Design and Model of Supply Chain Network for the Biodiesel Refinery Industry in the Southern Region of Thailand

Wichuta Saungmuang[1]
Sakesun Suthammanon[2]
Pallapat Penchamrat[3],
Nikorn Sirivongpaisal[4]

Business Logistics and Supply Chain Management Research Group
[1,2,4]Department of Industrial Engineering
Faculty of Engineering
Prince of Songkla University
Kho Hong, Hat Yai, Songkhla
Thailand 90112.

[3]Department of Business Administration
Faculty of Management Science
Prince of Songkla University
Kho Hong, Hat Yai, Songkhla
Thailand 90112.

Abstract

The present research study examines the total system wide cost of the biodiesel industry in southern Thailand through supply chain modeling. This information is used to consider the total systemwide cost of the supply chainnetwork and investigate the location and capacity allocation of biodiesel refinery plants in order to minimize the total cost. Supply chain in the research study consists of suppliers, Cruded-Palm-Oil plants, biodiesel refineries, depots, refineries, and gas stations, which are prevalent in southern Thailand.Models developed can be useful in decision making for those involved in the strategic planning of energy substitutionin Thailand.

Keywords: Supply Chain Modeling, Biodiesel Industry, Mixed-Integer Linear Programming

Acknowledgement

This research project was supported by a grant from Prince of Songkla University through Contract No. ENG50109900059S. The authors would like to thank Associate Professor Sunchai Klinpikul at Department of Industrial Engineering, Prince of Songkla University, and Associate Professor Saree Svetaserani at Department of Industrial Engineering, Kasetsart University, for their valuable comments that improved this research study.

1. Introduction

Currently, Thailand imports approximately 91% of commercial energy from the total energy used in the country,and 79% of crude oil is imported. Crude oil is processed into various forms of ready-made oil, which serve as the drivingforce in Thailand's economic development. In 2006, the total use of oil in the entire country was 35,976millions liters. The total consumption of oil by diesel users in transportation, industry, and commercial sectors was 18,317 millions liters, which was 51% of the ready-made oil usage. The price of crude and ready-made oil tends to continually rise, which affects most people in the country and reduces the balance of trade within the country. Thus, the Thai government has initiated and supported the development of various kinds of energy sources, such as sun, wind, biomass, and agricultural products, in order to prepare the country for rising prices of crude oil and the loss of trade balance. According to Thailand's strategic plan of energy substitution, the Ministry of Energy has stipulated the blending of 5% and 10% composite portions with high–speed diesel, called B5 and B10, by 2010 and 2012, respectively. It is expected that this will replace the usage of diesel by about 8.5 millions liters per day, or 3,100 millions liters per year.

In order to achieve Thailand's strategic plan, an understanding of the relationships among members of the palm oil and diesel oil industries is required. Mismatching between supply and demand can impact government policy regarding energy substitution from agricultural products. Additionally, this mismatch will decrease efficiency in the management of the biodiesel supply chain. This research study examines the total systemwide cost, which is utilized to measure the efficiency of the supply chain incurred in the biodiesel industry in southern Thailand. The research study also investigatesfactors that influence theeffectiveness of the biodiesel supply chain. The objective of this research is to investigate the location and capacity allocation of biodiesel refinery plant facilities in order to minimize the total systemwide cost of supply chains.

Contributions of this research include the design and model of the biodiesel logistics network, which will be beneficial for profound comprehension of the industry through conveying Thailand's strategic energy development plan in a concrete manner. Secondly, this study proposes the supply chain management concept, which focuses on upstream to downstream integration of the biodiesel industry and is also valuable for management of this industry. Finally, it is an endeavor of the application of Operations Research techniques into a practical problem.The remaining sections of this paper are organized as follows. In section 2, the literature review presents information about the locations and capacity allocations of the facilities. In section 3, the biodiesel network is described. In section 4, a description is provided about designing and modeling biodiesel supply chain networks, or network configurations, with a focus on model formulation for facility locations and capacity allocations. Finally,the conclusion and discussion are presented in section 5.

2. Literature Review

Decisions regarding the location and capacity allocation of a facility represent an important aspect of strategic planning for supply chain management. These decisions are instrumental in the determination of the sets of locations and allocation of capacity for a facility. This review focuses on the application of mathematical programming models in the strategic design and improvement of global logistics systems.

Jeff Ferrio and John Wassick (2008) explain that chemical supply chain network optimization with the objective of cost reduction functions through the redesign of the flow of materials from producers to customers. A mixed-integer linear program (MILP) is capable of optimizing a multi-product supply chain network made up of production sites, an arbitrary number of echelons of distribution centers, and customer sites.

Zhiqiang Lu and Nathalie Bostel (2007) discuss a two-level location problem with three types of facilities located in a specific reverse logistics system called, a "Remanufacturing Network (RMN)". An algorithm based on Lagrangian heuristics is developed, and the model is tested on data adapted from classical test problems. Andreas Fink and Torsten Reiners (2006) mention that the model and solve problems by means of minimum cost network flow optimizations taking into consideration essential practical needs, such as multi-period planning, a country-wide network, customized transportation relations, fleeting and de-fleeting, and car groups with partial substitutability.

Didier Vila et al. (2006) present generic methodology for designing the production-distribution network of divergent process industry companies in a multinational context. A mathematical programming model is used to map the industry manufacturing process to potential production-distribution facility locations and capacity options.

Francisca H.E. Wouda et al. (2002) propose the optimization of the supply network of Nutricia Hungary using a mixed–integer linear programming model. The objective of the study is to evaluate these strategies through identification of the optimal number of plants, locations, and allocations of the product portfolios, while minimizing the sum of production and transportation costs.

Marc Goetschalckx et al. (2002) suggest that logistics systems design problems are comprised of the following as follows: potential suppliers, potential manufacturing facilities, distribution centers with multiple possible configurations, and customers with demands that determine the configuration of the production–distribution system and transfer prices between various subsidiaries of a corporation. This includes seasonal customer demands and service requirements that are met after tax profits are maximized. After tax profits are the difference between the sale revenues minus the total system costs and taxes. The total cost is defined as the sum of supplies, production, transportation, inventory, and facility costs.

N. Sirivongpaisal and K.J. Rogers (2000) present a technique for the design and analysis of an integrated supply chain network in a stochastic environment when subjected to various sources of uncertainty in the network. The use of a combination of network modeling, stochastic linear programming, and discrete event simulation will be discussed.

