

Distribution Networks Consolidation and Optimization for a Large Industrial Conglomerate

by

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Submitted to the Engineering Systems Division in Partial Fulfillment of the
Requirements for the Degree of

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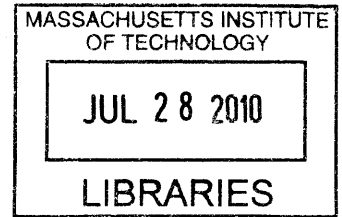
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ABSTRACT

Redesigning the distribution networks for the company's various supply chains to lower the cost of delivering products to customers is crucial to company's competitiveness. Redesign includes changing warehouse locations for a specific product to be closer to customers and warehouse consolidation, which requires sharing warehouse space by more than one product type and closing some existing warehouses that are not cost efficient to operate.

The objective of this project is to develop a decision tool to help an industrial conglomerate makes decisions related to the redesign its distribution networks. The data collection was done through collaboration with company's representatives. A Mixed Integer Linear Programming (MILP) model was developed as a tool to solve the optimization problem, which involves moving 9 product types from 21 manufacturing plants, through 22 warehouses, and to 26 destination zones,. The results from the model provides a useful information for the company about which warehouses should be retained, which warehouses should be closed, and what would be the new distribution networks, in order to minimize total distribution costs while still satisfy the customers' demand.

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Chapter 1 Introduction

This chapter explains the background and motivation to conduct this thesis. It illustrates the importance of the problems this study aims to solve. Also, the organization of this thesis document is explained at the end of this chapter.

1.1 Project Background and Motivation

For a company producing products that are common in the market and there are many other manufacturers produce the same kind of products, it has to inevitably compete on price. Consequently, it is essential for the company to preserve its margin through cost efficiency. So, today, most companies are paying a great deal of attention to improve their supply chain efficiency in order to reduce product distribution costs without negatively affecting customer service level.

Redesigning the distribution networks for the company's various supply chains to lower the cost of delivering products to customers is crucial to company's competitiveness. Redesign includes changing warehouse locations for a specific product to be closer to customers; warehouse consolidation which requires sharing warehouse space by more than one product type and closing some existing warehouses that are not cost efficient to operate.

AllSources, an industrial conglomerate in Thailand, is one of the companies facing this situation and trying to reduce its distribution costs throughout the company's supply chain by

redesigning its warehouse networks in central, eastern, and western parts of Thailand. Due to its large scale organization, with 5 business units (BUs), and multi products manufacturing, the company faces great complexity in the overlapping of its existing distribution networks. Also growing by acquisition of other firms, each of *AllSources* distribution networks is still managed separately by each of its subsidiary company. This practice leads to the inefficiency of *AllSources*' supply chain management in which the problem involves multiple products, manufacturing plants, warehouses, and distribution centers. Redesigning the distribution network is a strategic decision that has a long-lasting effect on the company, so *AllSources* needs to have a reliable tool to help it making decision on this network redesign problem. Figure 1.1 shows the location map of Thailand and its neighboring countries.

The objective of this project is to develop a decision tool to help *AllSources* make decisions related to the redesign its distribution networks. First, this thesis will examine the company's existing warehouse networks, and then second it will define the scope and number of warehouses that has the potential to be consolidated. Then, a Mixed-Integer Linear Programming (MILP) model will be developed as an optimization tool. Various scenarios will be run to test the sensitivity of the model. Finally, the optimization result will be analyzed and a new distribution network will be recommended for the company.

1.2 Overview of this document's structure

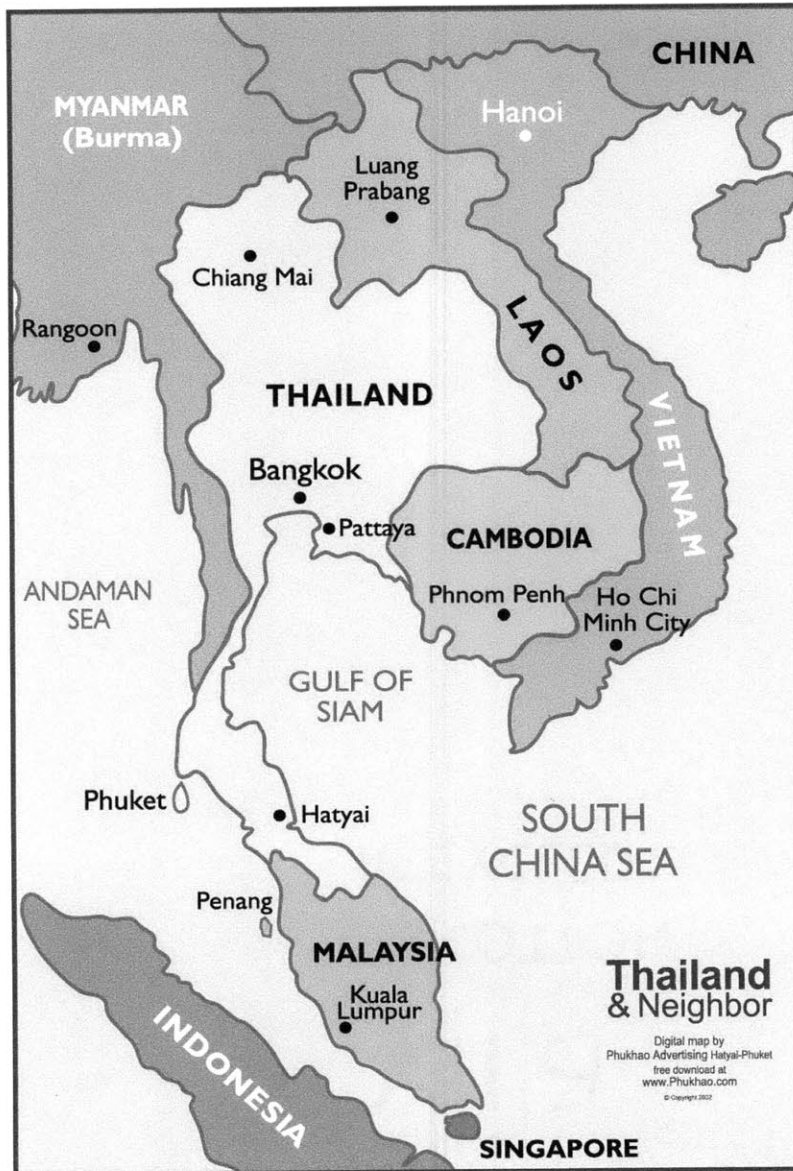
This first chapter gives information about the background and motivation of conducting this thesis. In the second chapter, the overview of the company's business structure is provided and a summary of company's existing supply chain and distribution networks is also discussed.

The third chapter discusses about the definition and scope of the problem that this thesis needs to solve.

In the fourth chapter, the prior literature related to this study is discussed. Two topics of the literature are reviewed; the importance and necessity of distribution network design and the previous studies of the redesigning of distribution network, using a Mixed Integer Linear Programming (MILP) approach. Chapter five identifies the data needed to be input into the model and explains how to obtain those data.

Chapter six explains the model development. In this chapter, the objective function, decision variables, and all constraints are identified, and all mathematical formulations in the model are presented. Also, all of the scenarios set for running the model are identified and explained. Chapter seven provides the model results of all scenarios, the comparison between existing distribution networks and the new networks suggested by the model, and some operational issues that *AllSources* has to concern when implementing the new networks. Lastly, chapter eight concludes what have been done in this thesis, the key learnings, and opportunities for future research expanding from this thesis.

Figure 1.1 Map of Thailand and its neighboring countries



Chapter 2 Company Business Structure

This chapter provides an overview of *AllSources*' business structure, which is comprised of five business units. In the second part, the company's existing supply chain and distribution networks are discussed.

2.1 Overview of Business Structure

At present, *AllSources* has 5 core business focused in chemicals, paper, cement, building materials, and distribution. The detail of each business unit is described below.

2.1.1 Chemicals Business

AllSources' chemicals business unit manufactures and supplies a full range of chemical products ranging from upstream chemicals such as olefins, intermediate chemicals such as styrene monomer, PTA, and MMA, to downstream chemicals such as polyethylene, polypropylene, polyvinyl chloride, and polystyrene resins. It is now one of the largest integrated chemical companies in Thailand and a key industry leader in the Asia-Pacific region.

Widely accepted for its quality products as well as excellent management and operational prowess, *AllSources*' chemicals business has entered into joint venture deals with a number of the world's leading chemicals firms.

AllSources' chemicals business has a policy of expanding its investment and business overseas. In 2006, the export sales volume of polyolefins products amounted to 43,600 million Baht or 36% of the total sales. *AllSources* exports its polyolefins products to more than 100 countries across the world. Currently, *AllSources* has 6 Sales Representative Offices in different Asian countries including Vietnam, China, Myanmar, the Philippines and Japan.

2.1.2 Paper Business

AllSources entered the paper business in 1975. At present, *AllSources'* paper business is the largest integrated producer of paper products in Thailand, consisting of pulp, printing and writing paper, packaging paper, and corrugated containers. The products have gained wide acceptance in both domestic and international markets for their world quality standards. The paper business remains the industry leader in Thailand and in the Association of Southeast Asian Nation (ASEAN) region.

To cope with the intense competition, the paper business strives to drive innovations, producing a wide range of value-added products and services to satisfy customer needs.

The paper business focuses on constant improvement of operation and management efficiency, which enhances the country's productivity and competitiveness. This enduring commitment has won the *AllSources* numerous prestigious awards in the past decade.

2.1.3 Cement Business

The cement business is the original business of *AllSources* since the company was founded in the early 19th century. This business produces and supplies cement, ready-mixed concrete, concrete products, white cement, and refractory as well as providing technical services and consultation on plant installation to customers both within and beyond the group.

The cement business has a policy of extending its cement investment both domestically and regionally. Examples include the construction of a grey cement plant in Cambodia and the establishment of a ready-mixed concrete plant network in the ASEAN region. The business exports its products to many ASEAN countries to create brand and product awareness among customers and to lay solid foundations for future business expansion in the region.

With extensive industry knowledge and advanced production technology, the company is now recognized as a leading manufacturer of a diverse range of products in Thailand and the Southeast Asia region.

2.1.4 Building Material Business

AllSources' building materials business commenced its operation in the 1980's as a complement to the cement business. Today, the building materials business offers a range of products including roofing materials, ceramic tiles, sanitary ware, faucets, paving blocks, and insulation products. With extensive industry knowledge, advanced production technology and

product design capability, the business is now recognized as a leading manufacturer of a diverse range of products in a wide variety of construction related applications in Thailand and the ASEAN region.

In addition to exports through a global distribution network, particularly to major market in ASEAN, U.S.A., Europe, and Australia, the business currently has 9 business operations in Indonesia, The Philippines, Cambodia, Laos and Vietnam.

2.1.5 Distribution Business

AllSources Distribution Business is involved in domestic and international trading, logistics, transportation, and warehouse management. This business unit does not manufacture any product; rather it deals with sales and marketing of the products manufactured by other business units. It is also a trader company, buying products from suppliers outside *AllSources* and selling them to other customers.

To strengthen the domestic distribution network for other *AllSources*' businesses, the distribution business adopts Partner Relationship Management (PRM) with its dealers throughout the country. The business is also adapting to the era of e-commerce, enabling customers to make transactions electronically. In the retail business, the distribution business is developing its retail network through dealer-owned stores.

For international trading, the distribution business continues to pursue trading opportunities in emerging markets and seeks new sources of quality products and raw materials. Its goals are to strengthen its customer base, boost customer confidence, and consolidate its role as a center for procurement for various local industries.

With proven experience and expertise in logistics, the distribution business focuses on enhancing transportation efficiency to reduce costs and develop its service quality to better satisfy customer demand. Radio Frequency Identification (RFID) together with Global Positioning System (GPS) has been deployed, allowing for close monitoring of the transportation status. The advanced tracking system enables on-time delivery and reduces costs.

