OPTIMIZATION OF FRUIT COLD CHAIN MANAGEMENT: A CASE STUDY OF MANGOSTEEN SUPPLY CHAIN IN SOUTHERN THAILAND

BY

MS. SIRILADDA SAMATIAT

AN INDEPENDENT STUDY SUBMITTED IN PARTIAL
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SYSTEMS ENGINEERING)
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ABSTRACT

Nowadays, the quality of food, freshness and food safety are getting more attention. Agricultural products have characteristics that are perishable, short shelf life and temperature sensitive. Thus, cold chain management is necessary. In order to ensure safe, fresh, high-quality products for customers, this article formulates a mathematical model aiming to generate the cold chain management plan for the potential fruit supply chain in each region of Thailand to maintain the quality and reduce loss and also increase the value of the product. The Mix-integer linear programing (MILP) model was developed to generate the planning, and the Excel Open Solver was used to solve the problem. The result indicates the cold chain management plan can suggest the route and modes of storage and transportation to convince the supply chain members to follow the plan and ensure maximum profit for each member, also for the whole supply chain and also for the benefit of customers at the end of the chain as well.

Keywords: Cold chain, Perishable supply chain, Agricultural products, Food quality, Food safety, Optimization, Mix-integer linear programming, Logistic, Distribution, Storage, Value-added product.

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CHAPTER 1
INTRODUCTION

1.1 Problem statement

The quality of food products, such as freshness or food safety, is more of a concern for consumers, especially in agricultural products and processed food, because these products are quickly perishable, with a short shelf life and are temperature sensitive. Thus, cold chain management is needed to manage the supply chain to maintain safety, freshness, and quality in the supply chain of perishable products to customers.

The cold chain refers to the supply chain that requires temperature control to ensure quality and safety from the origin node through the system and ends up with the customer. Farmers, wholesalers, retailers, storage services, and transportation services are all part of the cold chain. Cold chain activities consist of cold storage and transportation. Cold storage is responsible for storing cold chain products for a period of time waiting to be transported to the market or customers and cold transportation is responsible for transporting cold chain products from storage points or from various stakeholders to other stakeholders, markets or customers. The cold chain plays an important role in preserving quality, reducing food spoilage for customers, extending shelf life, and ensuring food safety. This leads to the ability to maintain the quality of products in storage and the ability to transport products across longer distances and increased customer satisfaction.

Thailand is an agricultural country and has many agricultural products, but Thailand is also a tropical country. Heat and humidity can affect these products and increase the chances of the product more easily spoilage or deteriorate that also reduce the chance to gain more profit. But producers need to maintain the quality of a product as much as possible to increase the value of the product and sell it at a good price and satisfy customer satisfaction. Likewise, customers want to consume good quality products at a reasonable price. Therefore, it is necessary to apply an approach to help maintain the quality of the product before the producer can deliver the product to the consumer.

This article focuses on a method to meet customer demand in the agricultural supply chain in each region of Thailand while maintaining the quality of fresh and processed products as much as possible through the use of cold chain management.

1.2 Research objectives

This article has a specific objective, as follows:

- To find a suitable product that is worth investing in for cold chain management to increase the value added.
- To formulate a mathematical model to maximize the total profit of the whole supply chain and also maximize the profit of each supply chain member.
- Determine the optimal solution that has the maximum profit for the overall stages of the supply chain.
- To generate the suggested plan for using cold chain management in the supply chain of agricultural products, attempting to find which stage in the supply chain should use cold storage and which route and transportation mode in the supply chain should use cold transport to maintain the quality of the product to satisfy customer demand.

1.3 Scope of research

The scope of this article is conducted for the purpose of finding suitable fruit and processed fruit in southern region of Thailand by considering an aggregate plan to use the cold chain in the supply chain for fresh and processed agricultural product. This article consists of mangosteen fruits in southern region and can be processed into peeled mangosteen.

The supply chain structure has four stages before sending to the end customers: supply sources, wholesale markets, small fruit stores and supermarkets. In retail, categorized into two groups are small fruit stores and supermarkets. Wholesale markets, small fruit stores, and supermarkets need storage and can have a processing stage at each stage. Transportation and storage in this supply chain have two modes, ambient and cold also required. Some input parameters such as some unit price or customer demand are assumption data.