3. Biodiesel Supply Chain Network

3.1. Concept of Supply Chain Systems

A supply chain system is a network of facilities and distribution options that obtains raw materials, transforms theminto intermediate and finished products, and distributes the products to customers. Each enterprise is different in complexity due to the size of the chain. Regardless ofcomplexity, the enterprises must operate in an integrated manner.A supply chain network may be separated into five important units. These units include (1) raw material supplier units, (2) inventory stocking units, (3) production units, (4) distribution center units, and (5) customer units. The functions of each unit are associated and related based on the concept of the supply chain. The flow of materials in each unit operates by a diversity of means. The inputs to each production unit are comprised of raw materials and/or work-in-process materials that different vendor or production units supply. Raw materials and/or work-in-process materials can be transformed or assembled into finished goods through the production process. Then, the outputs of finished goods from production units can be placed in the finished goods inventory or shipped to a distribution center unit. Lastly, the flow of materials, or finished goods, is distributed through a distribution network to the retail market in order to satisfy customer demands as shown in Figure 1.

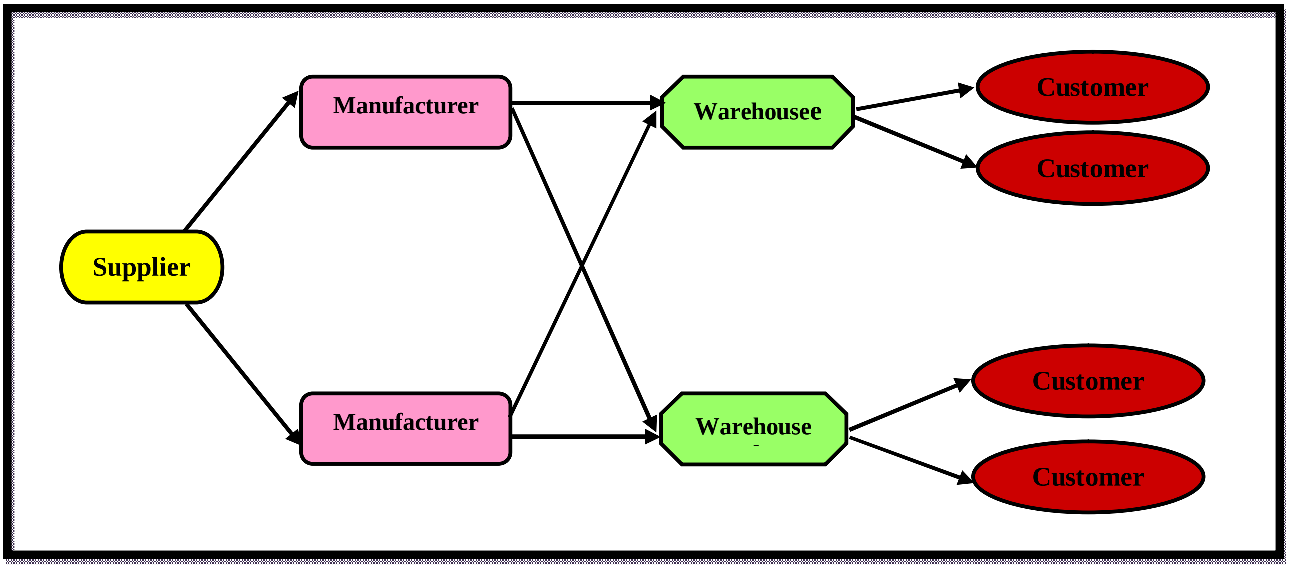

Figure 1. Flow of Materials in a Supply Chain Network

3.2. Facility Location and Capacity Allocation in Supply Chain Network

Facilities are the foundation of the supply chain infrastructure and include suppliers, plants, distribution centers, and customers. Facility location decisions must consider many trade-offs during network design. These decisions are instrumental in the construction of a distribution network and involve determining sets of locations and the capacity that will be established for each facility. The general goal is to maximize overall profitability of the resulting supply chain network, while providing customers with appropriate responsiveness. Revenue comes from product sales, whereas costs arise from facilities, labor, transportation, material, and inventories.A supply chain, or logistics network, has multiple members that may be considered from upstream to downstream. The general supply chain is similar to the biodiesel supply chain network in this research study as illustrated in Figure 2.

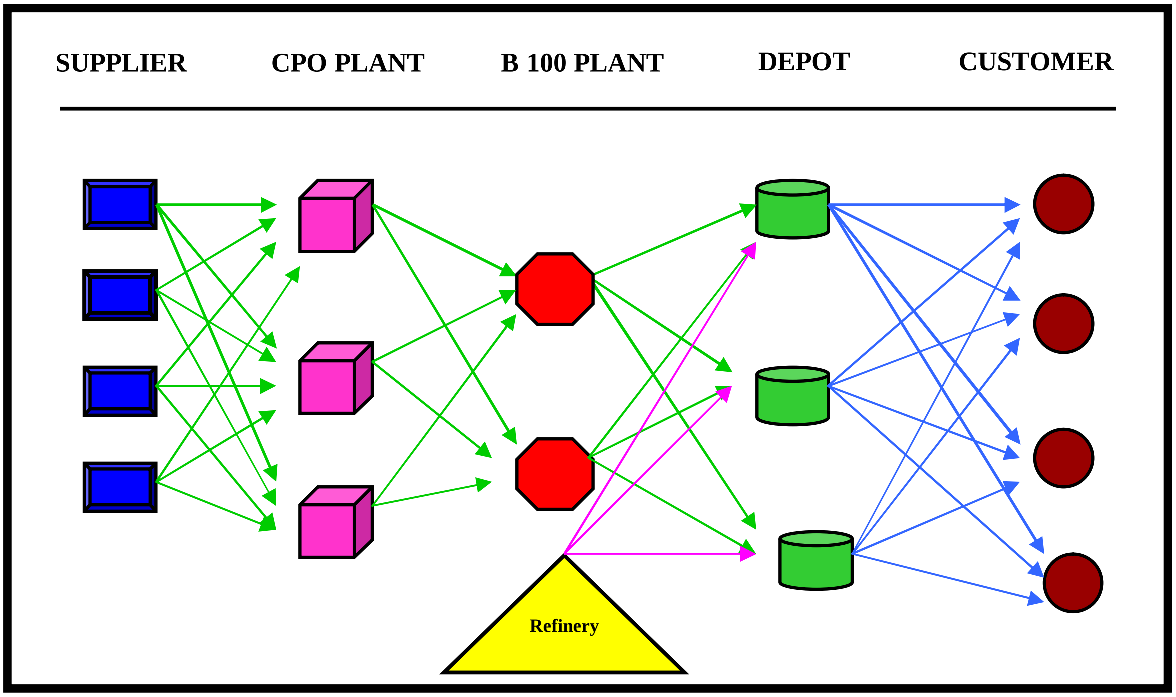

Figure 2. Biodiesel Supply Chain Network

The diagram in Figure 2 shows that the first member corresponds with the suppliers, who supply raw material, fresh fruit bunch, from fields. The second member corresponds with the plants that produce crude palm oil (CPO) from the fresh fruit bunches. The third member corresponds with the B100 plants that transform CPO into biodiesel. In this research study, these members are key for selecting the best locations for the biodiesel refinery industry. The best locations are the places where the total system wide costs of the supply chain are minimized. The fourth member corresponds with the refinery, where high–speed diesel oils are supplied andmixed with biodiesel in the next stage. The fifth member corresponds with the depots, where blending of high–speed diesel with biodiesel, called B5, occurs and is stored for customers. Finally, the sixth member corresponds with customersat gas stations in the southern region of Thailand.It can also be recognized from Figure 2 that the biodiesel supply chain network represents a symbol of nodes and arcs. Each facility from upstream to downstream can be drawn as nodes. Arcs connected between pairs of nodes represent the flow of materials between members in the supply chain. In addition, each arc contains variable costs incurred from activities associated with moving materials, such as production costs, inventory costs, and transportation costs, for example.