2.2 Company Supply Chain and Distribution Networks

This sub-section describes the company's existing distribution networks of selected business units that related to the scope of this thesis; cement, building materials, and distribution.

2.2.1 Profile of the Company Supply Chain

The supply chain network of *AllSources* is mainly a local network, that is, products are manufactured and sold to customers within the country because the products are considered commodity or low margin to volume. The company exports some products from any excess production capacity to customers outside Thailand. Export sales make up approximately 30% of

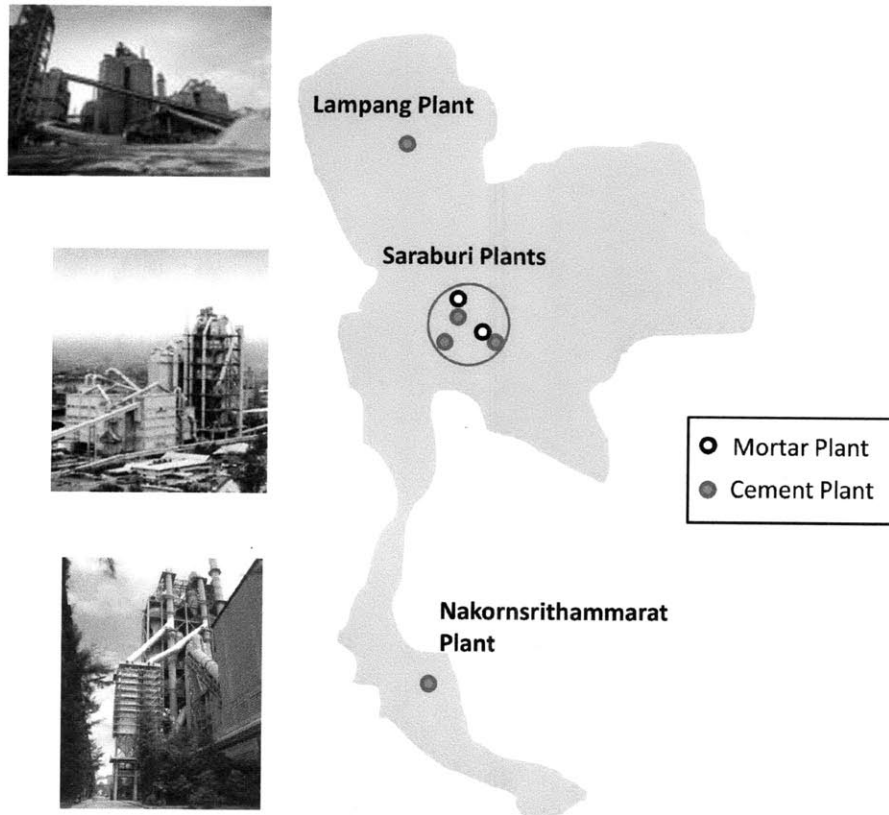
the company's sales revenue. Also *AllSources* does import some raw materials from outside the country.

While customer locations are scattered throughout the country, manufacturing sites are located near the sources of raw materials. Today, manufacturing sites ship products to their adjacent warehouses for local distribution, and to regional distribution centers for remote distribution.

2.2.2 Cement Distribution Networks

Most *AllSources* cement plants are located in central part of Thailand because limestone, a key raw material for cement production, is abundant in the area. There are also two small plants in the northern and southern parts of Thailand, which specifically serve customers in those areas. All cement plants have their own warehouses to store the products before delivery to customers. Figure 2.1 shows the locations of *AllSources* cement plants in Thailand.

Figure 2.1 Locations of *AllSources* Cement Plants

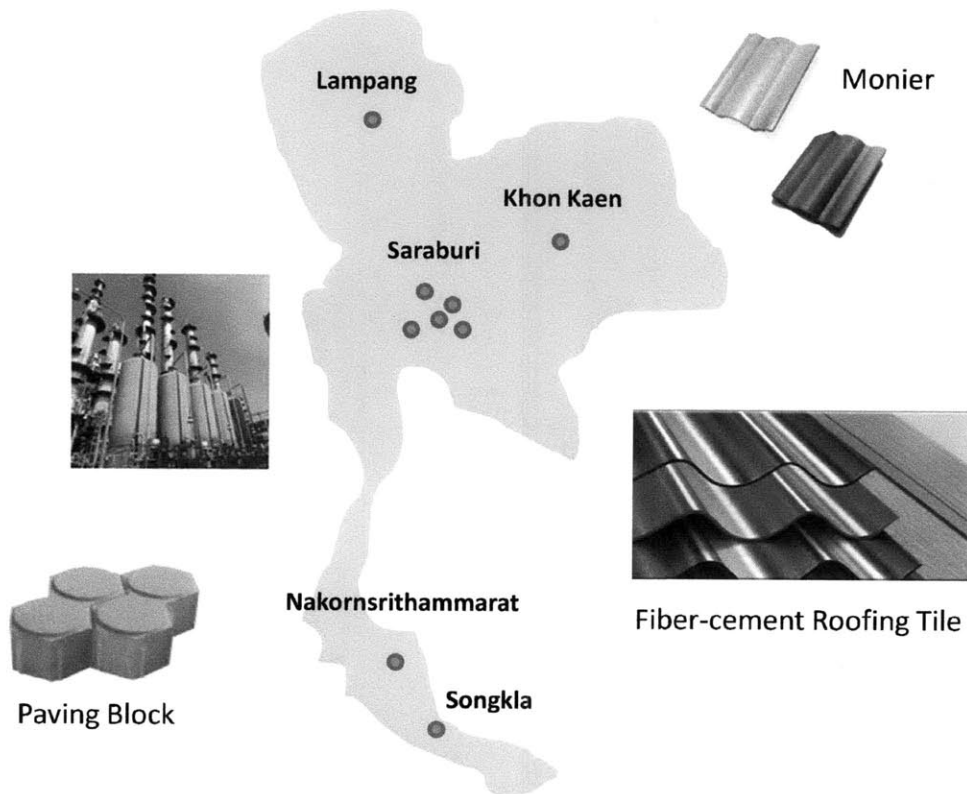


2.2.3 Building Materials Distribution Networks

Like cement products, most building material production plants are located in the central part of Thailand. Due to the variety of the products, there are many manufacturing plants in the area located close to each other, each producing only one type of product family. Products produced at these plants range from roofing tiles to ceramic floor/wall tiles, paving blocks, sanitary wares, and faucets. All building material plants have their own warehouses to store

products before delivery to customers, similar to cement plants. Figure 2.2 shows the locations of *AllSources* building material plants in Thailand.

Figure 2.2 Locations of *AllSources* Building Materials Plants



2.2.4 Transportation and Distribution Facilities

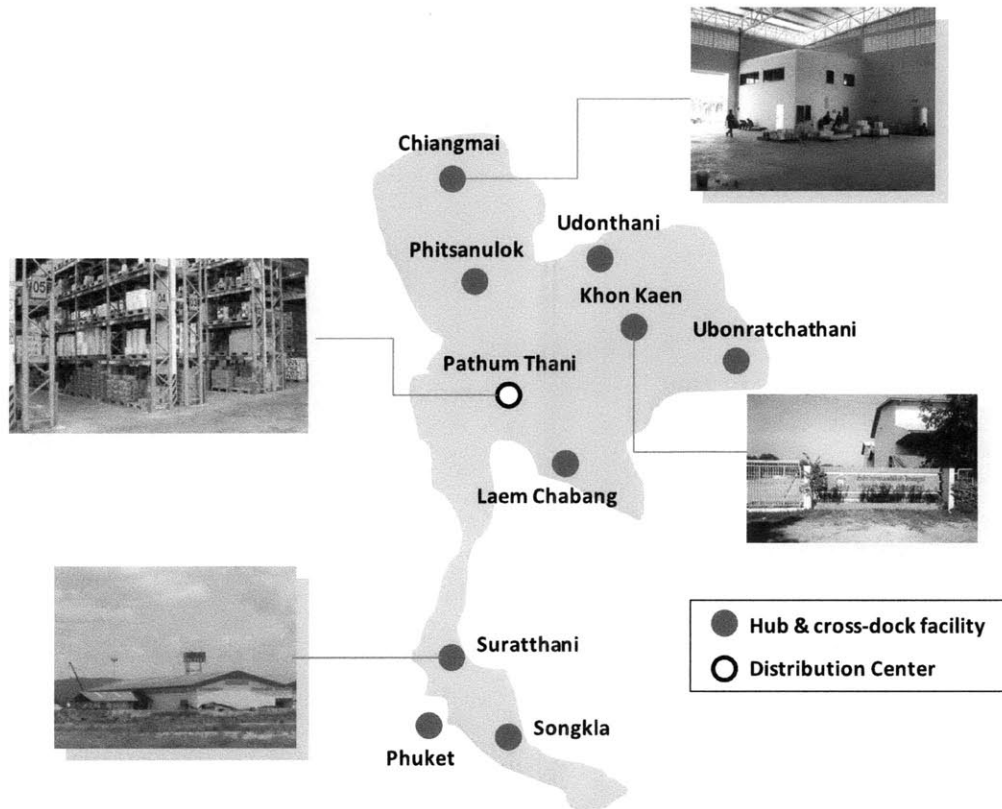
AllSources product distribution is managed centrally by *AllSources*' subsidiary companies in the distribution business. These companies have major roles in domestic sale,

international trading, and logistics. The distribution network of the company, covering the areas within Thailand, comprises of domestic dealer networks, multi-modal transportation including ground transportation with truck and train, inland waterway transportation with barge, and distribution facilities such as a distribution centers, hubs, cross-docking facilities, and ports.

Due to the variety of its products and customer locations scattered all over the country, *AllSources* has many distribution facilities spread out to serve its customers. Apart from the warehouses that are attached to all manufacturing plants, the company also owns regional distribution centers, called “hubs”, in the major provinces. These hubs are located in the northern, northeastern, and southern parts of Thailand, which are far from the central area where most of the manufacturing plants are located. Figure 2.3 shows locations of *AllSources*’ distribution centers.

For transportation of products, *Allsources* outsources its trucking activities to other carriers, of which some have developed good relationships with *AllSources* and become partner companies. The products are distributed in bulk form, e.g. bulk cement or ready mixed concrete with special type of trucks and barges, or shipped in bag or pallet form by truck or train. Most of the delivery is done by truck load (TL) service.

Figure 2.3 AllSources' Distribution Facilities



2.3 Managing the Supply Chain

Advanced IT systems are considered as a core mechanism of the company's supply chain management. *AllSources* utilizes SAP to manage all of its delivery transactions. These activities include order processing, inventory management, and managing both accounts payable and receivable financial transactions. For transportation activities, Transportation Management System (TMS) is used to manage its transportation activities including shipment processing, load

building, and load tendering to truck carriers. Global Positioning System (GPS) is widely used to track shipments delivered by trucking carriers and a Radio Frequency Identification (RFID) application is in place to automatically transfer delivery information into the company controlling system.

Multi-modal transportation is initiated to reduce transportation costs while back hauling transportation is emphasized to improve truck utilization and generate additional revenue. Cross docking activities are implemented to sort products before delivery to end customers with no inventory added. Also, the continuous move concept has been introduced to minimize deadhead distance and thus increase truck utilization.

Collaboration among subsidiary companies is promoted to improve efficiency of *AllSources'* supply chain management. Business processes have been integrated and information has been shared throughout the supply chain from production to operation and customers. Accuracy of demand forecasting has been improved by achieving consensus from all related parties in Sale and Operation Planning (S&OP) meetings. Customer Relationship Management (CRM) is also implemented to collect customer information. Finally, *AllSources* set up a Supply Chain Committee, which consists of representatives from all business units, to facilitate improvement of supply chain activities across business units and drive change in any supply chain related activities.

