,123 THB per year.

The multiple DC location model by MULTICOG module, Ayutthaya province is also suggested in every alternative network model (scenario 1-9). It can be analyzed that whenever the various number of DCs are calculated in MULTICOG module, Ayutthaya province is the first DC location to be suggested by the group because it is close to high volume demand in the Central region. Bangkok province is suggested as the second DC in group since the products are mainly distributed to retailers in the Bangkok area. Khonkaen province is suggested in scenario no.2, 3, 4, 5, 6, 8 and 9 since the products are distributed to retailers in the North East region. Chiang Mai province is suggested in scenario no.7,9 and 10 since the products are distributed to retailers in the Northern region while Suratthani province is suggested in scenario no.3, 4, 5, 6, 7, 8, 9 and 10 since the products are distributed to retailers in the Southern region.

In multiple DC location model by COG module run by region, Ayutthaya province is suggested as the best DC location in Central region, Chiang Mai in Northern region, Khonkaen in North East region, Ratchaburi in West region, Chonburi in East and Suratthani in Southern region.

4.1.2 DC Location and Transportation Cost

As COG principle, the distance, volume and transportation rate are key factors to determine the best DC location that can generate the lowest transportation cost.

Scenario no.1 (2 DCs) is compared with the baseline network.The distance between plant to Bangkok DC increases from 0 to 156 km (round trip) which affects the inbound transportation cost which increases from 0 to 27 million-THB per year while the distance between Bangkok DC to retailers in Samuthprakarn decreases from 150 to 52 km (round trip) which impact to the total outbound transportation cost which decreases from 283 to 245 million-THB per year. The total transportation of scenario no.1 also decreases from 283 to 272 million-THB per year.

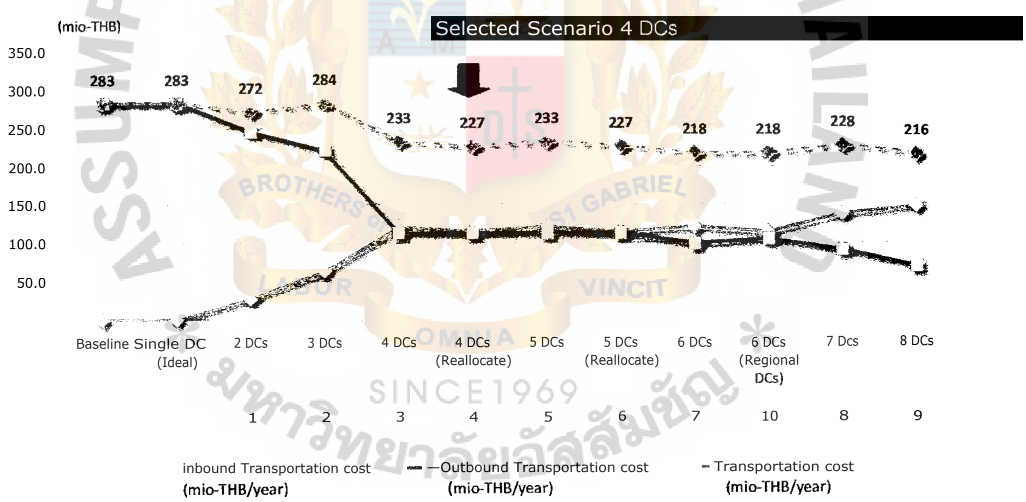
Scenario no.4 (4 DCs) is the optimal solution compared with the baseline network. The distance between plant to 4 DCs increases and affects the total inbound transportation cost which increases from 0 to 115 million-THB per year while the distance between 4 DCs to retailers decreases and affects the total outbound transportation cost which decreases from 283 to 112 million-THB per year. The total transportation of scenario no.4 decreases from 283 to 227 million-THB per year.

Scenario no.9 (8 DCs) is compared with baseline network. The distance between plant to 8 DCs increases and affects the total inbound transportation cost which increases from 0 to 148 million-THB per year while the distance between 8 DCs to retailers decreases and affects the total outbound transportation cost which decreases from 283 to 69 million-THB per year. The total transportation of scenario no.9 also decreases from 283 to 216 million-THB per year.

Scenario no.2 (3 DCs) generates the highest transportation cost of 284 million-THB per year because of high inbound transportation cost from plant to Bangkok DC while scenario no.9 (8 DCs) generates the lowest transportation cost at 216 million-THB per year. The total transportation cost of each scenario is shown in Figure 4.1

It can be analyzed that the increasing number of DCs affect the inbound transportation cost increase and the outbound transportation cost decrease. The total transportation decrease occurs because the DCs are located far away from the plant but close to the demand points.

Figure 4.1: Total Transportation Cost of Each Scenario



4.1.3 DC Location and Facility Cost

As the principle, the facility cost consists of fixed and variable cost, fixed cost is not varied by demand volume while the variable cost is varied by demand volume or space requirement.

From Table 3.22, for example the baseline generates the fixed cost 6 million-THB per year and variable cost 19.6 million-THB per year so total facility cost is 25.6 million-THB per year.

Scenario no.4 (4 DCs) is the optimal solution generates the fixed cost of 4 DCs 26.4 million-THB per year and variable cost 25 million-THB per year. The total facility cost is 51.4 million-THB per year which is higher than the baseline network.

Scenario no.9 (8 DCs) generates the fixed cost of 8 DCs 46.8 million-THB per year and variable cost 25.6 million-THB per year so total facility cost is 72.4 million-THB per year which is the highest facility cost because there are 8 DCs in the network.

Since the variable cost is calculated from space requirement which varies by the number of DCs, it can be analyzed that the increasing number of DCs affect the safety inventory increase, the variable cost increase and facility cost as well.

4.1.4 DC Location and Inventory Holding Cost

As the number of DCs in a network increases the inventory costs also increases as shown in Figure 3.12. In the study, the inventory is considered as *Decentralized System* which means that if the number of DCs increases the inventory costs also increases because of higher safety stock requirements from each DC.

Baseline network (1 DC) requires the safety inventory of 648 pallets and cycle inventory of 8,986 pallets so the average inventory is 9,670 pallets.

Scenario no.4 (4 DCs) is the optimal solution requires the safety inventory of 2,735 pallets and cycle inventory of 8,986 pallets so the average inventory is 11,721 pallets.