4. Designing and Modeling Biodiesel Supply Chain Network

According to Simchi-Levi et al. (2003), the principle of logistics network configuration contains several steps mostly concerning data collection. The following section represents each stage exercised in the development of the supply chain network model for the biodiesel refinery industry.

4.1. Model Input

During the model input stage the required data for logistics network modeling is collected. A typical network configuration problem involves large amounts of data, including information that will be discussed in subsequent sections.

1. Location of gas stations, depots, CPO plants, and fresh fruit bunch suppliers
2. Potential locations of biodiesel refinery plant, or B100 plant
3. Demand of each gas station per day
4. Transportation rates
5. Production costs per unit

6. Inventory costs per unit
7. Shipment sizes and frequency of customer delivery
8. Customer service requirements and goals

After all of the data is completely gathered, it is necessary to aggregate them on the criteria of location in the same district. As a result, the model developed in the next step is based on the following assumptions. First, data regarding the inventory cost is estimated to be 3% of the product price. Second, the capacity of the B100 plants is 100,000 and 200,000 kilograms per day, and the production costs of each facility are the same. Third, the data regarding transportation costs is collected from the questionnaire, and some of the information comes from secondary data. Finally, the location of the refinery sites is at the central capital of Thailand, Bangkok.

4.2. Formulation of Model for Facility Location and Capacity Allocation

The facility location and capacity allocation problem could be addressed by asking, “What is the optimal number of biodiesel refinery plants (B100), and what location and capacity of these plants minimizesthe total system wide cost of the biodiesel network?” The logistics network design problem can be formulated as a mixed integer programming (MIP) problem. In a mathematical model, the variables and the objective function can be represented as shown in Section 4.2.1, and the constraints are explained in Section 4.2.2.

4.2.1. The Variables and Objective Function

Model formulation in this research represents the variables and objective function as follows.
Indices:

e	number of supplier sites $(e = 1,2,..., r)$
g	number of CPO plants $(g = 1,2,..., t)$
h	number of potential B100 plant locations $(h = 1,2,..., l)$
i	number of depots $(i = 1,2,..., n)$
j	number of customers (retailed gas station) $(j = 1,2,..., m)$
k	number of oil refineries $(k = 1,2,..., p)$
f	fresh fruit bunch product
b	B100 oil product
d	high–speed diesel oil product
B_5	B5 oil product

Variables

x_{feg}	amount of fresh fruit bunch product produced and transported from supplier site e to CPO plant g
x_{bgh}	amount of B100 oil product produced, carried, and transported from CPO plant g to B100 plant h
x_{bhi}	amount of B100 oil product produced, carried, and transported from B100 plant h to depot i
x_{dki}	amount of high–speed diesel oil product produced, carried, and transported from oil refinery k to depot i
x_{B_5ij}	amount of B5 oil product blended, carried, and transported from depot i to customer j
Y_h	binary decision variable, either 1 if B100 plant is located at site h, or 0 otherwise

Coefficients

F_h	fixed cost of locating B100 plant at site h
c_{feg}	cost of production and transportation per one unit of fresh fruit bunch product from supplier site e to CPO plant g
c_{bgh}	cost of production, carrying activities, and transportation per one unit of B100 oil product from CPO plant g to B100 plant h
c_{bhi}	cost of production, carrying activities, and transportation per one unit of B100 oil product from B100 plant h to depot i
c_{dki}	cost of production, carrying activities, and transportation per one unit of high speed diesel oil product from oil refinery k to depot i
c_{B_5ij}	cost of blending, carrying activities, and transportation per one unit of B5 oil product from depot i to customer j
S_e	supply capacity of fresh fruit bunch of supplier site e
K_g	capacity of CPO plant g
B_h	potential capacity of B100 plant h
F_k	capacity of oil refinery k
W_i	capacity of depot i
D_j	demand from customer j

The objective function can be described using the following concept equation:

Minimize $\{$ fixed cost of locating B100 plant + production and transportation cost of fresh fruit bunch product from supplier to CPO plant + production, carrying, and transportation cost of B100 oil product from CPO plant to B100 plant + production, carrying, and transportation cost of B100 oil product from B100 plant to depot + production, carrying, and transportation cost of high speed diesel oil product from oil refinery to depot + blending, carrying, and transportation cost of B5 oil product from depot to customer $\}$

In addition, the biodiesel supply chain network coupled with decision variables is illustrated in Figure 3. It is slightly modified from Figure 2; however, it will be more comprehensible when it is used in the modeling stage.

In Figure 3, the biodiesel supply chain network is delineated. The first stage shows that the model starts with the supplier, who supplies the fresh fruit bunch product. It is used as the primary raw material for producing biodiesel, and it is widespread in the southern region of Thailand. It is classified as location e in this model. In this stage, cost is incurred due to the production of the fresh fruit bunch product and transportation to the CPO plants. The fresh fruit bunch production and transportation costs per one unit are different in each region e and are notated as C_{feg} .After collecting fresh fruit bunch, it is transported from location e to location g , which represents for CPO plant. At this location, fresh fruit bunch will be processed to crude palm oil, known as

CPO,and transported to location h, where is B100 plant. In addition, costs are incurred due to production, carrying inventory, and transportation. It is denoted by C_{bgh}.