Chapter 3 Problem Definition

AllSources is considering consolidating the warehouses of its business units (BUs). Each of its business units owns and operates its own warehouses separately from the others. The BUs have never considered using the warehouses owned by other BUs to store its products, even when their warehouses are located close to each other, and when there will be no effect on customer service level in terms of on-time delivery. This thesis focuses on three major business units; cement, building materials, and distribution.

AllSources' cement and building material BUs each has its own manufacturing plants and each plant has an adjacent warehouse attached to it. Currently, products manufactured at each plant are shipped to be stored at its adjacent warehouse before being distributed to end customers. The distribution BU does not manufacture any product, so it does not own a manufacturing plant. However it owns and operates one distribution center (DC).

AllSources is considering the consolidation of warehouses in central, eastern and western parts of Thailand. There are 21 manufacturing plants and 22 warehouses or DCs in this area. These warehouses and DCs serve a total of 26 of the 76 provinces in Thailand.

The cement BU has 5 manufacturing plants and 5 warehouses in the area, which produce and store 2 product families: bagged cement and bagged mortar. The building material BU has 14 manufacturing plants and 14 warehouses in the area, which produce and store 6 products families: corrugated roof tile, monier roof tile, ceramic tile, paving block, lightweight block, and

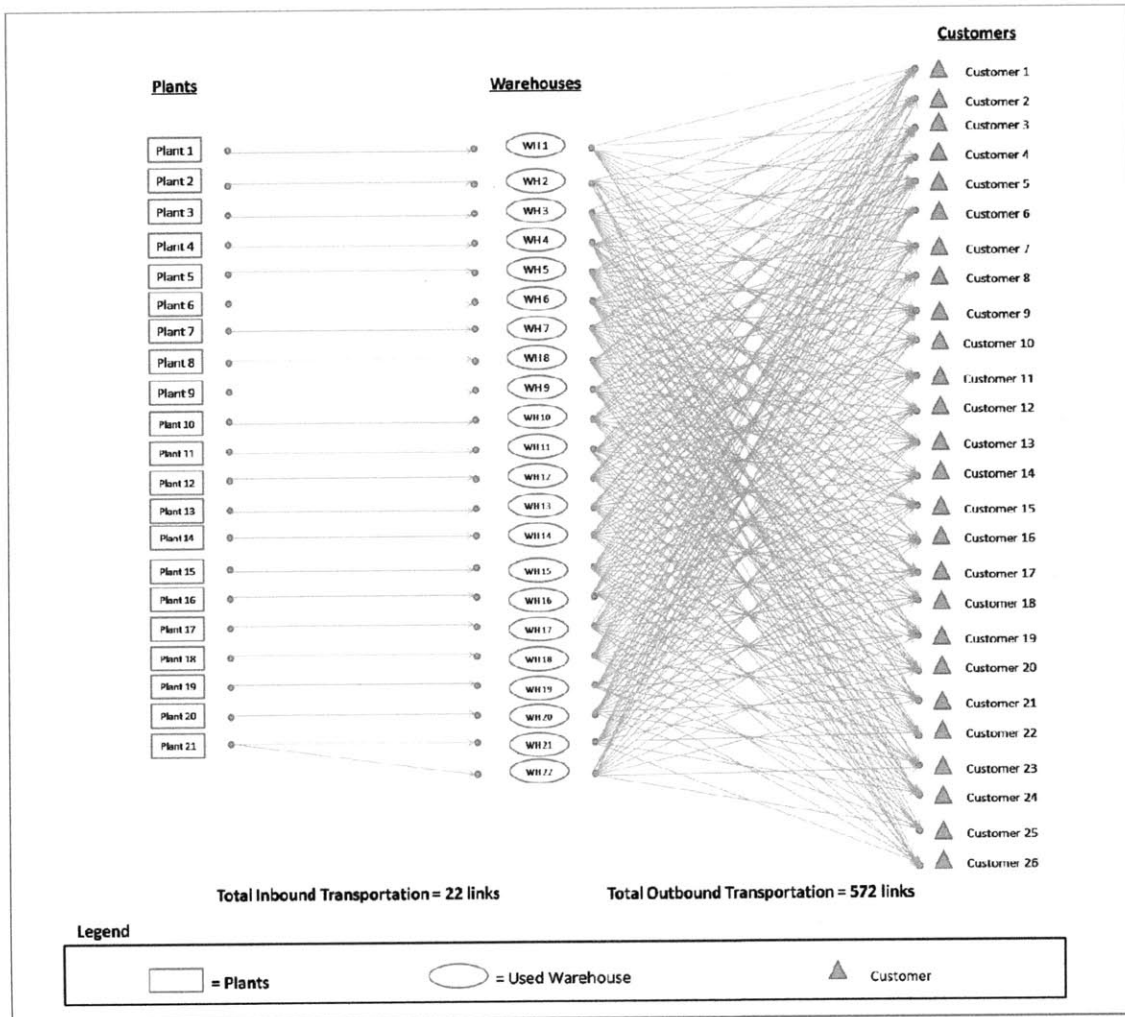
gypsum board. The distribution BU ships steel construction materials from 2 external manufacturer warehouses and stores the products at its own distribution center before delivery to end customers. So, it can be assumed that the distribution business is taking care of distribution of steel construction materials from 2 manufacturing plants and operating 3 warehouses; two of them located adjacent to the manufacturers' plants and another one located independently from any manufacturing plant. Table 3.1 shows the detail of manufacturing plants and warehouses in the study.

Table 3.1 Detail of Manufacturing Plants and Warehouses in the Study Area

Business Unit	No. of manufacturing plants	No. of warehouses	Products
Cement	5	5	1. Bagged Cement 2. Bagged Mortar
Building Materials	14	14	1. Corrugated Roof Tile 2. Ceramic Tile 3. Gypsum Board 4. Monier Roof Tile 5. Paving Block 6. Lightweight Block
Distribution	2	3	1. Steel Construction Material
Total	21	22	9 products

AllSources' outbound distribution networks are single echelon where all products move from a manufacturing plant through a warehouse and then to end customers. Figure 3.1 shows *AllSources'* existing distribution networks.

Figure 3.1 AllSources' Existing Distribution Network



Given the information about the number of warehouses and their locations above, it can be seen that these warehouses are located close to each other and the distribution network of each product always overlaps with other products'. This inefficiency comes from the current practice where the products can only be stored at the warehouse adjacent to their manufacturing plant, and cannot be stored at other warehouses which may be closer to end customers and that may incur lower distribution costs. To avoid this overlapping network, *AllSources* needs to redesign

the whole distribution network in the area. This idea is roughly evaluated as possible due to the fact that the current utilization of these warehouses is low so that space is available in these warehouses for moving other products in from other manufacturing plants. Total capacity of all warehouses is approximately 3,000,000 ton per year while the total product volume that passed through these warehouses is currently about 2,200,000 ton per year. So, these 22 warehouses have an excess capacity of 800,000 ton per year. Table 3.2 shows *AllSources'* warehouse capacity compared to current through product volume.

Table 3.2 Current Product Volume and Maximum Capacity of Each of *AllSources'* Warehouse by Business Unit

Business Unit	Product	Warehouse	Current Through Volume (Ton/Year)	Current Utilization	Maximum Capacity (Ton/Year)
Cement	Bagged Cement	CC1	259,092	50%	518,184
		CC2	300,274	50%	600,548
		CC3	25,343	50%	50,686
	Bagged Mortar	CM1	380,762	100%	380,762
		CM2	238,805	100%	238,805
Building Materials	Corrugated Roof Tile	BF1	120,960	90%	134,400
		BF2	112,424	90%	124,916
	Gypsum Board	BG	70,529	100%	70,529
	Monier Roof Tile	BM1	40,397	80%	50,496
		BM2	93,428	70%	133,469
		BM3	108,089	80%	135,111
		BM4	17,750	80%	22,188
	Paving Block	BP1	59,259	80%	74,074
		BP2	38,282	80%	47,853
		BP3	30,098	80%	37,623
		BP4	104,693	80%	130,866
	Ceramic Tile	BC	116,697	100%	116,697
	Lightweight Block	BL1	56,187	60%	93,645
BL2		5,713	60%	9,522	
Distribution	Steel Construction Materials	DS1	42,398	100%	42,398
		DS2	18,352	100%	18,352
		DS3	22,500	75%	30,000
	Total Product Volume			2,262,032	Total Warehouse Capacity

Another factor that supports the idea of warehouse consolidation is that all warehouses in the study area can handle all types of the products. In other words, the characteristics of all the warehouses are similar so that there will be no problem handling other products.

All 22 warehouses have different throughput capacity in term of total product volume that passes through it in a year, and different fixed and variable costs to operating them. Therefore, the closest warehouse to the end customers yielding the lowest outbound transportation cost may turn out to be costly because of its higher fixed and variable cost compared to other warehouses. On the other hand, a warehouse which incurs the lowest fixed and variable costs may be far away from *AllSources'* customers, thus yielding a very high outbound transportation cost.

To deal with these dilemmas, there is a need to have a systematic decision tool which considers all constraints and conflicting factors affecting the network restructuring, along with balancing tradeoffs among them. Mixed-Integer Linear Programming (MILP) is used as a decision-aid tool in this study. The model is designed to find the optimal number of warehouses, their locations, and new patterns of product flow in order to minimize the total distribution cost of *AllSources* in the study area.

Chapter 4 Literature Review

The distribution network design problem has been examined in a great deal of recent research and articles. This section reviews some of the literatures that related to cases similar to what is examined in this thesis.

Two topic areas are discussed. First, the important and necessity of distribution network design of the physical supply chain in today's highly competitive business environment is discussed, requiring an efficient supply chain network. The second part reviews previous studies of the redesigning of distribution network, using a Mixed Integer Linear Programming (MILP) approach, which is the methodology employed in this thesis.

4.1 Importance of Distribution Network Design

Simchi-Levi, et al (2008) clarified that network design is a strategic decision that has a long-lasting effect on the company. It usually involves a variety of decisions relating to plant and warehouse location, and also distribution and sourcing. The ultimate objective of network design is to reconfigure the logistic network in order to minimize systemwide costs. These costs include production and purchasing costs, inventory holding costs, warehouse storage and fixed costs, and lastly transportation costs, exposed to a set of service level requirements. However, there are clear trade-offs regarding the redesign of a distribution network. For example, increasing the number of warehouses for higher customer service levels in terms of a reduction in average travel time to the customer requires an increase in overhead and setup costs and also

inventory holding costs. The company must balance the advantages of being closer to customers and the costs of opening the new warehouse. Thus, warehouse location decision is an essential component of formulating supply chain strategy.

Ballou (2004) also emphasized that locating facilities in the supply chain network is the most significant issue in formulating a strategic plan for most companies. Typically, this is a very complex decision, dealing with multiple facilities, many products, and several customers at the same time. The redesign of warehouse network could yield around 5-10% saving of annual logistics cost for a firm.

Melachrinoudis and Min (2007) pointed out that the warehouse consolidation can improve inventory turns and increase asset utilization. This results from the implementation of more efficient inventory management tools, including cross-docking, radio frequency identification (RFID), or warehouse management system (WMS), and the elimination of under-utilized facilities. Also, the opportunity to consolidate products into larger volume shipments can potentially reduce transportation costs.

Taskin Gamus, et al (2009), highlighted that the supply chain network design is one of the biggest strategic decision problems for efficient long term operations in the whole supply chain. And because of this importance, network design needs optimization to figure out the numbers, capacity, layout, and type of the factories, warehouses, distribution centers, and also the product flow through these distribution channels in the supply chain.