Scenario no.9 (8 DCs) requires the safety inventory increase of 5,470 pallets and cycle inventory will still be the same at 8,986 pallets, so the average inventory is 14,456 pallets.

It can be analyzed that from the ten scenarios, the increasing number of DCs causes the inventory holding cost increase. Therefore the company must balance and try to consolidate and limit the number of facilities in the distribution network to decrease inventory holding cost.

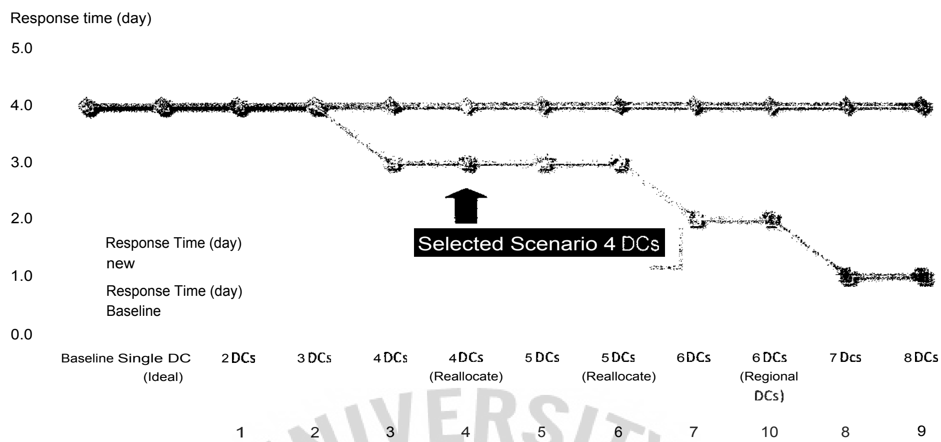
4.1.5 DC Location and Customer Response Time

As a company wants to reduce the response time for retailers in all regions, it may have to increase the number of facilities beyond the point that minimizes logistics costs.

Table 3.21 shows the distance between DCs to retailers and response time in a day. In the baseline network, the shortest distance is 30 km one way (Ayutthaya to retailers in Ayutthaya) and the longest distance is 1,213 km one way (Ayutthaya to retailers in Narathiwat) that is range of 1- 4 days response time. In scenario no.4, the shortest distance is 30 km one way and longest distance is 768 km one way (Ayutthaya to retailers in Chiang Rai) that is range of 1- 3 days response time. In scenario no.9, the shortest distance is 30 km one way and longest distance is 432 km one way (Chiang Mai to retailers in Nan) that is only 1 day response time. The relation between number of DCs and response is shown in Figure 4.2.

It can be analyzed that the increasing number of DCs helps reduce response time to retailers. Scenario no.4 can reduce response time for the longest route which reduces from 4 to 3 days response time. Therefore the company must trade-off between total logistics cost and response time for customers to experience the balance among of them and also satisfy customer service levels.

Figure 4.2: Number of DCs and Response Time to Retailers



4.2 Distribution Network Performance Evaluation (Total Logistics Cost Saving)

Since the criterion of distribution network evaluation is total logistics cost which consist of facility cost, transportation cost and inventory cost, the optimum solution is selected by considering the total logistics cost as a priority.

From Table 3.22, baseline network (1 DC) generates the total logistics cost 357 million-THB per year. Scenario no.2 (3 DCs) generates the highest total logistics cost of 382 million-THB per year which is higher than the baseline network of 25 million-THB per year or 7% increase from baseline network. This is because of the inbound and outbound transportation cost increase so there is no cost saving from this scenario. Scenario no.3-7 and 10 generates cost saving. Scenario no.4 (4 DCs) especially generates the lowest total logistics cost of 337 million-THB per year which is lower than the baseline network of 20.5 million-THB per year or 5.7% decrease from baseline network. The highest cost saving is from this scenario.

From Figure 4.3 shows the increasing number of DCs affects the facility cost (fixed and variable cost) increase, transportation cost decrease and inventory holding cost increase.

Figure 4.3: Annual Total Logistics Cost of Each Scenario (million-THB)

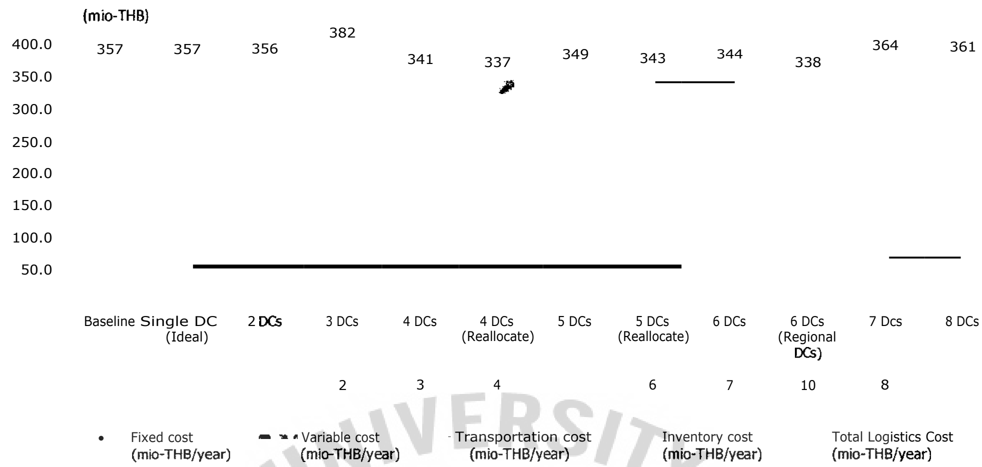
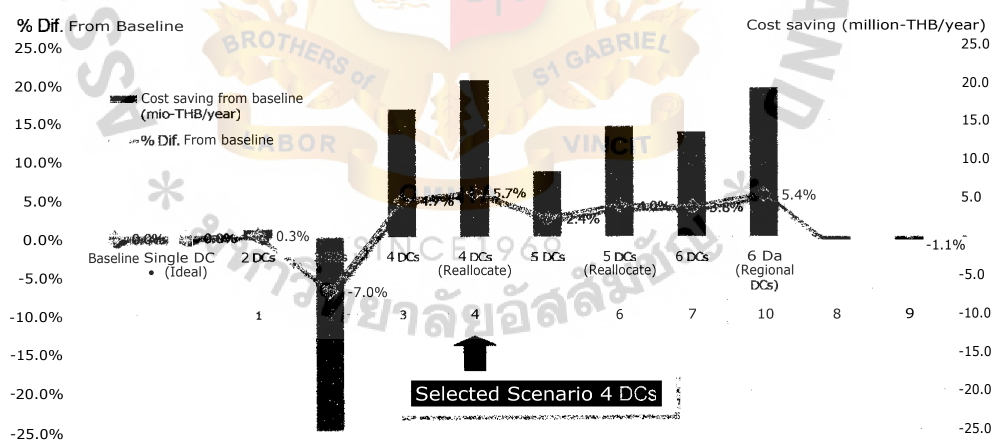


Figure 4.4 indicates that the optimum number of DCs can reduce the total logistics cost effectively in the opposite site, too many number of DCs affect the facility cost and inventory holding cost increase.