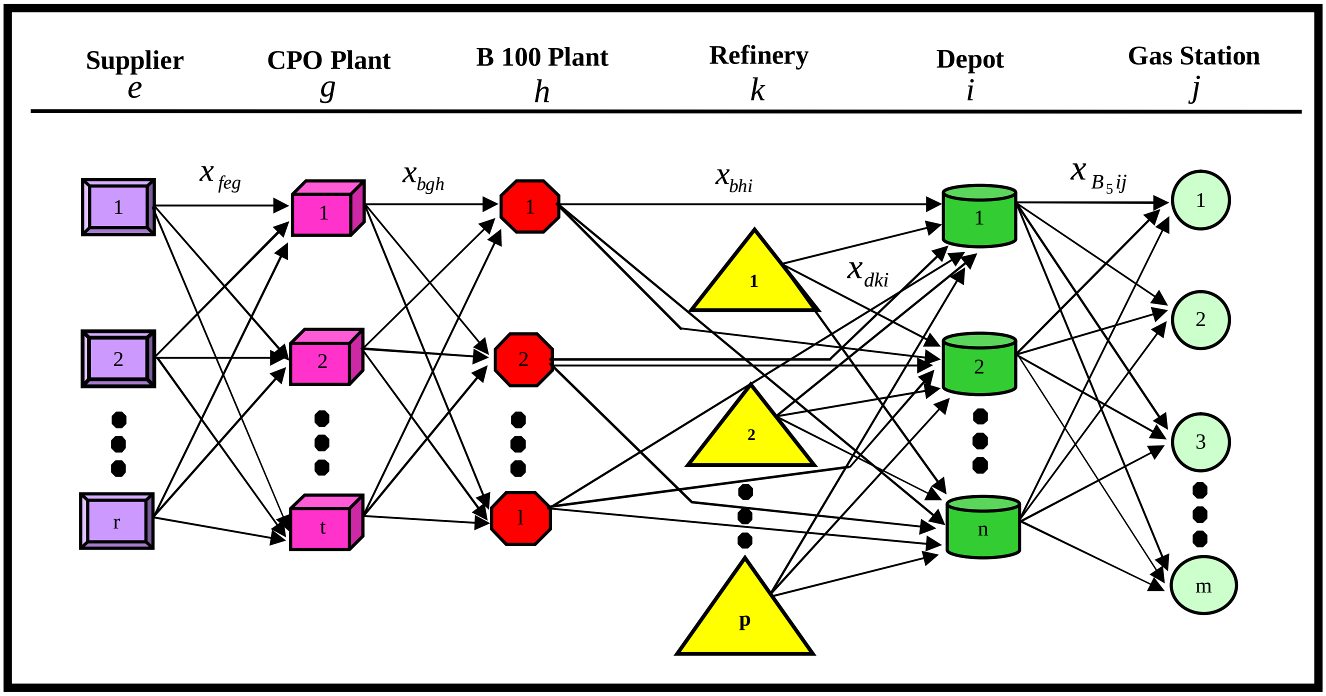

Figure 3. Biodiesel Supply Chain Network Coupled with Decision Variables

Next stage in biodiesel network, it is location h or B100 plant. Similar to prior stage, CPO from location g will be processed to biodiesel, known as B100 and then transported to depot, classified as location i in this model. The B100 production costs, inventory costs, and transportation costs per one unit also are different in each location h and are defined as C_{bhi}. Simultaneously, at location i high speed diesel from location k, which stands for refinery, is transported to depot in order to mix with B100. Again C_{dki} is denoted as production cost,carrying cost, and transportation cost per one unit of high speed diesel to depot. Besides, the strategic decision making as stated above is just about locating B100 plants. In order to cope with this challenge, fixed cost of locating each facility in region h will be deliberated and notated as F_h in this model. After ninety-five percentages of high speed diesel and five percentages of B100 product are blended, new product so called B5 is ready for distributing to customer, which is retail gas stations, where are prevalently located all over the southern region of Thailand. In this model, it is symbolized with location j. This is the last stage of biodiesel network. Certainly, costs of blending, carrying, transporting per one unit of B5 is incurred and denoted as C_{B_5ij} in this model.The model contains 28 binary decision variables and 3,148 continuous decision variables. The mathematical form of the objective function can be written as shown in Eq. (1).

Objective Function

$$Min\Big[\sum_{h=1}^{l} F_h Y_h + \sum_{e=1}^{r}\sum_{g=1}^{t} c_{feg}x_{beg} + \sum_{g=1}^{t}\sum_{h=1}^{l} c_{bgh}x_{bgh} + \sum_{h=1}^{l}\sum_{i=1}^{n} c_{bhi}x_{bhi} + \sum_{k=1}^{p}\sum_{i=1}^{n} c_{dki}x_{dki} + \sum_{i=1}^{n}\sum_{j=1}^{m} c_{B_5ij}x_{B_5ij}\ \Big] \qquad (1)$$

4.2.2. Constraints

In the previously illustrated biodiesel network model, a few constraints are used to correspond with the real circumstances in this industry, such as capacity of raw material sites, capacity of production sites, and balance of inflow and outflow at each location in the supply chain, etc. In addition, some constraints are illustrated in terms of production yields, which are shown as coefficients in the equations.

The unique equation in this research is at the depots, where high–speed diesel is blended with B100. This turns the physical action into a mathematical constraint. All constraints are presented and clarified in the following Eqs. (2) – (12). The developed supply chain network model is comprised of 331 constraints.

Constraints

$$\sum_{g=1}^{t} x_{feg} \le S_e \qquad \text{for} \qquad e = 1,2,\ldots,r \tag{2}$$

The total amount shipped from the raw material site cannot exceed the capacity of the raw material site

$$\sum_{e=1}^{r} (0.170) x_{feg} - \sum_{h=1}^{l} x_{bgh} \ge 0 \qquad \text{for} \qquad g = 1,2,\ldots,t \tag{3}$$

The amount shipped out of the CPO plant cannot exceed the quantity of raw material received at the site

$$\sum_{h=1}^{l} x_{bgh} \le K_g \qquad \text{for} \qquad g = 1,2,\ldots,t \tag{4}$$

The amount produced in the CPO plant cannot exceed the capacity of the CPO plant

$$\sum_{g=1}^{t} (0.935) x_{bgh} - \sum_{i=1}^{n} x_{bhi} \ge 0 \qquad \text{for} \qquad h = 1,2,\ldots,l \tag{5}$$

The amount shipped out of the B100 plant cannot exceed the quantity received by the CPO plant

$$\sum_{i=1}^{n} x_{bhi} \le B_h Y_h \qquad \text{for} \qquad h = 1,2,\ldots,l \tag{6}$$

The amount produced in the B100 plant cannot exceed the capacity of the B100 plant

$$\sum_{i=1}^{n} x_{dki} \le F_k \qquad \text{for} \qquad k = 1 \tag{7}$$

The amount produced in the oil refinery cannot exceed the capacity of the oil refinery

$$\sum_{h=1}^{l} (20) x_{bhi} - \sum_{j=1}^{m} x_{B_5 ij} \ge 0 \qquad \text{for} \qquad i = 1,2,\ldots,n$$

$$\sum_{k=1}^{p} (1.053) x_{dki} - \sum_{h=1}^{l} (20) x_{bhi} \ge 0 \qquad \text{for} \qquad i = 1,2,\ldots,n \tag{8}$$

The amount shipped out of the depot cannot exceed the quantity received from the B100 plant and oil refinery

$$\sum_{j=1}^{m} x_{B_5 ij} \le W_i \qquad \text{for} \qquad i = 1,2,\ldots,n \tag{9}$$

The amount produced in the depot cannot exceed the capacity of the depot

$$\sum_{i=1}^{n} x_{B_5 ij} = D_j \qquad \text{for} \qquad j = 1,2,\ldots,m \tag{10}$$

The amount shipped to the gas retail station must satisfy the demand

$$Y_h \in \{0,1\} \tag{11}$$

Each B100 plant is either open or closed

$$x_{feg}, x_{bgh}, x_{bhi}, x_{dki}, x_{B_5 ij} \ge 0 \tag{12}$$

All decision variables are of a non-negative value

4.3. Model Output and Sensitivity Analysis

After the design and model of the supply chain network and formulation of the mathematical model shown in the previous section, the data gathered can be used to optimize the total systemwidecost of the biodiesel supply chain network under different scenarios.