4.2 Distribution Network Design using Mixed Integer Linear Programming Approach

Manzini, et al (2006) proposed models using a mixed integer linear programming solver to find solutions in complex industrial applications even when several entities, including production plants, distribution centers, customers, are involved. The problem solved in this article is similar to the problem contained in this thesis and I will use the same approach to find the best solution for *AllSources* by changing variables and constraints to what *AllSources* is having presently.

Melachrinoudis and Min (2007) developed a mixed-integer programming model to solve the warehouse redesign problem of a firm distributing products to customers in the US and Canada, with a major constraint that the customers should be within 10 hours driving time from the nearest warehouse. They addressed the following issues; (1) which warehouses to retain, which warehouses to establish, and which warehouses to eliminate, (2) which customers to be served by which consolidated warehouses, and (3) how to evaluate the sensitivity of the redesign decisions. The size of the problem examined by Melachrinoudis and Min is 1 manufacturing plant, 21 warehouses, and 281 customers, while the size of the problem in this thesis is 21 manufacturing plants, 22 warehouses, and 26 customer zones.

Tsiakis and Papageorgiou (2008) proposed a mixed integer linear programming (MILP) model to find the optimal solution of a production and distribution network subject to operational and financial constraints. Those operational constraints include quality, and production and supply restriction, which are all related to the allocation of the production and the work-load

balance. Financial constraints included production costs, transportation costs, and duties of the material flowing subject to exchange rates. The purpose of this model is to be used for long term (quarterly, biannually, or yearly) to address strategic and tactical supply chain aspects.

Chapter 5 Data Collection

This chapter explains the data needed to input into the MILP model and how to collect and aggregate all of these data. Most of the data used are secondary data provided by *AllSources* and some missing data are calculated based on formulated assumptions which were agreed between *Allsources* and the author.

All the data needed includes:

1. Locations of customers, warehouses, and manufacturing plants,
2. Distance between all manufacturing plants and all warehouses, and between all warehouses and all customer points,
3. Product types,
4. Annual demand for each product by customer location,
5. Transportation cost,
6. Warehouse fixed and variable cost, and
7. Warehouse capacity.

5.1 Customer Locations

In this thesis, the study area is limited only the central, eastern, and western parts of Thailand. There are 26 destination provinces in the study area. The customer points in each province are aggregated and assumed to be located at the city center of each province, so there are also 26 customers or demand points in this study.

5.2 Manufacturing Plant and Warehouse Locations

There are 21 manufacturing plants and 22 warehouses in the study area as mentioned in chapter 4. Each manufacturing plant has its own warehouse attached to it, so it can be assumed that any manufacturing plant and its attached warehouse are located at the same location. Another warehouse is located separately without any manufacturing plant attached to it.

5.3 Distance Data

Distance between all manufacturing plants and all warehouses, and between all warehouses to all customer points must be collected as a basis for transportation cost calculation. All of the distances are extracted from the distance engine embedded in transportation management system (TMS) used by *AllSources* to manage their shipment deliveries.

5.4 Product Types

There are 9 product types studied for this warehouse consolidation problem; bagged cement, bagged mortar, corrugated roof tile, monier roof tile, paving block, lightweight block, ceramic tile, gypsum board, and steel construction materials. The storage requirements for these products align with characteristics of all the warehouses so that each product can be handled at every warehouse in the study area.

5.5 Annual Demand for Each Product by Customer Location

The annual demand data of each product by destination input in the model is the actual demand data of all products in 2009. The demand is converted into the unit of ton per year for all products. The secondary demand data obtained from *AllSources* for corrugated roof tile, monier roof tile, paving block, lightweight block, and gypsum board are in the units of square meter per year, so it has to be converted into the unit of ton per year using conversion factors of each product. The conversion factors used in this study are shown in Table 5.1

Table 5.1 Product Unit Conversion Factor

Product	Conversion Factor (Ton/Sq.M.)
Corrugated Roof Tile	0.0147
Gypsum Board	0.0063
Monier Roof Tile	0.0500
Paving Block	0.1777
Lightweight Block	0.0632

Source: AllSources

5.6 Transportation Costs

Transportation costs from all manufacturing plants to all warehouses and from all warehouses to all customer points are the products of distance and transportation rate, which is in the unit of Baht per ton per kilometer and varied by product type. Each product has its own transportation rates. In the current situation, there is no transportation cost from a manufacturing

plant to its adjacent warehouse, since it is assumed that these two facilities are located at the same location, thus the distance between them is equal to zero.

5.7 Warehouse Fixed and Variable costs

Warehouse fixed cost is in the unit of Baht per year, and warehouse variable cost is in Baht per ton. *AllSources* provided data on warehouse costs in 2009 for 11 out of its 22 warehouses. From these 11 warehouses, 20% of the warehouse cost is estimated to be warehouse fixed cost, while the rest 80% is warehouse variable cost. Warehouse variable cost is then divided by product volume that passed through the warehouse in 2009 to obtain variable cost in Baht per ton. For the other 11 warehouses that we have no real data about fixed and variable costs, it is assumed that warehouse variable cost is the same as those warehouses that we have the data, given that they have to handle the same product type. For warehouse fixed cost, it is assumed that warehouse fixed cost depends on the warehouse storage area in square meters. So, I divided the actual fixed cost for the warehouses for which the data was available by its storage area to get the rate of fixed cost per square meter. I then used this rate to calculate fixed warehouse cost of other warehouses. Warehouses' fixed and variable costs that are input into the model are shown in Table 5.2

Table 5.2 Warehouses' Fixed and Variable Costs by Business Units

Business Unit	Product	Warehouse	Fixed Cost (Baht/Year)	Variable Cost (Baht/Ton)	Note
Cement	Bagged Cement	CC1	1,251,081	15	Actual Data Available
		CC2	3,374,063	34	Actual Data Available
		CC3	284,774	34	Actual Data Available
	Bagged Mortar	CM1	727,184	7	Actual Data Available
		CM2	456,071	7	Actual Data Available
Building Materials	Corrugated Roof Tile	BF1	5,760,520	86	Actual Data Available
		BF2	6,103,197	98	Actual Data Available
	Gypsum Board	BG	1,000,000	25	Costs Calculated Based on Assumptions
	Monier Roof Tile	BM1	524,582	5	Actual Data Available
		BM2	1,357,545	5	Costs Calculated Based on Assumptions
		BM3	649,711	5	Costs Calculated Based on Assumptions
		BM4	980,259	5	Costs Calculated Based on Assumptions
	Paving Block	BP1	477,729	1	Costs Calculated Based on Assumptions
		BP2	64,620	1	Costs Calculated Based on Assumptions
		BP3	64,620	1	Costs Calculated Based on Assumptions
		BP4	255,249	1	Actual Data Available
	Ceramic Tile	BC	2,196,088	37	Actual Data Available
	Lightweight Block	BL1	96,930	1	Costs Calculated Based on Assumptions
		BL2	108,246	1	Costs Calculated Based on Assumptions
Distribution	Steel Construction Materials	DS1	1,000,000	25	Costs Calculated Based on Assumptions
		DS2	500,000	25	Costs Calculated Based on Assumptions
		DS3	13,282,316	25	Costs Calculated Based on Assumptions

5.8 Warehouse Capacity

Warehouse capacity is the maximum through capacity of the warehouse, or in other words, the maximum volume of product that can pass through the warehouse in a year.

Warehouse capacity is in the unit of tons per year and is calculated by dividing total product volume that passed through the warehouse in 2009 by percent of warehouse utilization.

Chapter 6 Model Development

To find the best possible flow of all products, a Mixed-Integer Linear Programming (MILP) model is used to optimize the network design problem in this study. The MILP model addresses the following issues:

1. Which warehouses are to be retained and which warehouse are to be closed in such a way that *AllSources'* redesigned distribution network minimizes total distribution cost to the company's supply chain, while meets all of the customer demand?
2. Which products are to be handled together at which warehouses?
3. Which destination provinces are to be served by which consolidated warehouses?

What's Best! Modeling software from LINDO Systems Inc. is used as a tool to run the MILP model. *What's Best!* 9.0 is an add-on application to Microsoft Excel, which increases computational speed and reliability. It enhances the capability of solving mixed-integer programming of standard Excel solver function, without the requirement to learn a new system interface.

6.1 Objective Function

The objective function of the model is to minimize yearly total distribution cost, including inbound transportation cost to warehouses, outbound transportation cost from

warehouses to customers, total warehouse fixed costs, and total warehouse variable costs for handling the products.

6.2 Decision Variables

Decision variables represent the decision about the flow of the product. The variables will address the following issues:

1. How much of each product should be shipped from each plant to each warehouse?
2. How much of each product should be shipped from each warehouse to each customer zone?
3. Which warehouses should be retained and which warehouses should be closed?

Table 6.1 summarizes the detail and number of decision variables in the model

Table 6.1 Summary of Decision Variables

Decision Variable	Number	Note
Inbound Product Flow	462	21 Plants x 22 Warehouses
Outbound Product Flow	5,148	22 Warehouses x 26 Customers x 9 Products
Binary Variables for Warehouse Closing Decisions	22	22 Warehouses
Total Decision Variables	5,632	

6.3 Constraints

To achieve the objective function, which is to minimize total product distribution cost, a set of constraints must be included in the MILP model. In total, four constraints are included in the model, which reflect the following facts:

- Inbound volume of all products to a warehouse must not exceed the warehouse's capacity.
- Inbound volume of a product to all warehouses from a plant must be equal to production volume of the plant.
- Outbound volume of a product from warehouses to a destination province must equal to the demand of the product of that destination province.
- Outbound volume of a product from a warehouse must be equal to inbound volume of that product to that warehouse.

There is an additional constraint on eligibility of some warehouses. Warehouse BG, DS1, and DS2 can store only the product manufactured from its adjacent manufacturing plant and products manufactured from other plants are not allowed to be stored at these three warehouses.

6.4 Model Formulation

The following mathematical formulations are used to develop the MILP model.

6.4.1 Indices and Sets

p = index for manufacturing plants; $p \in P$

k = index for customer zones; $k \in K$

i = index for warehouses; $i \in A$

g = index for products; $g \in G$

6.4.2 Model Parameters

t_{gpi} = unit transportation cost of product g from plant p to warehouse i (Baht/Ton)

s_{gik} = unit transportation cost of product g from warehouse i to customer zone k
(Baht/Ton)

f_i = fixed cost of opening warehouse i (Baht/Year)

v_i = variable cost of warehouse i (Baht/Ton)

c_i = throughput capacity of warehouse i (Ton/Year)

d_{gk} = demand of product g for customer zone k (Ton/Year)

q_{gp} = production capacity of manufacturing plant p for product g (Ton/Year)

6.4.3 Decision variables

x_{gpi} = volume of product g supplied by plant p to warehouse i

y_{gik} = volume of product g shipped from warehouse i to customer k

z_i = $\begin{cases} 1, & \text{if warehouse } i \text{ is used} \\ 0, & \text{otherwise} \end{cases}$

6.4.4 Mathematical Formulation

Objective function

Minimize

$$\sum_{g \in G} \sum_{p \in P} \sum_{i \in A} x_{gpi} t_{gpi} + \sum_{g \in G} \sum_{i \in A} \sum_{k \in K} y_{gik} s_{gik} + \sum_{i \in A} z_i f_i + \sum_{i \in A} (v_i \sum_{p \in P} x_{pi}) \quad \text{Eq. 6.1}$$

Subject to

$$\sum_{i \in A} x_{pi} = q_p \quad \forall p \in P \quad \text{Eq. 6.2}$$

$$\sum_{p \in P} x_{gpi} = \sum_{k \in K} y_{gik} \quad \forall i \in A, g \in G \quad \text{Eq. 6.3}$$

$$\sum_{i \in A} y_{gik} = d_{gk} \quad \forall k \in K, g \in G \quad \text{Eq. 6.4}$$

$$\sum_{p \in P} x_{pi} \leq c_i \quad \forall i \in A \quad \text{Eq. 6.5}$$

$$x_{gpi} \geq 0 \quad \forall g \in G, i \in A, p \in P \quad \text{Eq. 6.6}$$

$$y_{gik} \geq 0 \quad \forall g \in G, i \in A, k \in K \quad \text{Eq. 6.7}$$

$$z_i \in (0, 1) \quad \forall i \in A \quad \text{Eq. 6.8}$$

6.5 Scenarios

The MILP model was run with both the existing situation and with other eight scenarios to see the sensitivity of warehouse selection due to the variability of warehouse fixed cost and capacity. The six scenarios are

Scenario 1: Baseline

In this scenario, the model is run by setting each warehouse's capacity at 95% of its maximum capacity. This is to allow space at each warehouse to be at the appropriate level for convenient warehouse operation. *AllSources* agreed to use 95% of maximum warehouse capacity as a baseline of the model.