Figure 4.4: Total Logistics Cost Saving of Each Scenario (million-THB)



Therefore scenario no.4 is the optimal solution that can help the company reduce total logistics cost 20.5 million-THB per year or 5.7% decrease from the baseline network as shown in Table 4.1

Table 4.1: Total Cost Saving of Optimal Solution Compare with Baseline Network

Cost component	Baseline network	Optimal Solution	Dif. (Baseline - Optimal)	%Dif
Transportation cost	283,315,224	226,752,290	56,562,934	20.0%
Facility cost	25,571,163	51,413,301	-25,842,138	-101.1%
Variable cost	19,571,163	25,013,301	-5,442,138	-27.8%
Fixed cost	6,000,000	26,400,000	-20,400,000	-340.0%
Inventory holding cost	48,347,736	58,603,238	-10.255.502	-21.2%
Total logistics cost	**357,234,123**	**336,768,829**	**20,465,294**	**5.7%**

4.3 Summary

In conclusion, the optimal distribution network is scenario no.4 with 4 DCs because it generates the lowest total logistics cost of 337 million-THB per year compared to baseline network of 357 million-THB per year. The total logistics cost is decreased by 20 million-THB per year or 5.7% decrease from baseline network cost. By cost components, the transportation cost decreases by 57 million-THB per year or 20% of baseline network. The facility cost increases by 26 million-THB per year or 101% of baseline network and inventory holding cost increases by 10 million-THB or 21% of baseline network. Moreover the optimal distribution network can reduce customer response time from 4 days to 3 days.

CHAPTER V

SUMMARY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

The distribution network redesign from COG method by calculation in LOGWARE program and Excel for the ten scenarios explains the benefit and negative impact of implementation of the new distribution network project at the company. The summary findings, conclusion of this proposed project of distribution network redesigning are summarized from the detailed analysis. Recommendations for further study in the areas of distribution network redesign are added at the end of this chapter.

5.1 Summary of the Findings

The key finding from the study are summarized as below.

5.1.1 The increasing number of DCs affects the inbound transportation cost increases and outbound transportation cost decreases so the total transportation decreases because of DCs are located close to the demand points.

5.1.2 The increasing number of DCs affects the facility cost and inventory holding cost increases while the optimum number of DCs affects the total logistics cost decreases but too much number of DCs affects the total logistics cost increase.

5.1.3 The increasing number of DCs affects the customer response time decreases.

5.1.4 The optimal distribution network is scenario no.4 with 4 DCs because of it provides the lowest total logistics cost off 337 million-THB per year and also generate the cost saving by 20 million-THB per year or 5.7% decrease from the baseline network.

5.2 Conclusions

The objectives of this study is to redesign the distribution network of NW company to improve the total logistics cost and customer service level by answering the questions of how many DCs number are needed, where should DCs be located, what customers to allocate to DCs, what transportation method should be applied in a model, and what size of DCs and inventory level should be required that results in total logistics cost which should be minimized. All of these questions can help a company encounter when they need to expand the capacity to serve the demand growth.

The methodology of this study is divided mainly into three sections, using the historical data of customer demand from the year 2006-2010 to determine sales contribution between customer groups (Modern Trade and Traditional Trade), growth and peak factors of drinking water product. The data of customer demand for the year 2011 is also used as the baseline and database for analysis.

In the first section, the current distribution network (baseline) is evaluated. The distribution network performance that results in the total logistics cost which is the highest cost and contributes the biggest part is the transportation cost. This is because almost all products are shipped from central DC to retailers in all regions when caused long distance and long response time for retailers. Then the distribution network redesigning is considered by comparing between single and multiple DC location models to find out the optimal solution with the lowest total logistics cost and also reduce response time for retailers.

In the second section, the alternative distribution network of single DC location is calculated by using COG method. The result shows that the current DC in Ayutthaya province is already in the best location and there is no cost saving from single DC location model. The multiple DC location model is calculated by using MULTICOG method run in all regions with various number of DCs put into the LOGWARE program. The COG method is run by region and there are 10 scenarios of alternative multiple DC models. The results show the optimal solution with the lowest total logistics cost and improvement of response time. The assignment of retailers to each

DC is allocated by LOGWARE computation, using the concept of exact center-of gravity. Moreover, another key approach of transportation cost is the assignment of transportation method by increasing shipment size to be larger trucks of transport products from the plant to DCs that help minimize total transportation cost effectively.

In the third section, the optimal location of distribution centers is determined that results in total logistic cost savings and also satisfies customer service levels.

In conclusion the optimal solution of distribution network redesigning can answer the question of NW Company's problems. The capacity of distribution center by implementing the multiple DCs locations which can minimize transportation cost from baseline network and also improve customer response time needs to be increased.

5.3 Theoretical Implications

The theoretical implications of the study are summarized as follows:

5.3.1 This study applies Location Allocation by using Center-of-Gravity (COG) method to determine the optimal DC location that can help the company to minimize cost and reduce customer response time efficiently. As the principle of COG method, the distance between two points and transportation rate are key factors in transportation cost calculation. The geographic coordinates (X, Y) are used to find straight-line distances between two points and a conversion factor or scaling factor is applied in calculation to approximate the distance. It is popular to estimate the transportation cost by first estimating and then verifying the transportation cost by using the actual distance between two points in the excel sheet for the next step. However the transportation cost calculation from excel sheet gives the similar outcome with COG method. Therefore it can be clearly stated that COG method can be use efficiently in this study.