As explained earlier, this model is formulated as the facility location and capacity allocation problem, which can be solved for the optimal number of biodiesel refinery plants (B100 plant), including location and capacity, also the allocation of the physical flow of materials among each stage in the network.

Scenario 1:According to Thailand's strategic plan of energy substitution, the Ministry of Energy has stimulated the plan as blending 5% biodiesel with 95% high–speed diesel, B5, by the year 2010.

Scenario 2:By the year 2012, there will be an increase in the blending portion of B5 to B10, which requires 10% biodiesel blended with 90% high–speed diesel.

Results from these two scenarios are illustrated in Table 1 and Table 2. Table 1 represents the optimal number of B100 plants, their locations and capacities, with the minimum total systemwide cost of the biodiesel supply chain network for each scenario. It should be recognized that scaling up from the B5 to B10 substitution plan will require twice as much capacity allocation, from 300 tons per day to 600 tons per day, and the addition of another B100 plant.

Table 1. Optimization Results from the Biodiesel Supply Chain Model

Scenario	Total Systemwide Cost (Baht/Day)	Optimal Number of B100 Plants and Location	Capacity Allocation (Tons/Day)
1	157,596,900	Pun Pin, Suratthani	200
		Klong Tom, Krabi	100
2	162,904,200	PriPraYa, Krabi	200
		Pun Pin, Suratthani	200
		SinghaNakorn, Songkhla	200

Table 2 represents the costs between each stage of the biodiesel supply chain. As previously mentioned, costs that are accounted for in this supply chain include production, transportation, and inventory carrying activities during each stage from upstream to downstream. Data from Table 2 is graphically represented in Figures 4 – 6.

Table 2. Supply Chain Cost Comparison in Each Stage of Two Scenarios

Cost Between Stage of Biodiesel Supply Chain	Scenario 1 (Baht/Day)	Scenario 2 (Baht/Day)
• Cost from Suppliers to CPO Plants	2,865,493	5,754,012
• Cost from CPO Plants to B100 Plants	4,251,675	8,573,174
• Cost from B100 Plants to Depots	4,485,298	8,911,274
• Cost from Refinery to Depots	142,079,553	134,617,631
• Cost from Depots to Gas Stations	3,914,881	5,048,109
Total System wide Cost	**157,596,900**	**162,904,200**