Scenario 2: No warehouse fixed cost

This scenario is used to determine the sensitivity of warehouse selection by considering only warehouse variable cost and capacity. Given that the warehouse fixed cost is not considered by the model, the eligibility of warehouse will be highly depended on variable cost.

Scenario 3: Lower warehouse fixed cost by 5% for warehouses that were not selected in Baseline scenario

This scenario examines whether the warehouses that were not selected by the model in Baseline scenario will be selected if their fixed costs were decreased by 5%. In other words, this is to see how much reduction in the fixed cost will make the warehouse eligible; higher or lower than 5%.

Scenario 4: Raise warehouse fixed cost by 5% for warehouse that were selected in Baseline scenario

This scenario examines whether the warehouses that were selected by the model in Baseline scenario, will be selected again if their fixed costs were increased by 5%. In other words, this is to see how much increase in the fixed cost will make the warehouse ineligible; higher or lower than 5%.

Scenario 5: Two times warehouse capacity**Scenario 6: Three times warehouse capacity****Scenario 7: Four times warehouse capacity****Scenario 8: Five times warehouse capacity**

The objective of these four scenarios is to determine the sensitivity of warehouses selection due to the increase of warehouse capacity. These increasing of capacities were based on 95% of maximum capacity. It can be seen from these four scenarios that if all the warehouses' capacities were increased, which warehouses will be neglected by the model. The warehouses that will still be selected can be implied that they are located at the right locations and should be considered expanding their capacities to be able to store more products, which can help to reduce total distribution cost for *AllSources*.

In order to use the model to determine the optimal locations and number of warehouses, I conducted an experiment. In the experiment, I increased the capacity of each warehouse to be 2x, 3x, 4x, and 5x their original capacity. This was done to allow the MILP to shift more loads through warehouses in favorable locations and pull loads away from warehouses in less favorable locations. In order to conduct the experiment, I also changed the variable cost of each warehouse to be the same to avoid the situation where MILP would choose to heavily load on out-of-way warehouses which happened to have a very low variable cost. I also increased the fixed cost of the warehouses but not linearly. For this experiment, I assumed that the fixed cost would rise at the rate of \sqrt{n} , where n was the multiplier of the capacity.

Intuitively, if the warehouses' capacity were increased, the number of warehouses selected by the model will decrease. This is due to the fact that the warehouses located at the appropriate locations can handle more product volume, thus the products that were stored at other warehouses in Baseline scenario will be stored at these appropriate warehouses instead. So, that will lead to the smaller number of warehouses selected by the model. And if we

continue to increase the warehouses' capacity, the number of warehouses selected by the model will continue to decrease. The number of warehouses selected will decrease until the total distribution cost cannot go down further. We can determine the optimal number of warehouses for *AllSources* by continuing to increase warehouses' capacity and seeing that at which point the model will not suggest using fewer warehouses. The fewest number of warehouses selected by the model can be assumed to be the optimum number of warehouses, if *AllSources* could expand its warehouses' capacity.

Chapter 7 Result Analysis

This chapter analyzes the results of running the MILP model in the eight scenarios mentioned in the previous chapter. The reasons why some warehouses were used and others were not used in each scenario are explained, and the total distribution cost of *Allsources'* existing distribution network and the cost of the networks suggested by the model are compared.

7.1 Optimization Results

The results from running the model in six scenarios are shown in Table 7.1. The analysis of the optimization result of each scenario is as following;

Scenario 1: Baseline (95% warehouse capacity)

Three warehouses; BF1, BF2, and DS3 are not selected by the model, so the total number of warehouses used in this scenario is 19 out of 22 warehouses. The reason why the model does not recommend using these 3 warehouses is the high fixed cost of the warehouses compared to other warehouses. For the 19 warehouses that are selected, 16 of them are utilized at their maximum capacity, while the other 3 warehouses, CC1, CC2, and BG, are utilized at approximately 60% of their maximum capacity.

Table 7.1 Optimization Results

Warehouse	95% capacity (Ton/Year)	Fixed Cost (Baht/Year)	Variable Cost (Baht/Ton)	Warehouse Utilization								
				Existing Distribution Networks	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
					95% WH Capacity	No Fixed Cost	Lower WH cost 5% for unused WH	Raise WH Cost 5% for used WH	2 Times WH Capacity	3 Times WH Capacity	4 Times WH Capacity	5 Times WH Capacity
CC1	492,275	1,251,081	15	50%	68%	66%	68%	68%	54%	0%	0%	0%
CC2	570,521	3,374,063	34	50%	62%	60%	62%	63%	0%	0%	0%	0%
CC3	48,152	284,774	34	50%	100%	100%	100%	100%	100%	100%	100%	100%
CM1	361,724	727,184	7	100%	100%	100%	100%	100%	0%	25%	6%	5%
CM2	226,865	456,071	7	100%	100%	100%	100%	100%	71%	35%	23%	18%
BF1	127,680	5,760,520	86	90%	0%	0%	0%	0%	0%	0%	0%	0%
BF2	118,670	6,103,197	98	90%	0%	0%	0%	0%	0%	0%	0%	0%
BG	67,003	1,000,000	25	100%	62%	53%	62%	62%	0%	0%	0%	0%
BM1	47,971	524,582	5	80%	100%	100%	100%	100%	100%	57%	43%	34%
BM2	126,796	1,357,545	5	70%	100%	100%	100%	100%	100%	85%	62%	48%
BM3	128,355	649,711	5	80%	100%	100%	100%	100%	100%	100%	100%	94%
BM4	21,079	980,259	5	80%	100%	100%	100%	100%	0%	0%	0%	0%
BP1	70,370	477,729	5	80%	100%	100%	100%	100%	69%	48%	23%	0%
BP2	45,460	64,620	1	80%	100%	100%	100%	100%	73%	48%	33%	24%
BP3	35,742	64,620	1	80%	100%	100%	100%	100%	100%	96%	67%	54%
BP4	124,323	255,249	1	80%	100%	100%	100%	100%	100%	100%	96%	75%
BC	110,862	2,196,088	37	100%	100%	100%	100%	100%	0%	0%	0%	0%
BL1	88,963	96,930	1	60%	100%	100%	100%	100%	95%	48%	28%	11%
BL2	9,046	108,246	1	60%	100%	100%	100%	100%	100%	100%	100%	100%
DS1	40,278	1,000,000	25	100%	100%	100%	100%	100%	0%	0%	0%	0%
DS2	17,434	500,000	25	100%	100%	100%	100%	100%	53%	0%	0%	0%
DS3	28,500	13,282,316	25	70%	0%	100%	0%	0%	0%	0%	0%	0%
No. of Warehouse Used				22	19	20	19	19	13	12	12	11

Scenario 2: No fixed cost

Twenty warehouses are selected by the model in this scenario. Only 2 warehouses that are not selected are BF1 and BF2. These 2 warehouses have the highest variable cost among all the warehouses. For warehouse DS3, which has highest fixed cost among all warehouses, when I exclude the fixed cost in optimization this warehouse is selected with 100% utilization. This emphasizes the result from Baseline scenario that DS3 is not selected because of its very high fixed cost.

Scenario 3: Lower warehouse fixed cost by 5% for warehouses that were not selected in Baseline scenario

The optimization result of this scenario is not different from Baseline scenario. So, by lowering fixed cost of those unselected warehouses in Baseline scenario by 5%, it is not enough to lower total distribution cost for the entire network because those fixed costs are still much higher than other warehouses'.

Scenario 4: Raise warehouse fixed cost by 5% for warehouse that were selected in Baseline scenario

Again, the optimization result of this scenario is not different from Baseline scenario. So, by increasing fixed costs of those already selected warehouses in Baseline scenario by 5%, these warehouses' fixed costs are still much lower than those of unselected warehouses.

Scenario 5: Two times warehouse capacity

Compared to the Baseline scenario, six more warehouses were not selected: CC2, CM1, BG, BM4, BC, and DS1. So the total number of warehouses used in this scenario is 13 out of 22 warehouses. These warehouses that were now neglected tend to have both higher fixed costs and less appropriate location than those selected warehouse. The products previously stored in these warehouses are moved to the remaining (selected) warehouses instead.

Scenario 6: Three times warehouse capacity and Scenario 7: Four times warehouse capacity

The results of these two scenarios are the same. Compared to scenario 5, two more warehouses, CC1 and DS2, were dropped by the model, while warehouse CM1 was selected by the model again. So In these three scenarios, 12 out of 22 warehouses are used.

Scenario 8: Five times warehouse capacity

. Compared to scenario 6 and 7, one more warehouse, BP1, was dropped by the model. So, in this scenario, 11 out of 22 warehouses are used.

From the optimization results of above scenarios, it can be seen that some warehouses are selected by the model in every scenario, some warehouses are not selected at all, and some warehouses are sensitive to the changing in warehouse capacity. So these warehouses can be ranked by eligibility in to 3 categories as shown in Table 7.2.

Table 7.2 Warehouse Categories by Model Preference

Category	Importance	Criteria	Warehouse
Always Selected	First Group	Been selected in all scenarios with 100% utilization	CC3, BM3, BP4, BL2
	Second Group	Been selected in all scenarios with 100% utilization except at less than 100% utilization in 3 times capacity scenario	BM1, BM2, BP3
	Third Group	Been selected in all scenarios with 100% utilization except at less than 100% utilization in 2 times and 3 times capacity scenario	CM2, BP1, BP2, BL1
Capacity Sensitive	Fourth Group	Not been selected in 3 times capacity scenario	CC1, CM1, DS2
	Fifth Group	Not been selected in 2 times and 3 times capacity scenario	CC2, BG, BM3, BC, DS1
Never Been Selected	Sixth Group	Not been selected in all scenarios	BF1, BF2, DS3

The information in the above table is useful for *AllSources* in order to make any decision about its warehouses. The table shows which warehouses are preferred by the model, which can be implied that they are located at the appropriate locations. So, managers will have a guideline about which warehouses he/she should pay more attention to.