5.3.2 The Center-of Gravity (COG) method focuses on minimizing the transportation cost. The other costs like facility cost and inventory cost are not calculated by COG method. Therefore it is suggested to separate calculation in the excel sheet.

5.3.3 The geographic or natural barriers in a country are not considered in the COG method therefore re-allocation of customers to DC in some region is applied in the study because this is more practical for real implementation (for example scenario no.4 and 6).

5.3.4 The Multiple-Center-of-Gravity (MULTICOG) module in LOGWARE program limits the desired number of locations at 20. However in this study the desired locations are generated at a maximum of 8 DCs which is the highest number for the study.

5.3.5 The optimization of shipment size is considered and used in the study to obtain the lower transportation cost. The bigger shipment size (18 wheel semi-trailer) is approached for inbound transportation from the plant to DCs. This can minimize total transportation cost significantly.

5.3.6 Even though the Center-of-Gravity (COG) method can be used in the study practically to determine DC location with lowest transportation cost, decisions of optimal distribution networks should trade-off and balance the cost and customer service levels by a company.

5.4 Managerial Implications

The proposed distribution network model provides a means by which transportation, inventory and location strategies can be evaluated by a company. The investigation of transportation, inventory and location strategies could lead to more competitive strategies. The model could be used to vary the number of open DCs and evaluate their effect on the transportation cost, facility cost and the amount of inventory (safety and cycle stock) that needs to be carried by these DC based on their location in the distribution network.

As this study is conducted from the cost perspective, the conclusions of this study have illustrated the importance of adopting a new distribution network for the company. The most important areas of business management have focus in the logistics area. In addition to contributions, the implementation of new distribution networks are also related to the whole management of supply chain processes in which purchasing, manufacturing, distribution center and third party logistics (3PL) functions should possibly be involved. The managerial implications can be described in three categories as below.

5.4.1 Inventory Management

The inventory management in each DC should be considered through planning process and the challenge can be how to coordinate the inventory replenishments from the plant to multiple DC and how to improve visibility within the distribution network, given the fluctuation in demand.

5.4.2 Order Management

In baseline network, the customer order is centralize in central DC so the challenge can be how to design a network to consolidate and communicate the orders more effectively between central DC, regional DCs and customers. Given the different delivery requirements from different customers, DC and 3PL need to determine which customers should be served from which DC to meet the delivery lead time requirement.

5.4.3 Third Party Logistics (3PL) Management

In purchasing view of business, the third party transportation service or 3PL is emphasized and to be used to move the products into each location effectively. The transportation cost also should be managed as a contract agreement. The similar transportation conditions are provided where similar carriers in a given route are required to charge the same price for the same service. Therefore good transportation management along the network can be one of the factors creating competitive advantage for the supply chain.

5.5 Limitations of the Research

5.5.1 This study is analyzed by using the historical data only. There are other factors are not considered in the study such as fuel price fluctuation, labor price increase and future demand change in the market.

5.5.2 The plant location is fixed according to the selection of a qualified water resource (well) location which cannot be moved to other sources so there is a limited opportunity to find the lowest cost location.

5.6 Recommendations for Future Research

5.6.1 In this study facility location decision considers only quantitative factors but in real situation of project implementation the qualitative factors should be considered such as labor availability, labor skill, DC's infrastructure and conditions, the environment surrounding DC, information technology system and communication, utilities, road condition, congestion, etc. Therefore the future research can add the qualitative factors in distribution network redesigning of a company.

5.6.2 The Center-of-Gravity method is used in the study, since the location allocation of facility decision can be solved by many methods like integer programming. This might be used for future research as a comparative study and to check the different cost in the distribution.

5.6.3 The future demand can be added in future research and relationships within the model that represent those experienced in practice and financial functions can be included to maximizing the profit.

5.6.4 The methodology of this study can be applied to other products of the company such as distribution network redesigning of bottled drinking water in a big format (home and office delivery) which has high transportation cost and also has benefits for a company.

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APPENDICES

APPENDIX A

Table of Distance between province in country (kilometer: km)