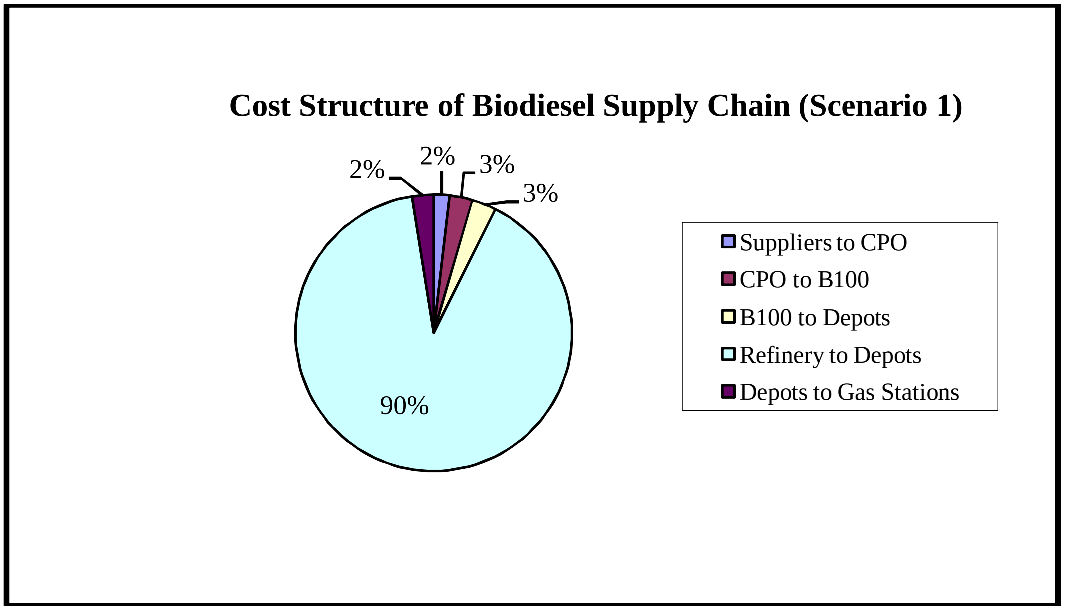

Figure 4. Cost in Each Stage under Scenario 1

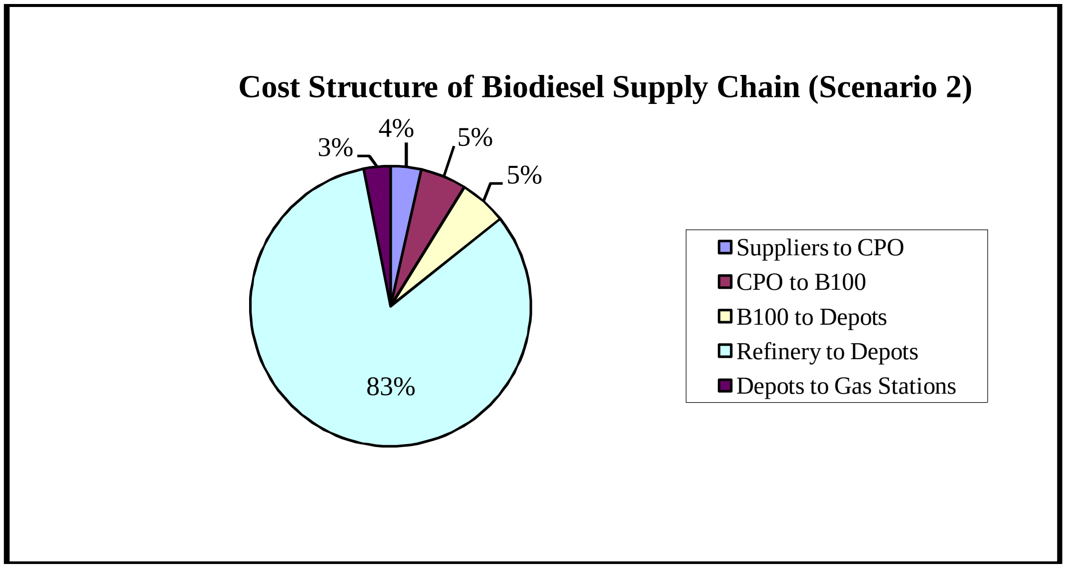

Figure 5. Cost in Each Stage under Scenario 2

The pie chart shown in Figure 4 reveals some interesting information regarding cost behavior. About ninety percent of the total system wide cost can be attributed to logistic activities in the stage of refinery to depots. The remaining ten percent of the cost is generated from the stage of suppliers - CPO plants, CPO plants - B100 plants, B100 plants - depots, and depots - gas stations. A similar pattern is shown in Figure 5, in which about eighty percent can be attributed to logistic activities in the stage of refinery to depots. Approximately twenty percent of the chart represents the rest of each stage in the biodiesel supply chain.Clarification of the cost behavior is made in the following section. At the stage of supply chain from suppliers - CPO plants - B100 plants - depots, the quantity of materials flow, B100, both substitution plans (5% and 10%) do not have a significant effect on the total system wide cost resulting from logistic activities in the supply chain, including production, transportation, and carrying inventory. Therefore, the logistic costs are absolutely proportional to the quantity of material flow in the supply chain. In contrast, the stage from refinery to depots shows that the flow quantity of high–speed diesel causes numerous logistic activities in the biodiesel supply chain. This is why it requires a major percentage of the total systemwide cost. This analysis offers ideas for managing the biodiesel supply chain through a focus of planning and controlled logistic activities regarding high–speed diesel physical flows.

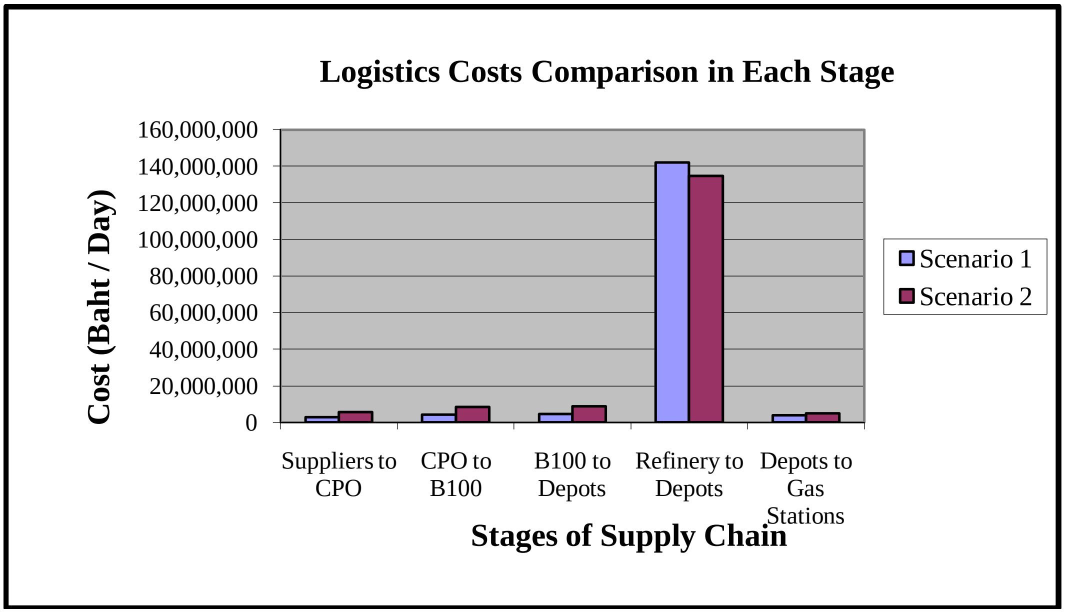

Figure 6. Costs Comparison between Scenarios 1 and 2

The bar chart shown in Figure 6 demonstrates the comparison of logistic costs in each stage of the biodiesel supply chain and can provide comprehension regarding the functioning of this industry. The cost at the stage of suppliers - CPO plants, CPO plants - B100 plants, B100 plants - depots, and depots - gas stations - is lower in scenario 1 than in scenario 2, while the cost at the stage of refinery to depots is higher in scenario 1 than in scenario 2. However, the cost at the stage of depots to gas stations is not significantly different between the two scenarios. The reason that the first three stages of scenario 1 (substitution plan, B5) require a lower quantity of materials than scenario 2 (substitution plan, B10) is because they require half the amount of materials to be blended with high–speed diesel. The lower the amount of materials flow, the lower the logistic costs that are expended. The stage of refinery to depots requires quite a different explanation and can be considered from the logistic cost trade-off point of view.

Regarding Table 1, the B5 plan requires two B100 plants with a total capacity of 300 tons per day, and the B10 plan requires three B100 plants with a total capacity of 600 tons per day. The greater the materials flow, the more logistic costs that are expended. Nevertheless, the more B100 plants that are located near each other, the closer the depots can connect to the customers. The outbound logistic costs will decrease, especially for transportation. Adding inbound and outbound logistic costs for both scenarios reveals that scenario 2 is more economical than scenario 1. From this investigation, it is shown that a trade-off concept will be beneficial for managing the biodiesel industry.The optimum solution of the B100 plants location is different with each scenario. The optimum locations for scenario 1 are at (1) Pun Pin, Suratthani, with a capacity of 200 tons per day, and (2) Klong Tom, Krabi, with a capacity of 100 tons per day. The optimum locations for scenario 2 are at (1) PriPraYa, Krabi, with a capacity of 200 tons per day, (2) Pun Pin, Suratthani, with a capacity of 200 tons per day, and (3) SinghaNakorn, Songkhla, with a capacity of 200 tons per day.Besides, sensitivity analysis is also examined. The factors that are considered in this research are raw material (fresh fruit bunch) price, supplier’s capacity, and demand uncertainty. Reports from sensitivity analysis are illustrated as follows in Figure 7, Figure 8, and Figure 9, respectively.