1.4 Product overview

1.4.1 Fresh mangosteen

From the Official of Agricultural Economics, the overall productivity of mangosteen in Thailand was 351,740 tons or 827 Kilograms per Rai. In this research, we focus on productivity in Southern Thailand. Mangosteen was highly produced in Nakhon Si Thammarat province, totaling 51,375 tons or 592 Kilograms per Rai. The shelf life in ambient temperature was seven days. Supposing that we used the proper cold chain (13-15°C), the shelf life of mangosteen will extend to 21 days or three weeks. The production cost at the stage supply source was 15.33 Baht.

Figure 1.1 Fresh mangosteen.

1.4.2 Peeled mangosteen

The peeled mangosteen is well-known at Nakhon Sri Thammarat province that used the raw mangosteen to process and make more value-added. When farmers collect mangosteen, there will be some raw fruits mixed with fresh fruits. Raw mangosteen that has green color without a vein on the texture of mangosteen cannot sell at markets.

However, the farmer at Nakhon Sri Thammarat used the raw mangosteen to process as peeled mangosteen. This product can add more value to the overall supply chain because they can sell this product at a high price.

Figure 1.2 Peeled mangosteen.

1.5 Overview of research

The remainder of this article is organized as follows. Section 2 summarizes the literature that is related to research topics. Section 3 represents the sets, parameters, and decision variables followed by generic mathematical model. Section 4 explains the data collection and case study of mangosteen in southern region including the specific network and mathematical model. Section 5 shows the result and discussion for fresh and processed mangosteen along with sensitivity analysis of some input parameters. In section 6, the conclusions and recommendations for further research.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Qualitative study

Nowadays the cold chain system is the popular way to maintain and ensure the quality of foods and perishable products. However, the environmental issues are also important and must be considered about the emission of Carbon. Otherwise, It might be a problem in the future. They suggested providing good operating systems for education and training (Heap 2006). The refrigerate is necessary for keeping perishable food, and fresh agricultural products. If not kept at the optimal temperature, the spoilage will occur and cause foodborne illness or food wastes and loss of money (Mercier, Vileneuve, Mondor, and Uysal 2017). Around 60% of New Zealand exports food products in a refrigerated condition. The current status of the cold chain in New Zealand, the Ministry for Primary Industries provides the regulation that will cover the information about standard temperature control for various food products. Processors and exporters will take this responsibility along the cold chain and regular audit by the Ministry for Primary Industries (Carson, and East 2018). On the other hand, Indian citizens have an understanding of ensuring perishable foods but still lack awareness in cold chain management. In this article, they collected the data by using a questionnaire and evaluated by Microsoft Excel and SPSS program (Joshi, Banwet, and Shankar 2010). Indian economy is the second-largest agricultural producer (fruits and vegetable products), but also has the biggest waste due to the fruits and vegetable products is perishability. They state the importance of a proper cold chain system in both storage and transportation to reduce the losses and spoiled rate. In the same way, It can make more revenue and develop the economy of Indian citizens (Negi, and Anand 2015). The integration of the Cold Chain system and Value Chain analysis in China. Value Chain analysis is used to analyze the different scenarios for constructing the direction and policy for cold chain companies. This can lead to an increase in the rate of the cold supply chain due to the growth of high-quality food that can raise the customer demand (Wang, and Yip 2018). The key success factors from the Indian food industry are developed and analyzed by ten sustainable cold chain management (SCCM). They also construct the semi-structured questionnaire for the cold chain companies. Then, they analyzed the answer from the questionnaire to descriptive statistics. So, sustainability has an impact on cold chain performance, but the customer was not aware of the benefits of low carbon emission (Shashi, Singh, and Shabani 2016). The China economy is also producing agricultural products, which are perishable and short shelf life. The current status of the cold chain system in China is not fully utilized, and also has a lot of wastes and losses. In addition, the refrigerants that are used for the cold chain system produce greatly CFCs and HCFCs (Zhao, Liu, Tian, Yan, and Wang 2018). In the American Potato Trade Alliance (APTA), they examined the business correlation of cold supply chains used for exploring new food markets in developing countries by using the on-site observation and interview by open-ended questionnaire. So, the problem that they pointed out is the lack of quality of cold storage capacity outside of the capital city and the distribution cost was expensive (Salin, and Nayga 2002). In order to analyze the cold chain in fresh agricultural products, the temperature is one of the main effects on the deterioration and has an impact on fruit quality. This paper focused on the temperature breaks in case of exporting the product from Western Cape, South Africa to America in the phases of the oranges farm to cold storage and from cold chain to the port. The analysis is measured by using the iButton to record the temperature inside the pulp of fruits and ambient temperature every 30 minutes in both phases. From the result, they conclude that to make the fruit dry after drenching and set the same temperature as in the packaging place (Goedhals-Gerber, and Khumalo 2020). Similarly, in the study of the temperature profile of an apple in the case of the Ceres district. They also used the iButton device to measure the temperature inside and outside the apples. However, this research suggested harvesting apples from 7 AM to 9 AM and delivered directly to cold storage. According to the temperature in cold storage is not stable at -0.5 °C due to the storage being regularly open and closed. So, they also suggested improving the operation of the cold chain (Valentine, and Goedhals-Gerber 2017). The quality of agricultural products and food depends on temperature. It should have any device that traces and controls the temperature, to ensure the quality of the product.