	Chaiya um	Loei	Nongbua Lampoo	Nong Kai	Udon Thani	Khonkae	Ma rakam	Roiet		Sako Nakhon	Nakhon om	Mukd	A. roc'aroen	Yasotho	Ubon Ratchathani	Cisake	Surin	Buriram	Na hon Ratchas ma	Sara	Maehong rn	Chang Ma.	Lampun	Chiang R.	Paya	Nan	Pha	ang	Tak	Kampnaeng Phe	Suk Nth.	Utharad	Phitsanu Lo	Pichit	Nakhon Sawan	Phetcha Bun	Bangkok	Nontha Buri	Pathum Thani
ha ya Ph	30	^o	19^	288	1	128	166	~05		339	428	372	324	174	369	286	227	181	120	225	9^	640	619	N	63	600	402			368	380	413	321	278	9	21	59	I.	29
Loei	228	30	92	10?		0	289	329		18	5		450	389	495	466	447	402	348	422	906	602			588	564	4		0	372	328	38/	269		O	90	8	548	528
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Kai	288	192	V	30		173	267	306		209	8	432	428	^	4	444	426	0	373	2	122	818	797		804	7	El	9		8	544	603	85	a	m	93	65		
ih	251	141	51	52	30	1	186	14		177		2	391	3	436	390	375	328	320	469	171	767	A				612	67			495	552	34	.	Li	342	60		1
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		329	S.			115		30			249	149	129	6	174	6	146	149	233	383	109		744	845	1	27	610	6	7		491	560	32	63	475	353	3	523	
m	2	93	7	40	174	0	52	49		130	219	159	168	6	222	199	199	200	262		103	729	708	09	715	6	574	6 0		499	455	14		29	179	316		533	
Sakon Nakhon	39	318	227		177	8	180	161		0	94	114	199	178	280	314	325	340	390	53	61	957	836	37	8	9	702	768		627			.	567	608	444	67	661	
Nakhon Panor	8	426	321	8	253	297	269	249		94	30	104	190	219	271	305	38		479	62			929	30		912	795			720	76		N	650	01	27	761	751	
kdahan		454	373	4	292	231	188	149	5	114	104		87	116	168	207	271	305					877	975	8	58	740		0	649	621	680	62	95		481	70	693	
Amnat Charoen		5	71		3	246		.2,	.3,	199		87		63	81	m	199	235	5	484		8	872		876	853	35		95	0	515	5	7	90	6	82	61	607	
Yasothon		89	09	67	313	85		68	11	178		116		30	108		140	174	2		IA	339	818		822		581	747	541	05	562	521	503	^		8	55	545	
U Ratc	369	5	13	73	436	290		174		280		68		108	30		171	223		4	238	937	916		920	897	779	845	739	04	660		601	634			62	17	
Sisaket	286	466	84		35	2	87	146	19	14	5	202	118	8		O	105	157	2,	9	13	7	956		978	937	819	885	773	5	717		8	615	N	5	56	5	
Surin	227	t	368	426		230	68	146		325			199	140		105	30	52	2		179	72	861		47	2	714		2		612		5	10		7	45		
Burnam	181	02	1	380	37	7	148	149		340	2		275	174	2		5	30		278	136	822	801		04	2	664	0	8		562			460		197	41	00	
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S	225	422	1	522		2	305	383	411		28	556		d am	429	2	278		30	860	25	604	718	24	60	6		61		6		305	289	5	39	116	1		
	961	.	933	2	1		9	069	103	1		1199	194			284	7	6	101		30		341	417	5		438		2				5	641	91	19	936	926	
	640	602	649	818	767	652		765	2	857	0	898	893				7	822	777	625	360	30	39	190	15	342	10		ED					400	463	491	70	796	
	619	581	634	797	746	631		744		836	3	877						801	756	04	11	39	30	11	79	308	177	82	41		299			367	47	458	674		644
Ra	722	682	729	898	847		05	45	30	937	30	975	0		0			904	870		17	190	211	30	92	307	234	229	11	2	02	3				56	838	828	1;
	631	588	35	8 4	7	638	11	751		843	6	881				978					1	159		92	30	148	14	142	20	381	312		323	388		466	70	696	676
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	482					•	70	610	7	702	795	740				819		664	635		4	210	177	34		19	30	96	I.	5	16		175	240		318		547	
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	436	407		62		7	0	0		2	755		.		739	773		618	5	2		280	241	1	320	3	226	1		62				17	184	300		416	6
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u			-	485	34	319		432		524	617	562	5	03			5	503	57	305	576	349		14		292	175	238	142					7		177	27		9
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Nakhon Sawan	259	374		576	15	5		475	t	608	704	631	653	520		96	49	441	77	175	69	463		5		433	315		184		182		34	4	30	174	24	40	229
	215	190	31	393	3	240		353	'	444	37	481	482	.			44		310	239			456			5	318		00		7		77	33	174	30	27		345
	59	558	54	664	60		497	533		67	61	7	617	555		6	45	410	283	6	936	706	674	338		.	1		26		427			49	48	375	30	30	42
	349	548	544	644	591	65		523		66	51	693		545	7			400	..		926	696	664			665	547	3	16					29			20	30	27
Pathum Than	329	528	24	624		445	7	503				673		525	7			380	253		906	6	644			5	527		96					319	229	345	42	27	30

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		285	305		375	385		225	355	285	0		444	355	425		40	605	416	480		3	32	48	643			996	1161	1267	116	11	158	17	4			a.	
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			602			682		22	652	582		702	739	652	722		37	902	711	775		692	27	781	938					2	45							1789	
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		4	49		561		79				9		628		611	681	26		600	664	5	581	16	670				1									3	1678	
on		9		674	689	699	608		669		61		756	669	739	E	54	9	728	792	773	709	t												1655			1806	652
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Phitsanu Lok		69	239	79	159				260	365		589		64			6							506								9						1514	
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Uthai Thani		72		2	619					89			34	3	645	79	474	426	301	153	1	486		a	86		7		206	154			129		43	155		216	
		8			629			3			788			583	655	89	484	438	311	102	1	581		3		30			301	249						250	1		
	2	74					[redacted]					631	53	520	660	96	491		327			463	432			33				132	82						248		22
			2	22	69	34	65	3			628	556		423	4	29	324	278	151		60	5					83	535		293	2	4		2	1			1	8
	35			652	99				54		758	686	141	3	626	59		408	281											248	3	W	260				180		
Navok	28		48	582	529		25			599	688	616	441	483		189														353									98
achin Bun	3	502	121	602	549					191	708	636	164	03		109	404	581		86		642	to 1			811			62	510			515	5		511			136
		602		702	649						808		164		6	509	504		3	184	11	916			16	88			636	584		703	58			585			238
Sa				739	686	6	582	618		61	846		102	2	71	546	542	495	68		962	2	700	864	732	70	583		452	400		519	105	5	74	401	26		61
	355	2		652	9		495	513		669	758	686	614	553	625	559		408		150	1021	791	759	923	791	76	642		511	459		576	464		333		85		113
	42	2		22	669	54	565	583	6	739	828		384	3	695	329	524	478	351	2 1	1036	806	774	o	806	77	657	713	526	474	527	593	9		348	475	100		128
	495			92		61	635	653	60	809	898			693	71	599	59	548	421	272	112	893	861	1025	893	86		80	613	561	614	680	566		136	56			215
Bu	540			7	7	65	680	698				871	9	738				593				960	928	1092	960	929			680	628			633		502			281	
		C			8		745	6				35					4	658		80			996	1160	8			135	748	696	9		701		570			28	350
P	16				58			90						612	684	18		467	340	173			1	895		2		670	483	431		0		6	305				99
	480			776	722		618	654		792	882	824	36	676		82	578	53		237	105	827	99	959	827					495		614	500	470	369	496	2		163
03		660									863		19	7		63	559	512		218	1038	808		0	806		659						481		350				144
					39			571						9			95		321	154				76									417	387	286	413		66	80
	432		62	7	674	548	570	606			834					4	530		356	189						74		686		447			452			448		103	115
B	48			81	728	5	24								754	668			410	243			801			80			553	501			506		375	502			169
	643							817			1045	987	0	39	9								958							658			663	633			64		3
				1 10			953	989			1217	159						8		572							1013			830				805		8			498
											1333		89				1029	982		688						124	1129		998	946						947			614
Tha	996	1195												1192				10		763						2	1194		1063	1011					885	1012	37		679
Ng							99					105	19					12 2		18				1640		147	1359		1228	1176					1050	1177	02		844
			1162	562							69			163			6	31	91				8			56	1465		1334	1282					1156		08	938	950
		1359		65							62							2														2			1			831	843
																		12																				882	
h		0	6 1								1560		1416	1354			1256	2												1173		129							
	7		3 1	1522									40	1423				2		984			1542				1425			1242						1243	18		
		1542		628			1481	517	1527	166			87	160	1539		441		67				1668			165	1541			1358			6			1359			1
	1405			00	1647		1543	1579	27	17			49	1663			3						1720				1603			420						1421			1088
	1459			4			597				1861	80	1717			27							74																
				1788				1668		1806				1690	1							184	1809				1692					1628							1177
											1742				3	08																							