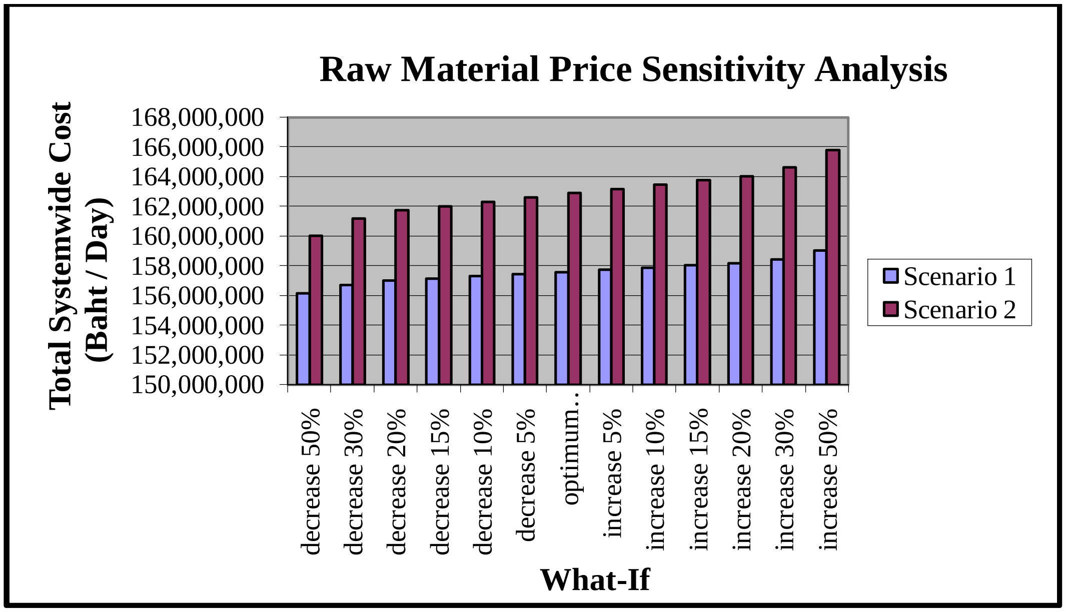

Figure 7. Sensitivity Analysis of Raw Material Price

In Figure 7, the bar graph illustrates the result of sensitivity analysis from raw material price perspective. In nature, fresh fruit bunch will behave in seasonal characteristics so its price can be drastically fluctuated. Then in this research, the projection of the price situation is ranging from fifty percentages decline to fifty percentages incline. It can be found out that no matter what scenarios when fresh fruit bunch price increases, total systemwide cost will gradually increase. While the price decreases, it also steadily decreases.About the optimum solution of B100 plants location is not changed since quantity of raw material, widely spread in the southern region, can be satisfied the demand of B5 or B10 production.

Thus even the price of raw material fluctuates; it will not affect to the B100 plant locations. This kind of analysis also has the benefit for managing the biodiesel industry under situation of raw material's price uncertainty.

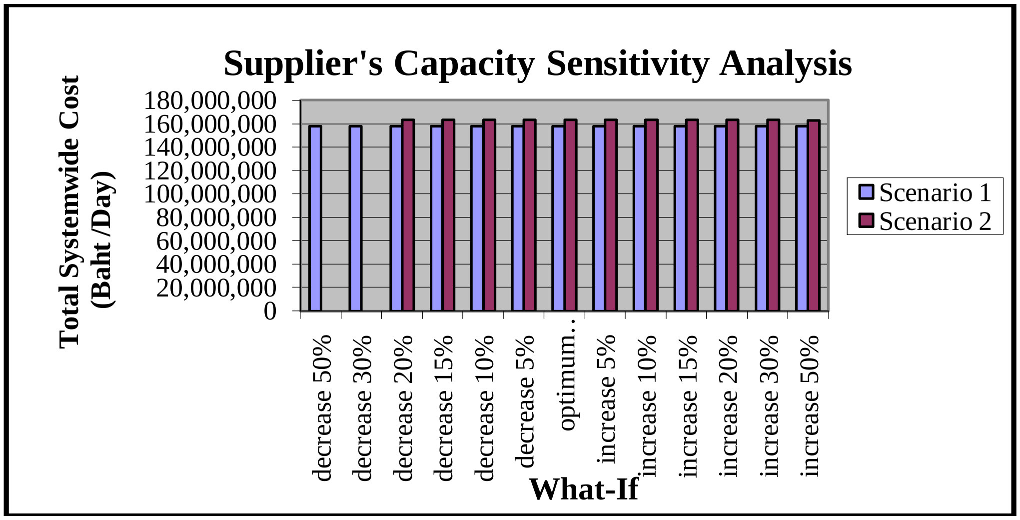

Figure 8. Sensitivity Analysis of Supplier's Capacity

In Figure 8, the chart illustrates the result of sensitivity analysis from supplier's capacity perspective. Supplier's capacity is essential since it is associated to the capability of plantation management. The higher the capability, the higher the yield crop of palm trees. Thus in this research, the projection of the supplier's capacity is similarly ranging as above. It can be found out that if capacities incline five percentages to fifty percentages, total systemwide cost under both scenarios are slightly different, compared with the optimum solution. Similarly, the same behavior occurs if capacities decline five percentages to fifty percentages under both scenarios.

Except supplier's capacity decreases to thirty percentages and fifty percentages under scenario 2, there will no be feasible solutions. This can be interpreted as there is mismatching between supply quantity and demand quantity, which is fresh fruit bunch supply is not enough for producing biodiesel.

About the optimum solution of B100 plants location also changes only under scenario 2 if supplier's capacity increases to thirty percentages and fifty percentages. Optimum locations are at (1) PriPraYa, Krabi, (2) Pun Pin, Suratthani and (3) SinghaNakorn, Songkhla. It will be changed from SinghaNakorn, Songkhla to Klong Tom, Krabi , with the same production capacity, 200 Tons/day. And the rest of locations are the same.

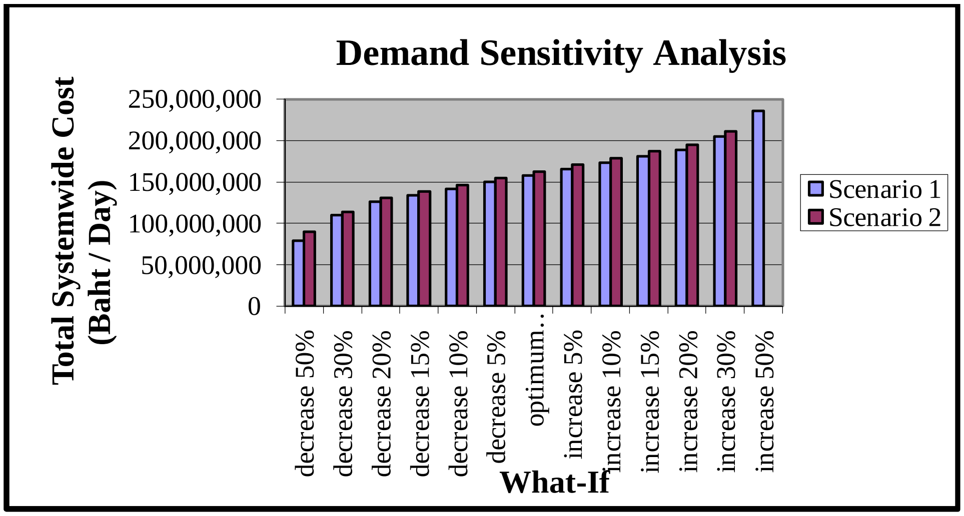

Figure 9. Sensitivity Analysis of Demand

In Figure 9, the chart illustrates the result of sensitivity analysis from demand perspective. Indeed, demand of any product always constantly changes, no exception for biodiesel. As a result in this research, the projection of the demand uncertainty is similarly ranging as above.