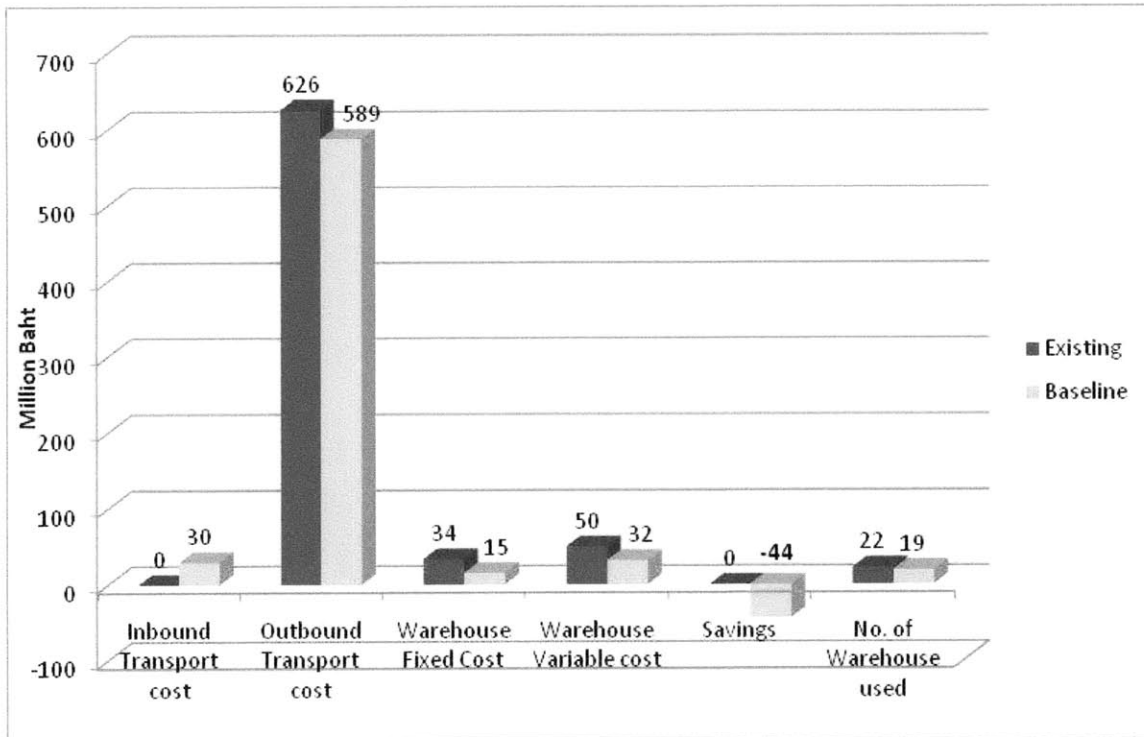
7.2 Comparison between Existing Networks with Model Suggestions

From the previous section, we can see that the MILP model suggests new different distribution networks for *AllSources* from the existing networks. This section compares the characteristics of the existing networks to the suggested networks.

Total Distribution Costs

The comparison between total distribution cost of existing networks and the suggested networks by cost elements is shown in Figure 7.1

Figure 7.1 Comparisons of Total Distribution Costs of Existing and Suggested Networks



Using new suggested distribution networks can save 44 million Baht per year, or about 6% of total distribution costs of existing networks. This saving stems from the total of savings from 4 cost components; inbound transportation cost, outbound transportation cost, warehouse fixed cost, and warehouse variable cost.

Inbound transportation cost of the suggested networks does not incur any saving; instead it is approximately 30 million Baht higher than the existing networks'. This is because in the existing networks, products manufactured at any plant are stored only at the warehouse adjacent to the plant and there is no transportation cost of moving products from plant to adjacent warehouse. For the suggested networks, about 640,000 tons of products (approximately 29% of

product manufactured) have to be moved from their manufacturing plants and stored at warehouses other than the warehouse adjacent to its manufacturing plant. This creates total product movement of about 15 million ton-kilometer and incurs about 30 million Baht per year of inbound transportation cost for the suggested networks.

The second element of total distribution cost is the outbound transportation cost. Most of savings come from this component of distribution cost; approximately 37 million Baht per year. This saving comes from moving products from manufacturing plants and storing them at warehouses which are closer to customers. Normally, outbound transportation cost is higher than inbound transportation cost because of smaller truck has higher rate per ton per kilometer than the bigger truck. So, storing products at warehouses close to customers is a way to minimize outbound distance, and thus minimize outbound transportation cost. From the suggested networks, total products movement for outbound transportation is approximately 270.5 million ton-kilometer, while in the existing networks it is about 258.4 million ton-kilometer.

The third element of total distribution cost is warehouse fixed cost. The model suggests *AllSources* to use only 19 warehouses instead of 22 warehouses in the existing networks. Those 3 warehouses that are not selected have very high fixed cost compared to other 19 warehouses. By having 3 warehouses less, *AllSources* can save about 19 million Baht per year of warehouse fixed cost, and also maximize asset utilization for the remaining warehouses. This assumes that if *AllSources* stopped using the three warehouses that it could indeed not spend the 19 million Baht per year. Table 7.3 compares warehouses utilization of existing and suggested distribution networks.

Table 7.3 Comparison of Warehouse Utilization of Existing and Suggested Networks

Warehouse	Warehouse Utilization	
	Existing Networks	Suggested Networks
CC1	50%	68%
CC2	50%	62%
CC3	50%	95%
CM1	100%	95%
CM2	100%	95%
BF1	90%	0%
BF2	90%	0%
BG	100%	62%
BM1	80%	95%
BM2	70%	95%
BM3	80%	95%
BM4	80%	95%
BP1	80%	95%
BP2	80%	95%
BP3	80%	95%
BP4	80%	95%
BC	100%	95%
BL1	60%	95%
BL2	60%	95%
DS1	100%	95%
DS2	100%	95%
DS3	60%	0%
Average Utilization	79%	90%

The last component of Total distribution costs is warehouse variable cost. The suggested networks can save 18 million Baht of variable cost per year by not storing products at high variable cost warehouse and storing it at other warehouses that have lower variable cost per ton.

Even though, the new distribution networks suggested by the model use only 3 warehouses less than the existing networks, which is intuitively seen as not much network

efficiency improvement, however this is because I limited all the warehouse capacity in the baseline scenario at only 95% of its maximum capacity. If we carefully look at the results from the scenarios of increasing warehouse capacity from two to five times, we can see a lot of improvements in terms of cost savings and the number of warehouse used. Table 7.4 shows the comparison between existing distribution networks and the model results of baseline scenario and all increasing warehouse capacity scenarios.

It can be seen from the table that if we can increase the capacity of all warehouses the cost saving will increase dramatically while the number of warehouses used will decrease. Cost improvement is mainly occur by reducing number of outbound transportation links from warehouses to customers, thus makes significant reduction in outbound transportation costs. The total distribution cost will be at the lowest point in the scenario that increase warehouse capacity by four times and with only twelve warehouses are used. Even if warehouses' capacity is increased by five times and only eleven warehouses were selected by the model, the reduction in outbound transportation cost will be canceled out by the increase of inbound transportation cost and warehouses' fixed cost. That makes total distribution cost in five times capacity scenario higher than those in four times capacity scenario. So, it can be seen that the optimal number of warehouses is twelve warehouses. Thus, the experiment of increasing each warehouse capacity and making their variable costs the same tells us what the optimal warehouse networks would look like if *AllSources* could start with the clean slate: it would have twelve warehouses with capacity and connections as shown in the Table 7.5. Figure 7.2 to 7.5 show the distribution networks suggested by the model in baseline scenario and the increase capacity scenarios.

Table 7.4 Comparisons between Existing Networks and the Model Results of Increasing Capacity Scenarios

	Unit	Existing Networks	Scenario 1: Baseline	Scenario 5: 2 Times Warehouse Capacity	Scenario 6: 3 Times Warehouse Capacity	Scenario 7: 4 Times Warehouse Capacity	Scenario 8: 5 Times Warehouse Capacity
Inbound Transport cost	Million Baht	0.0	29.6	118.7	170.5	201.4	202.5
Outbound Transport cost	Million Baht	626.2	588.6	478.1	420.0	386.4	385.6
Warehouse Fixed Cost	Million Baht	33.5	15.4	8.6	8.8	10.1	10.3
Warehouse Variable cost	Million Baht	49.9	31.6	56.0	56.0	56.0	56.0
Total Distribution Cost	Million Baht	709.6	665.2	661.4	655.3	653.8	654.4
Savings	Million Baht	0.0	44.4	48.2	54.3	55.8	55.2
% Cost Saving	%	0.0%	6.3%	6.8%	7.7%	7.9%	7.8%
No. of Inbound Links	Links	22	52	62	68	69	67
No. of Outbound Links	Links	572	186	133	130	111	110
No. of Warehouse used		22	19	13	12	12	11
No. of Warehouse That Have At Least 95% Utilization		6	16	8	5	2	2
Warehouses Used		CC1, CC2, CC3, CM1, CM2, BF1, BF2, BG, BM1, BM2, BM3, BM4, BP1, BP2, BP3, BP4, BC, BL1, BL2, DS1, DS2, DS3	CC1, CC2, CC3, CM1, CM2, BG, BM1, BM2, BM3, BM4, BP1, BP2, BP3, BP4, BC, BL1, BL2, DS1, DS2	CC1, CC3, CM2, BM1, BM2, BM3, BP1, BP2, BP3, BP4, BL1, BL2, DS2	CC3, CM1, CM2, BM1, BM2, BM3, BP1, BP2, BP3, BP4, BL1, BL2	CC3, CM1, CM2, BM1, BM2, BM3, BP1, BP2, BP3, BP4, BL1, BL2	CC3, CM1, CM2, BM1, BM2, BM3, BP2, BP3, BP4, BL1, BL2

**Table 7.5 Detail of Warehouses as Suggested by the Model from
Four Times Capacity Scenario**

Warehouse	Optimal Product Volume (Ton/Year)	Destination Province	Product Handled
CC3	192,608	Nonthaburi, Pathum Thani, Lopburi, Saraburi, Kanchanaburi, Chainat, Singburi, Suphan Buri, Ayudhaya, Ang Thong	Bagged Cement Bagged Mortar Corrugated Roof Tile Gypsum Board
CM1	93,995	Chachoengsao, Nakhon Nayok, Prachin Buri, Sa Kaeo, Saraburi	Bagged Cement Bagged Mortar
CM2	206,322	Pathum Thani, Lopburi, Saraburi, Kanchanaburi, Chainat, Singburi, Suphan Buri, Ang Thong	Bagged Cement Bagged Mortar
BM1	81,830	Chanthaburi, Chachoengsao, Chonburi, Trat, Nakhon Nayok, Prachin Buri, Rayong, Sa Kaeo	Bagged Cement Bagged Mortar Ceramic Tile Steel Construction Material Monier Roof Tile Corrugated Roof Tile Paving Block Gypsum Board
BM2	312,392	Bangkok, Phetchaburi, Kanchanaburi, Nakhon Pathom, Prachuab Khirikhan, Ratchaburi, Samut Songkhram, Samut Sakhon	Bagged Cement Bagged Mortar Ceramic Tile Steel Construction Material Monier Roof Tile Corrugated Roof Tile Lightweight Block Paving Block Gypsum Board
BM3	513,420	Bangkok, Nonthaburi, Pathum Thani, Chachoengsao, Nakhon Nayok, Prachin Buri, Lopburi, Sa Kaeo, Saraburi, Kanchanaburi, Prachuab Khirikhan, Suphan Buri, Ayudhaya, Ang Thong	Bagged Cement Bagged Mortar Ceramic Tile Steel Construction Material Monier Roof Tile Corrugated Roof Tile Paving Block Gypsum Board
BP1	65,444	Bangkok, Chachoengsao, Prachin Buri, Lopburi, Saraburi, Kanchanaburi, Chainat, Singburi, Suphan Buri, Ayudhaya, Ang Thong	Bagged Cement Bagged Mortar Ceramic Tile Monier Roof Tile Corrugated Roof Tile Paving Block