Angthong
Chainat
Utha Thani
Suphan Buri
Nakhon Sawan
ra
Lopburi
Nakhon Nayok
[illegible]
S[illegible]
hachaengsao
Chon Buri
Rayong
Chatha Buri
Nakhon Pathom
Kanchana Buri
Ratchaburi
Samut Sakhon
Samut Songkram
Phetcha Buri
Phrachuap Khirikhan
Chumporn
Ranong
Surat Thani
Phanh Ngal
Phuket
Kra
Thr akh
Phatthalung
Songkhla
Pattani
ala
Na athiwat
Satun

APPENDIX B

Table of Customer demand and facility cost

Province	Volume		Modem Trade	Traditional Trade	Fixed Warehouse Cost	Variable Warehouse Cost
	Cases	Pallets	% of Volume	% of Volume	THB per Month	THB per Sqm per Month
Ayutthaya	10,754,154	84,017	94%	6%	500,000.00	110.00
Bangkok	10,997,810	85,920	78%	22%	800,000.00	120.00
Lopburi	344,112	2,688	0%	100%	400,000.00	100.00
Nakhon Nayok	183,203	1,431	0%	100%	400,000.00	100.00
Nontha Buri	7,048,856	55,069	83%	17%	400,000.00	100.00
Phetcha Bun	183,948	1,437	0%	100%	400,000.00	100.00
Phichit	40,620	317	0%	100%	400,000.00	100.00
Phitsanu Lok	373,387	2,917	0%	100%	400,000.00	100.00
Samut Prakan	1,233,148	9,634	0%	100%	400,000.00	100.00
Saraburi	460,697	3,599	0%	100%	400,000.00	100.00
Suphan Burl	318,708	2,490	0%	100%	400,000.00	100.00
Uthai Thani	23,263	182	0%	100%	400,000.00	100.00
Chantha Buri	424,726	3,318	0%	100%	400,000.00	100.00
Chon Buri	2,047,938	16,000	0%	100%	400,000.00	100.00
Prachin Buri	341,184	2,666	0%	100%	400,000.00	100.00
Rayong	699,562	5,465	0%	100%	400,000.00	100.00
Khanchana Buri	190,985	1,492	0%	100%	400,000.00	100.00
Phetcha Buri	359,796	2,811	0%	100%	400,000.00	100.00
Phrachuap Khirikhan	71,489	559	0%	100%	400,000.00	100.00
Ratcha Buri	367,970	2,875	0%	100%	400,000.00	100.00
Chiang Mai	2,000,125	15,626	45%	55%	500,000.00	110.00
Chiang Rai	514,392	4,019	0%	100%	400,000.00	100.00
Kamphaeng Phet	526,366	4,112	0%	100%	400,000.00	100.00
Lampang	119,953	937	0%	100%	400,000.00	100.00
Nakhon Sawan	214,589	1,676	0%	100%	400,000.00	100.00
Nan	140,887	1,101	0%	100%	400,000.00	100.00
Phare	266,119	2,079	0%	100%	400,000.00	100.00
Amnat Charoen	81,708	638	0%	100%	400,000.00	100.00
Buriram	395,910	3,093	0%	100%	400,000.00	100.00
Chaiya Phum	170,662	1,333	0%	100%	400,000.00	100.00
Khonkaen	1,577,861	12,327	56%	44%	500,000.00	110.00
Loei	221,549	1,731	0%	100%	400,000.00	100.00
Mukdahan	184,606	1,442	0%	100%	400,000.00	100.00
Nakhon Ratchasima	670,171	5,236	3%	97%	400,000.00	100.00
Roiet	62,851	491	0%	100%	400,000.00	100.00
Sakon Nakhon	336,504	2,629	0%	100%	400,000.00	100.00
Sisaket	92,786	725	0%	100%	400,000.00	100.00
Ubon Ratchathani	474,194	3,705	0%	100%	400,000.00	100.00
Udon Thani	671,736	5,248	0%	100%	400,000.00	100.00
Chumphon	246,946	1,929	0%	100%	400,000.00	100.00
Nakhon Sithammarat	598,877	4,679	0%	100%	400,000.00	100.00
Narathiwat	77,930	609	0%	100%	400,000.00	100.00
Pattani	87,310	682	0%	100%	400,000.00	100.00
Phang Nga	21,454	168	0%	100%	400,000.00	100.00
Phatthalung	109,520	856	0%	100%	400,000.00	100.00
Phuket	3,394,303	26,518	0%	100%	500,000.00	110.00
Satun	46,601	364	0%	100%	400,000.00	100.00
Songkhla	1,617,048	12,633	0%	100%	400,000.00	100.00
Surat Thani	3,677,488	28,730	73%	27%	400,000.00	100.00
Trang	43,774	342	0%	100%	400,000.00	100.00
Yala	56,374	440	0%	100%	400,000.00	100.00
Total	**55,166,148**	**430,986**				