Hence it can be discovered that no matter what scenarios when demand increases, total systemwide cost will increase. And when it decreases, total systemwide cost as well decreases. Yet there will be no feasible solution if demand increases to fifty percentages under scenario 2. Again the optimum solution of B100 plants location also changes for both scenarios. Under scenario 1, the optimum locations are at (1) Pun Pin, Suratthani with capacity 200 tons/day and (2) Klong Tom, Krabi with capacity 100 tons/day. Under scenario 2, the optimum locations are at (1) PriPraYa, Krabi with capacity 200 tons/day, (2) Pun Pin, Suratthani with capacity 200 tons/day and (3) SinghaNakorn, Songkhla with capacity 200 tons/day. Summary of new locations and capacities under each degree of sensitivity is illustrated in the following Table 3. Definitely, this kind of analysis has an advantage for managing the biodiesel industry, as well.

Table 3. New Locations and Capacities of Scenario 1 and Scenario 2

Degree of Demand Sensitivity	Location and Capacity of Scenario 1	Location and Capacity of Scenario 2
5% incline	Not changed	Not changed
10% incline	Not changed	PraSeang, Suratthani - 200 Tons/day Pun Pin, Suratthani - 200 Tons/day SinghaNakorn, Songkhla - 200 Tons/day
15% incline	Not changed	PraSeang, Suratthani - 200 Tons/day Pun Pin, Suratthani - 200 Tons/day SinghaNakorn, Songkhla - 200 Tons/day
20% incline	Klong Tom, Krabi - 200 Tons /day Pun Pin, Suratthani - 200 Tons /day	Pun Pin, Suratthani - 200 Tons/day Muang, Chumporn - 200 Tons /day SinghaNakorn, Songkhla - 200 Tons /day AoLuek,Krabi - 100 Tons /day
30% incline	Klong Tom, Krabi - 200 Tons /day Pun Pin, Suratthani - 200 Tons /day	PraSeang, Suratthani - 200 Tons /day Pun Pin, Suratthani - 200 Tons /day SinghaNakorn, Songkhla - 200 Tons /day Muang, Chumporn - 100 Tons /day
50% incline	Klong Tom, Krabi - 200 Tons /day Pun Pin, Suratthani - 200 Tons /day	No Feasible Solution
5% decline	Not changed	Pun Pin, Suratthani - 200 Tons /day SinghaNakorn, Songkhla - 200 Tons /day PriPraYa, Krabi - 100 Tons /day
10% decline	Not changed	Klong Tom, Krabi - 200 Tons /day Pun Pin, Suratthani - 200 Tons /day PriPraYa, Krabi - 100 Tons /day
15% decline	Not changed	Klong Tom, Krabi - 200 Tons /day Pun Pin, Suratthani - 200 Tons /day PriPraYa, Krabi - 100 Tons /day
20% decline	Not changed	Klong Tom, Krabi - 200 Tons /day Pun Pin, Suratthani - 200 Tons /day AoLuek, Krabi - 100 Tons /day
30% decline	Pun Pin, Suratthani - 200 Tons /day	Klong Tom, Krabi - 200 Tons /day Pun Pin, Suratthani - 200 Tons /day
50% decline	Pun Pin, Suratthani - 200 Tons /day	Pun Pin, Suratthani - 200 Tons /day Klong Tom, Krabi - 100 Tons /day

5. Conclusions

In this research study, the biodiesel supply chain refinery industry in the southern region of Thailand has been examined in order to develop the logistics network model. The main objective of the development of this model is to study the total system wide costs of the supply chain and investigate the locations and capacity allocations of refinery plants (B100 plant) in order to minimize the total system wide costs. The scope of the supply chain model, which consisted of suppliers, CPO plants, B100 plants, depots, refineries, and gas stations, was considered to be prevalent in the southern region of Thailand.

The mixed integer programming model has been developed in accordance with the data collected from various members of this supply chain. Results reveal that the total system wide cost of the biodiesel industry, considering upstream to downstream in southern Thailand, is about 320 Million Baht under the substitution plan of blending 5% biodiesel with 95% high–speed diesel, called B5, by year 2010. The total systemwide cost is about 322 Million Baht under the substitution plan of 10% biodiesel and 90% high–speed diesel, B10. Additionally, sensitivity analysis has been achieved, and the results play a significant role in supply chain management of the biodiesel industry.

Obtaining and analyzing this model would be absolutely valuable for policy makers while making decisions about biodiesel industry policies in Thailand. The model presented in this study supports Thailand’s strategic plan in energy substitution and promotes the usage of biodiesel. Various scenarios and policies will be explored in future related studies in order to study changes in total systemwide costs of the industry. Since total cost is one of the key success factors in the managing supply chain industry and if it cannot compete with regular diesel, users are not motivated to swap to biodiesel. Therefore, the government must be interested in initiating policies that can adequately encourage the increased usage of biodiesel as an energy substitution in Thailand.

References

Ahuja, R. K., Magnanti, T. C., and Orlin, J. B. (1993). Network Flow: Theory, Algorithum, and Application. Pearson Education, Inc., New Jersey, U.S.A.

Chopra, S. and Meindl, P. (2007). Supply Chain Management Strategy, Planning & Operations. Pearson Education, Inc., New Jersey, U.S.A.

Fink, A. and Reiners, T. (2006). Modeling and Solving the Short-Term Car Rental Logistics Problem. Journal of Transportation Research Part E, 42: 272-292.

Goetschalckx, M., Vidal, C. J. and Dogan, K. (2002). Modeling and Design of Global Logistics Systems: A Review of Integrated Strategic and Tactical Models and Design Algorithms. European Journal of Operational Research, 143: 1-18.

Ko, H. J. and Evans, G. W. (2007). A Genetic Algorithm-Based Heuristic for the Dynamic Integrated Forward / Reverse Logistics Network for 3PLs. Journal of Computer & Operation Research, 34: 346-366.

Lu, Z. and Bostel, N. (2007).A Facility Location Model for Logistics Systems Including Reverse Flow: The Case of Remanufacturing Activities. Journal of Computer & Operation Research, 34: 299-323.

Ratliff, H. D. and Nulty, W. G. (1996).Logistics Composite Modeling.The Logistics Institute at Georgia Tech.

Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E. (2003). Designing and Managing the Supply Chain. McGraw-Hill.

Sirivongpaisal, N. and Rogers, K.J. (2000). Minimum Cost Flow in a Supply Chain Problem Using a Stochastic Linear Programming Approach, Proceeding of 2000 International Conference on Production Research, Bangkok, Thailand.

Vila, D. and Martel, A. (2006).Designing Logistics Networks in Divergent Process Industries: A Methodology and Its Application to the Lumber Industry. International Journal of Production Economics, 102: 358-378.

Wouda, F. H.E., van Beek, P., van der Vorst, J. G.A. J. and Tacke, H. (2002).An Application of Mixed-Integer Linear Programming Model on the Redesign of the Supply Network of Nutricia Dairy & Drinks Group in Hungary. Journal of OR Spectrum, 24: 449-465.