**Table 7.5 Detail of Warehouses as Suggested by the Model from
Four Times Capacity Scenario (Cont.)**

Warehouse	Optimal Product Volume (Ton/Year)	Destination Province	Product Handled
BP2	60,725	Bangkok, Pathum Thani, Nakhon Nayok , Prachin Buri, Sa Kaeo , Chainat , Singburi, Suphan Buri , Ayudhaya	Monier Roof Tile Corrugated Roof Tile Lightweight Block Paving Block Gypsum Board
BP3	95,940	Samut Prakan, Chonburi, Rayong, Phetchaburi , Prachuab Khirikhan, Samut Songkhram, Samut Sakhon	Bagged Cement Bagged Mortar Ceramic Tile Steel Construction Material Corrugated Roof Tile Paving Block Gypsum Board
BP4	479,485	Bangkok, Nonthaburi, Pathum Thani, Samut Prakan, Chanthaburi , Chachoengsao, Chonburi, Trat, Rayong, Phetchaburi , Chainat , Prachuab Khirikhan, Samut Songkhram, Samut Sakhon, Singburi, Suphan Buri , Ayudhaya, Ang Thong	Bagged Cement Bagged Mortar Ceramic Tile Steel Construction Material Monier Roof Tile Corrugated Roof Tile Lightweight Block Paving Block Gypsum Board
BL1	101,187	Bangkok, Nonthaburi, Pathum Thani, Chachoengsao, Lopburi, Saraburi, Chainat , Singburi, Suphan Buri , Ayudhaya, Ang Thong	Bagged Mortar Monier Roof Tile Lightweight Block
BL2	36,184	Phetchaburi , Kanchanaburi , Nakhon Pathom , Prachuab Khirikhan, Ratchaburi, Samut Songkhram	Monier Roof Tile Corrugated Roof Tile Lightweight Block Gypsum Board