APPENDIX C

Table of Coordinate (X, Y) of demand point and source point

Demand point number	Point (i)	Province	Region	Coordinates		Volume (pallet)	Transport Rate (THB/PL/km)
				X	Y		
1	C1	Ayutthaya	Central	5.52	8.37	84,017	2.86
2	C2	Bangkok	Central	5.48	7.73	85,920	2.72
3	C3	Lopburi	Central	5.89	9.08	2,688	2.01
4	C4	Nakhon Nayok	Central	6.06	8.14	**1,431**	2.01
5	C5	Nontha Burl	Central	5.39	7.94	55,069	2.76
6	C6	Phetcha Bun	Central	6.16	10.44	1,437	2.00
7	C7	Phichit	Central	5.35	10.24	317	2.04
8	C8	Phitsanu Lok	Central	5.43	10.85	2,917	2.01
9	C9	Samut Prakan	Central	5/6	7.64	9,634	2.00
10	C10	Saraburi	Central	5.88	8.54	3,599	2.00
11	C11	Suphan Buri	Central	4.99	8.55	2,490	2.00
12	C12	Uthai Thani	Central	4.43	9.35	182	2.11
13	C13	Kamphaeng Phet	Central	4.37	10.16	4,112	2.00
14	C14	Nakhon Sawan	Central	5.43	9.76	1,676	2.00
15	EI	Chantha Burl	East	7.13	6.85	3,318	2.00
16	E2	Chon Buri	East	6.23	7.24	16,000	2.00
17	E3	Prachin Buri	East	6.58	8.16	2,666	2.01
18	E4	Rayong	East	6.43	6.88	5,465	2.00
19	W1	Khanchana Bud	West	4.02	8.70	1,492	2.01
20	W2	Phetcha Burl	West	4.58	6.98	2,811	2.01
21	W3	Phrachuap Khirikhan	West	4.87	6.34	559	2.02
22	W4	Ratcha Bud	West	4.60	7.48	2,875	2.00
23	N1	Chiang Mai	North	3.59	12.88	15,626	2.41
24	N2	Chiang Rai	North	4.71	13.91	4,019	2.00
25	N3	Lampang	North	4.72	12.80	937	2.02
26	N4	Nan	North	5.80	12.71	1,101	2.01
27	N5	Phare	North	5.12	12.42	2,079	2.01
28	M1	Amnat Charoen	North East	9.74	10.00	638	2.03
29	M2	Buriram	North East	7.96	8.92	3,093	2.00
30	M3	Chaiya Phum	North East	6.89	10.07	1,333	2.02
31	M4	Khonkaen	North East	7.61	10.00	12,327	2.52
32	M5	Loei	North East	6.61	11.46	1,731	2.01
33	M6	Mukdahan	North East	9.57	10.50	1,442	2.01
34	M7	Nakhon Ratchasima	North East	7.26	8.90	5,236	2.03
35	M8	Roiet	North East	8.73	9.94	491	2.00
36	M9	Sakon Nakhon	North East	8.73	11.41	2,629	2.01
37	M10	Sisaket	North East	9.49	8.79	725	2.02
38	M11	Ubon Ratchathani	North East	10.22	9.08	3,705	2.00
39	M12	Udon Thani	North East	10.22	9.08	5,248	2.00
40	S1	Chumphon	South	4.07	4.68	1,929	2.00
41	S2	Nakhon Sithammarat	South	4.76	2.62	4,679	2.00
42	S3	Narathiwat	South	6.80	0.27	609	2.01
43	S4	Pattani	South	6.43	0.80	682	2.01
44	S5	Phang Nga	South	3.39	2.69	168	2.00
45	S6	Phatthalung	South	5.00	1.65	856	2.02
46	S7	Phuket	South	3.33	2.10	26,518	2.00
47	S8	Satun	South	4.98	0.93	364	2.04
48	S9	Songkhla	South	5.55	0.90	12,633	2.00
49	S10	Surat Thani	South	4.05	2.97	28,730	2.67
50	S11	Trang	South	4.65	1.60	342	2.04
51	S12	Yala	South	6.29	0.29	**440**	2.02
52	P1	Plant (source point)	South	5.52	8.37	430,986	2.86

APPENDIX D

Table of Approximate Center-of-Gravity Method

Province	Volume	Distance (DC to retailers)	Transportation cost (THB/PL/km)	Center of gravity (X,Y) (Approx. Method)		
	Pallets	Round trip (km)	(R)	V x R x X	V x R x Y	V x R
Ayutthaya	84,017	60	2.86	1,328,949	2,013,504	240,538
Bangkok	85,920	156	2.72	1,278,576	1,804,109	233,510
Lopburi	2,688	148	2.01	31,822	49,018	5,400
Nakhon Nayok	1,431	220	2.01	17,462	23,449	2,880
Nontha Buri	55,069	150	2.76	819,412	1,207,106	151,938
Phetcha Bun	1,437	610	2.00	17,747	30,056	2,880
Phichit	317	558	2.04	3,466	6,633	648
Phitsanu Lok	2,917	618	2.01	31,807	63,518	5,856
Samut Prakan	9,634	210	2.00	110,922	147,148	19,272
Saraburi	3,599	138	2.00	42,311	61,496	7,200
Suphan Bud	2,490	154	2.00	24,920	42,690	4,992
Uthai Thani	182	292	2.11	1,700	3,590	384
Chantha Buri	3,318	640	2.00	47,393	45,570	6,648
Chon Buri	16,000	350	2.00	199,397	231,794	32,016
Prachin Buri	2,666	288	2.01	35,214	43,661	5,352
Rayong	5,465	546	2.00	70,324	75,252	10,944
Khanchana Buri	1,492	398	2.01	12,059	26,102	3,000
Phetcha Burl	2,811	410	2.01	25,832	39,385	5,640
Phrachuap Khirikhan	559	724	2.02	5,489	7,152	1,128
Ratcha Bud	2,875	360	2.00	26,508	43,057	5,760
Chiang Mai	15,626	1272	2.41	135,220	484,773	37,652
Chiang Rai	4,019	1536	2.00	37,884	111,848	8,040
Kamphaeng Phet	4,112	608	2.00	35,985	83,653	8,232
Lampang	937	1086	2.02	8,955	24,273	1,896
Nakhon Sawan	1,676	344	2.00	18,231	32,795	3,360
Nan	1,101	1210	2.01	12,805	28,061	2,208
Phare	2,079	974	2.01	21,374	51,854	4,176
Amnat Charoen	638	1094	2.03	12,628	12,965	1,296
Buriram	3,093	680	2.00	49,312	55,255	6,192
Chaiya Phum	1,333	578	2.02	18,513	27,060	2,688
Khonkaen	12,327	810	2.52	236,377	310,631	31,052
Loei	1,731	976	2.01	23,012	39,865	3,480
Mukdahan	1,442	1266	2.01	27,785	30,505	2,904
Nakhon Ratchasima	5,236	426	2.03	77,269	94,682	10,642
Roiet	491	926	2.00	8,593	9,781	984
Sakon Nakhon	2,629	1202	2.01	46,110	60,236	5,280
Sisaket	725	982	2.02	13,887	12,862	1,464
Ubon Ratchathani	3,705	1114	2.00	75,803	67,358	7,416
Udon Thani	5,248	1062	2.00	107,449	95,478	10,512
Chumphon	1,929	1068	2.00	15,745	18,092	3,864
Nakhon Sithammarat	4,679	1754	2.00	44,515	24,565	9,360
Narathiwat	609	2426	2.01	8,322	332	1,224
Pattani	682	2248	2.01	8,790	1,088	1,368
Phang Nga	168	1760	2.00	1,140	904	336
Phatthalung	856	1892	2.02	8,636	2,844	1,728
Phuket	26,518	1972	2.00	176,498	111,529	53,040
Satun	364	2118	2.04	3,702	689	744
Songkhla	12,633	2124	2.00	140,181	22,861	25,272
Surat Thani	28,730	1430	2.67	310,520	227,707	76,620
Trang	342	1860	2.04	3,234	1,115	696
Yala	440	2356	2.02	5,589	261	888
Total	**430,986**			**5,825,371**	**8,010,207**	**1,070,600**

Approximate Method --> **5.44** ***748***

APPENDIX E

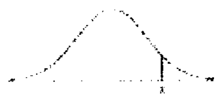
Table of Assignment of Retailers to DCs of Each Scenario

Sc ario	mb DC	DC L cation	Chaiya Phum	Loei	Udon Thani	Khonkaen	Roiet	Sakon Nakhon	Mukdahan	Amnat Charoen	Ubon Ratchathani	Sisaket	Buriram	Nakhon Ratchasima	Saraburi	Chiang Mai	Chiang Rai	Nan	Phare	Lampang	Kamphaeng Phet	Phitsanu Lok	Pichit	Nakhon Sawan	Phetcha Bun	Bangkok	Nontha Buri	Ayutthaya	Utha Thani	Suphan Buri	Lopburi	Nakhon Nayok	Prachin Buri	Samut Prakan	Chon Buri	Rayong	Chatha Buri	Kanchana Buri	Ratcha Buri	Phetcha Buri	Phrachuap Khirikhan	Chumporn	Surat Thani	Phang Nga	Phuket	Trang	Sithammarat	Phatthalung	Songkhla	Pattani	Yala	Narathiwat	Satun
Ba		Ayu a	1		1			1	1	1	1	1		1	1	1		1		1	1	1		1		1	1	1	1	1	1	1	1	1	1	1		1	1		1		1		1	1		1	1	1		1	1
		Ay a	1			1		1	1	1	1			1	1	1			1	1	1	1		1						1	1	1	1																				
		Ba																								1	1								1	1		1		1		1		1			1		1	1		1	1	
2	3DCs	Ayutthaya													1						1		1	1				1	1	1	1	1	1						1															
		Bangkok																								1	1							1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1		1		1	1	1	1	1			1																												
3	4DCs	Ayutthaya													1						1		1	1				1	1	1	1	1	1						1															
		Bangkok																								1	1							1	1	1	1		1	1	1													
		Khonkaen	1		1	1	1	1	1	1	1	1	1	1		1		1	1	1	1	1			1																												
		Surat Thani																																							1	1	1	1	1	1	1	1	1	1	1	1
	4DCs	Ayutthaya													1	1	1	1	1	1	1	1	1	1				1	1	1	1	1	1						1															
		Bangkok																								1	1							1	1	1	1		1	1	1													
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1											1																												
		Surat Thani																																							1	1	1	1	1	1	1	1	1	1	1	1
5	5DCs	Ayutthaya													1						1			1				1	1	1	1	1	1						1															
		Bangkok																								1								1	1	1	1			1	1													
		Nonthaburi																									1												1														
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1			1																												
		Suratthani																																							1	1	1	1	1	1	1	1	1	1	1	1
6	5DCs	Ayutthaya													1	1	1	1	1	1	1	1	1	1				1	1	1	1	1	1						1															
		Bangkok																								1								1	1	1	1			1	1													
		Nonthaburi																									1												1														
		Khonkaen	1		1	1	1	1	1		1	1	1	1											1																												
		Suratthani																																							1	1	1	1	1	1	1	1	1	1	1	1
7	6DCs	Ayutthaya	1	1	1	1	1	1	1	1	1	1	1	1	1						1	1	1	1	1			1	1	1	1	1	1						1															
		Bangkok																								1								1	1	1	1			1	1													
		Nonthaburi																									1												1														
		Chiang Mai														1	1	1	1	1																																	
		Suratthani																																								1	1		1						
		Songkla																																										1		1	1	1	1	1	1
8	7DCs	Ayutthaya													1	1					1	1	1	1	1			1	1	1	1	1	1						1															
		Bangkok																								1								1	1	1	1			1	1													
		Nonthaburi																									1												1														
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1			1	1	1	1																																	
		Phuket																																								1	1								
		Songkla																																										1			1	1	1	1	1
		Suratthani																																							1	1				1						
	8 DCs	Ayutthaya													1						1		1	1				1	1	1	1	1							1															
		Bangkok																								1								1						1	1													
		Nonthaburi																									1												1														
		Chon Buri																														1		1	1	1																
		Chang mai														1	1	1	1	1																																	
		Khonkaen	1	1	1	1	1	1	1	1	1	1	1	1								1			1																												
		Suratthani																																							1	1	1	1		1						
		Songkla																																										1			1	1	1	1	1
	6DCs (Region)	Ayutthaya													1						1	1	1	1	1	1	1		1	1	1	1	1	1																			
		Chon Buri																																1		1																
		Ratcha Buri																																			1	1	1	1													
		Chiang Mai														1	1	1	1	1																																	
		Nakhon Ratchasima	1	1	1	1	1	1	1	1	1	1	1	1																																							
		Surat Thani																																							1	1	1	1	1	1	1	1	1	1	1	1

APPENDIX F

Table of Standard Normal Distribution

Tables of the Normal Distribution



Probability Content from -∞ to Z

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990