Figure 7.2 Distribution Networks from Baseline Scenario

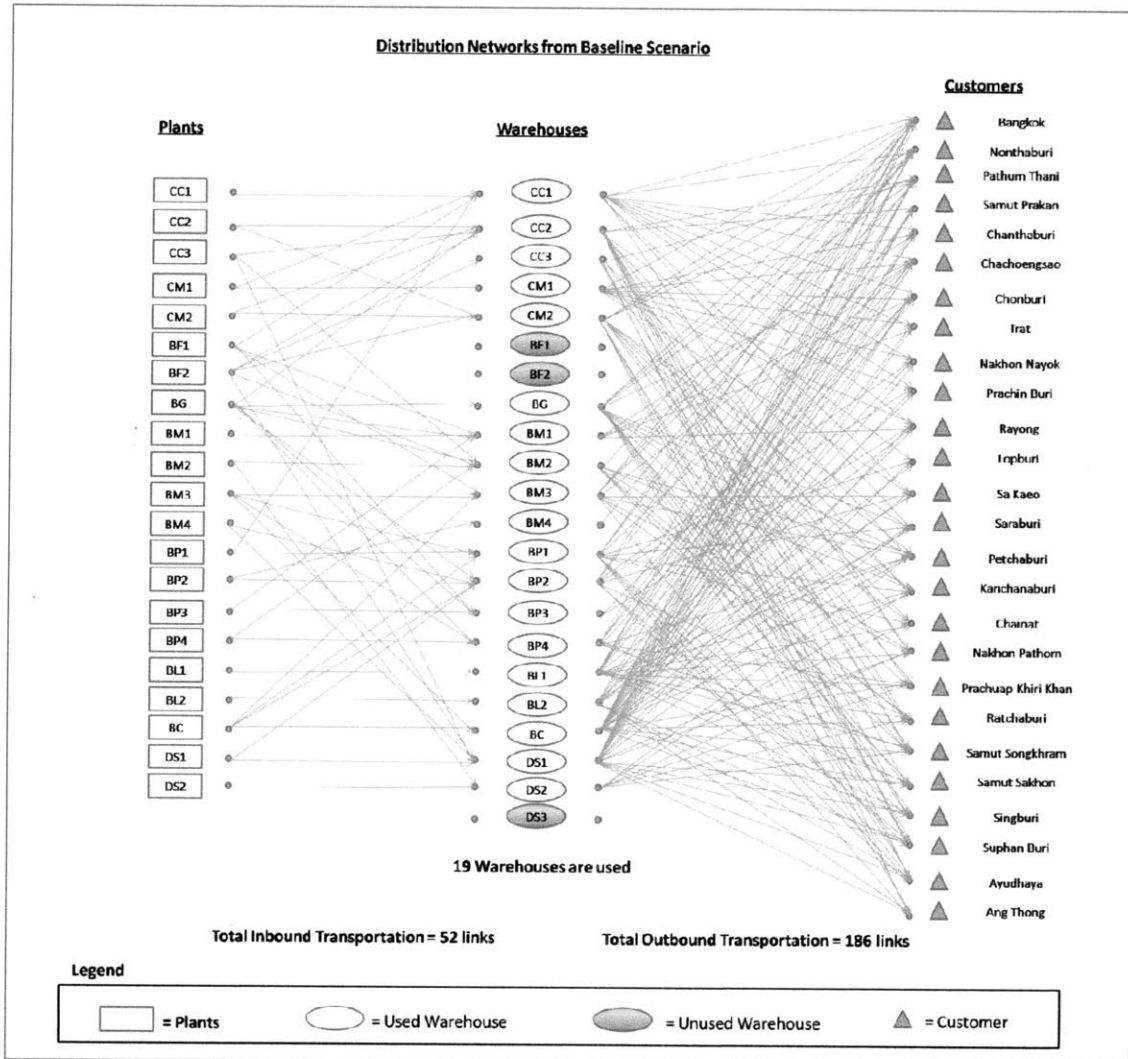


Figure 7.3 Distribution Networks from Two Times Warehouse Capacity Scenario

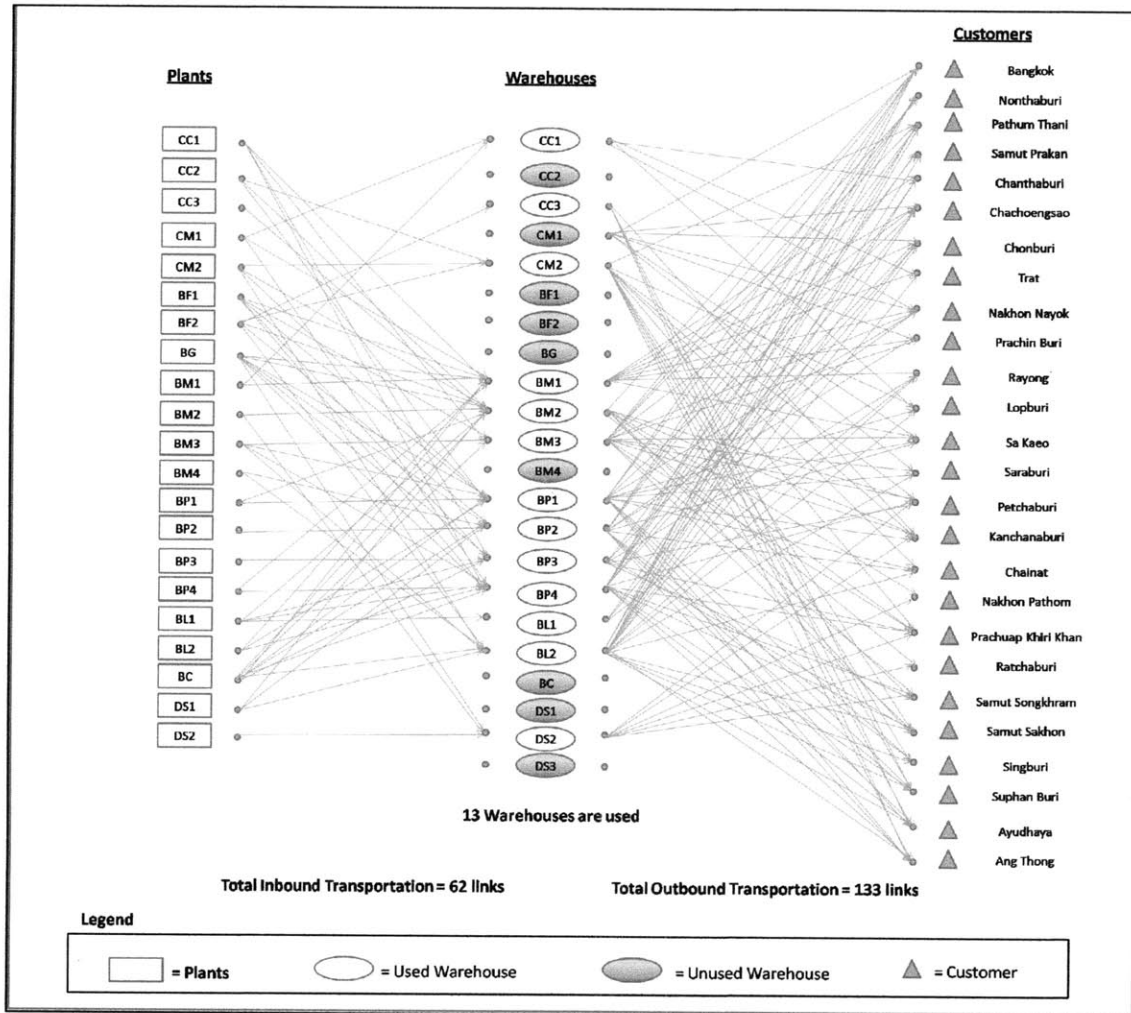


Figure 7.4 Distribution Networks from Three Times Warehouse Capacity Scenario

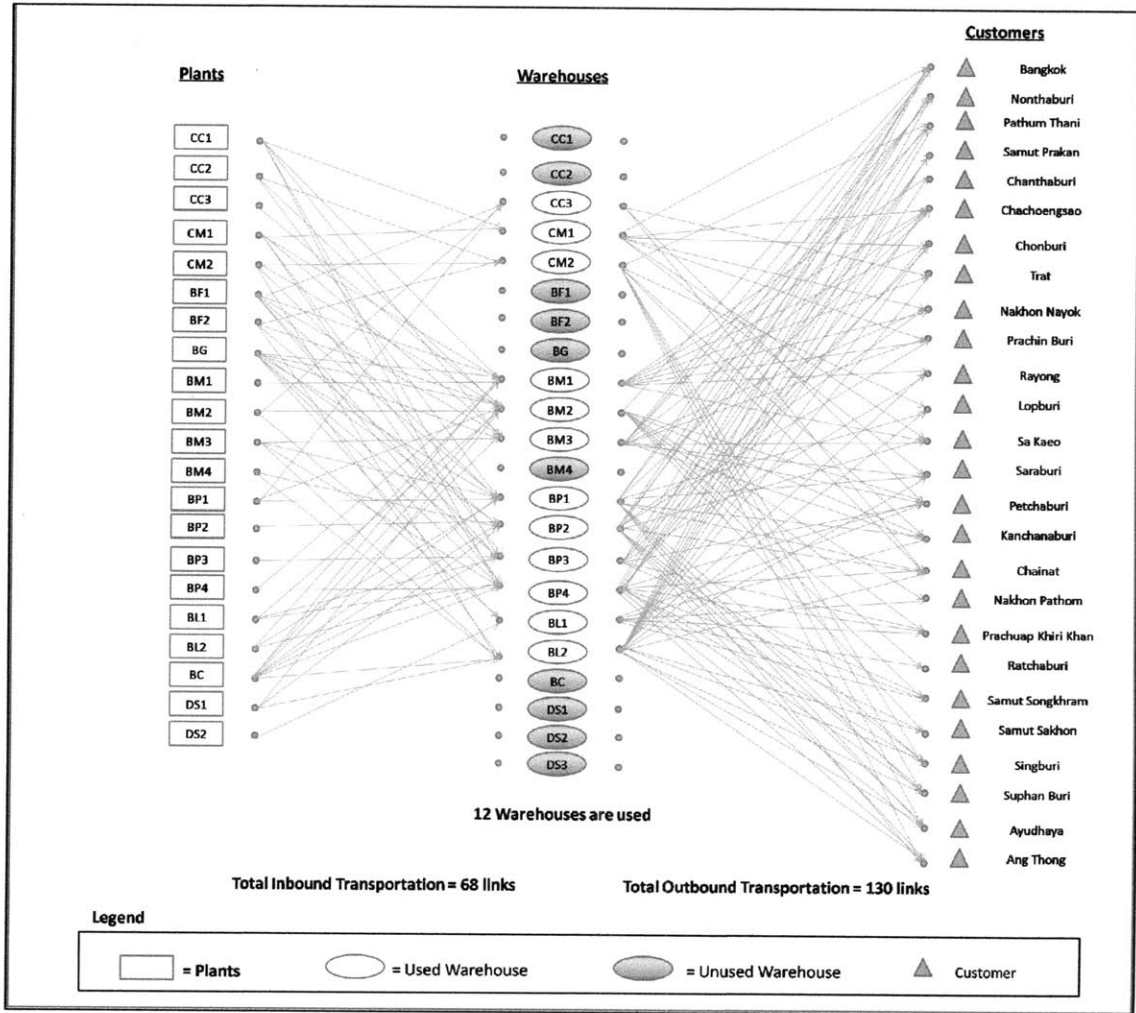
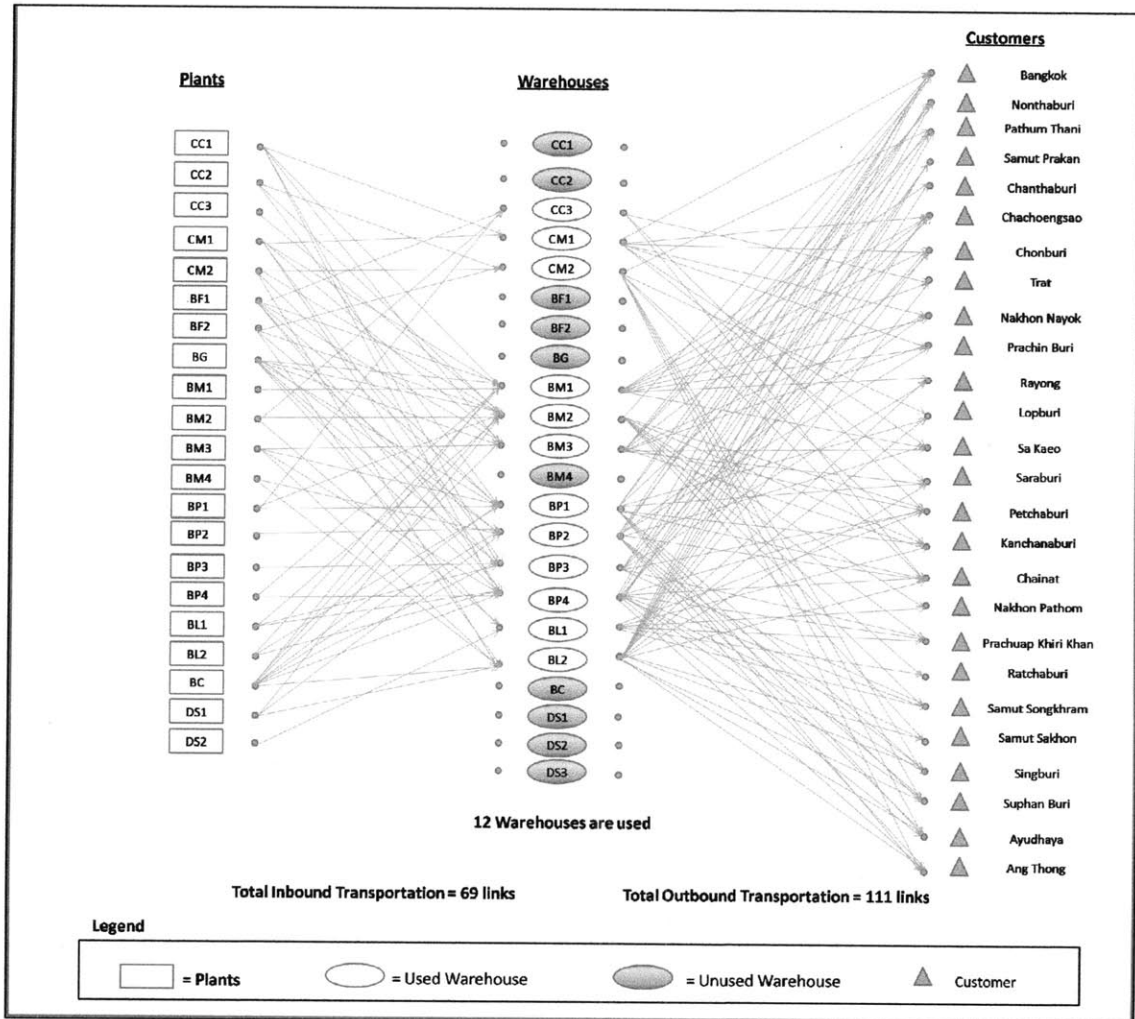


Figure 7.5 Distribution Networks from Four Times Warehouse Capacity Scenario



7.3 Operational Issues

Apart from the change of distribution networks that the model suggests, warehouse operation has to be changed too. This is because warehouse consolidation allows more than one product to be stored together at the same warehouse, which different from *AllSources*, existing

warehouse operation that only one product from one manufacturing plant is stored at any particular warehouse. *AllSources* needs to change its warehouse operation to support multi-product handling. Also, in the existing distribution networks, products manufactured from any plant are shipped to only the adjacent warehouse. But in the new networks suggested by the model, products manufactured at a plant can be shipped to store at more than one warehouse. *AllSources* also needs to change its transportation operation to support multi-destination delivery of the products. Table 7.5 shows the number of product types that will be stored at the warehouses as suggested by the model. The number of products stored at each warehouse is ranging from 1 to 5 products. On average, a warehouse has to store 2.68 product types. Table 7.6 shows the number of warehouse destinations from all the plants as suggested by the model. The number of destination warehouses is ranging from 1 to 7 warehouses with the average of 2.4 warehouses.

**Table 7.6 Number of Product Types Stored at Each Warehouses
as Suggested by the Model**

Warehouse	Number of Stored Products
CC1	4
CC2	5
CC3	1
CM1	1
CM2	2
BG	1
BM1	4
BM2	5
BM3	3
BM4	1
BP1	3
BP2	5
BP3	3
BP4	3
BC	2
BL1	4
BL2	2
DS1	1
DS2	1
Average	2.68

**Table 7.7 Number of Destination Warehouses of Product Delivery
from Manufacturing Plants**

Plants	Number of Destination Ware houses
CC1	1
CC2	2
CC3	3
CM1	2
CM2	2
BF1	4
BF2	4
BG	7
BM1	1
BM2	2
BM3	4
BM4	2
BP1	2
BP2	2
BP3	2
BP4	2
BC	4
BL1	2
BL2	1
DS1	1
DS2	1
Average	2.4

Chapter 8 Conclusion and Opportunities for Future Research

This chapter summarizes the work done in this thesis and discusses the key learning. The final part of the chapter identifies the opportunities for future research that can be extended from this thesis.

8.1 Summary of the Thesis

This thesis focuses on developing an optimization model to redesign product distribution networks for an industrial conglomerate, *AllSources*, which is trying to minimize its total distribution costs to increase its competitiveness in the market. *AllSources*' existing distribution networks are complex and overlapping with each other. With 21 manufacturing plants, 22 warehouses to serve customer demand in 26 provinces in the central, eastern, and western region of Thailand, *AllSources* decided to consolidate some of its warehouses to handle and store more than one product and to close the warehouses which are not cost efficient to operate.

The scope of this thesis is to focus on three *AllSources*' business units; cement, building materials, and distribution. In total, there are nine products included in this network redesign problem. The data collection was primarily done by *AllSources*' employees. Those data included the location of manufacturing plants, warehouses, and customer points, and the distance between these facilities, inbound and outbound transportation costs, warehouses' fixed and variable costs, and their through capacity, and finally the customer demand of each product.

Mixed Integer Linear Programming (MILP) is used to solve optimization of this complex problem. The real data was input into the model together with some calculated data based on assumptions provided by *AllSources*. The model was run in six scenarios to examine the sensitivity of warehouse selection due to the variability of warehouse capacity and fixed cost. We found that some warehouses were always selected by the model, some were not selected in any scenario, and some were selected in some scenarios and were not selected in others. Then these warehouses were ranked by eligibility as a guide for supply chain manager when making decision on these warehouses in the future.

Comparison between existing networks and the model suggested networks was done on total distribution cost and warehouse utilization. The result showed that *AllSources* can save 44 million Baht per year from the suggested distribution networks. Lastly, some concerns about warehouse operation that has to be changed to support the new distribution networks were discussed.

8.2 Key Learnings

Because of globalization, companies have to adapt their business processes to align with the rapidly and constantly changing business environment in order to be competitive. One approach is to redesign companies' supply chain networks to minimize total product distribution costs while still satisfying customer service level. Redesign of distribution networks is a strategic decision that has long lasting effects on the company's performance, so it requires

collaboration from related organizations inside and outside the company, including suppliers and customers.

In doing the network optimization problem using the model, the data input into the model is a key factor to obtain the reliable result. A company has to pay great attention in data collection process to obtain the correct information from all related parties, such as sales, operation, and financial departments. Wrong data can lead to unreliable model result which may incur huge loss for the company, had it be applied and implemented in the real situation.

Finally, to change its business processes, the company needs to balance the trade-off between benefit gained, e.g. cost savings, and implementation difficulty, e.g. how to change warehouse operation from single product handling to multi-product handling with no negative effect to customers. This requires effective change management and excellent collaboration in the organization and also all related parties in the supply chain.

8.3 Opportunities for Future Research

This thesis develops a MILP model to optimize product distribution networks for *AllSources*. However, some of the data input into the model is not the actual data because I cannot obtain the actual data from *AllSources*, so these data were calculated based on assumptions set by *AllSources*. These data were fixed and variable costs of some warehouses, actual warehouses through capacity, and actual storage area of some warehouses. Model accuracy can be greatly improved by having the real data input into the model. It is very

important to have people from all related parties to validate the data. Warehouse fixed and variable costs are very important as they are key determinants in the model selection. So, having a representative from financial department to verify the costs before input into the model is preferable. *AllSources* really needs to invest the effort to obtain the accurate data to be input in the model. This will make the model results more reliable and can be implemented with more confidence from all related departments.

In this thesis, transportation cost assumptions are based on truck load rates. However, the initial optimization results show that many of the outbound transportation legs will be less than truck load (LTL) delivery. So, to obtain more accurate model result, the transportation rates on each lane need to be matched to the expected shipment sizes on those lanes. Therefore, LTL transportation rates need to be input in to the model on certain lanes to reflect true transportation costs. Then the model needs to be rerun, and the transportation costs adjusted again, etc.

Another area to conduct further research is to include warehouses owned by other two business units, chemicals and paper, into consideration. In this thesis, only warehouses of cement, building materials, and distribution business units of *AllSources* are included in the model. The warehouses owned by chemicals and paper BUs aren't yet taken into consideration. By expanding the scope to cover warehouses from all business units into the model, *AllSources* can benefit more from greater opportunity of warehouse consolidation with higher cost saving.

The last issue that can be more interesting for further research is about opportunity cost. In this thesis, opportunity cost from closing warehouses is not considered, and thus not included

in the model. This opportunity cost can be the revenue from leasing or selling the warehouses that the model suggests to close. As it is currently formulated, the model assumes that if it stops using a warehouse, *AllSources* will not have to pay the fixed cost of that warehouse. In real life, it may be that some warehouses can be easily sold or leased to other parties and some warehouses may be very difficult for *AllSources* to get rid of. Knowing which is which would lead to a more usable model results. Considering this opportunity cost in the model helps making the model more realistic.

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