They state that Radio Frequency Identify (RFID) Tags and Time-Temperature Indicators and Integrators (TTIs) are used to integrate the time and indicate the shelf life. Temperature monitoring is used in the truck warehouse. Computational Fluid Dynamics (CFD) used to solve the industrial solid problem (Asadi, and Hosseini 2014). The possible problem that makes money lost during the broken fruit cold chain in Africa investigated by analyzing the temperature of export fruits (Apples, pears, and grapes). They focus on two segments which are the time that is taken to transport from cold storage to the port, the average time that the fruits spend in a port, and also measure the temperature in both segments. From the results, they conclude that the main possible problem is from the port, and almost a quarter of the broken cold chain occurred from 12 PM to 3 PM (Freiboth, Goedhals-Gerber, Dyk, and Dodd 2013). As the quality of the fruits physically can be degraded throughout the fruit chain for example, damage occurs during harvesting, grading, packing, and distribution to customers. The quality aspects of the overall fruit chain can be evaluated by the customer and supplier perception by using the QFD approach, which is a technique to effectively convert the voice of the consumer into a product's engineering features [14].

2.2 Forecasting and data analysis

According to China’s economic development, the trends of food consumption of Chinese citizens are also increasing. The need for food freshness, quality, and fast delivery is more than previous. They used the multiple linear regression in order to predict the demand for fresh food cold chain logistics (Hang, and Mengyao 2014). In order to know the capability of the cold chain in China. They focused on analyzing the development of the cold chain system by using the PEST, and SWOT analysis. After that, they forecasted the demand for fresh agricultural products (fruits, vegetables, milk, eggs, meat, and aquatic products) in the integration of Tianjin, Beijing, and Hebei region by the exponential smoothing methods in 6 years. From the result of exponential smoothing, they concluded that the sales of agricultural products in the future are rising and worth investing in cold chain logistics (Liu, Li, and Wei 2017). The level of the food chain in Beijing is higher than in other cities in China. So, the cold chain is important because it can ensure the food quality and quality of citizens. They analyzed the demand status for the food cold chain by using the information of per capita consumption, and wholesales market trading volume and forecasted the demand for cold storage by turnover rate of inventory. As a result, the need for refrigerated cars and warehouses does not meet the daily needs in Beijing. However, many people lacked awareness of the importance of a cold supply chain, and most of the firms might not be able to invest in the cold chain system. So, they only store and deliver by room temperature warehouse and cars (Lan, and Tian 2013). On the other hand, this research used the fundamental data and the data from the survey and predicted by analyzing the excess of cold chain storage facilities. So, the cold chain storage facilities in South Korea are excessive by 7% for the nationwide average (Son 2012).

2.3 Optimization model

There is a lot of research about optimization in the cold chain. The perishable food supply chain proposed the research to consider the optimal temperature of a storage and transportation and also consider the cost of energy consumption to optimal price and make a decision by using non-linear optimization to maximize the profit (Yang, et al., 2017). Besides, there is also some research on perishable product optimization, using a mix-integer linear programming model (MILP) to formulate the production-distribution planning with indicating an influence of the weather conditions to minimize overall cost (Riccardo, et al., 2017) another research that focus on the distribution planning to formulate the mathematical model to generate a distribution plan for fulfilling the customer requirement for various foods with quality concern by adapted biogeography-based optimization (BBO) to solve the problem and also applied the genetic algorithm (GA) to be a benchmarking method to minimize the overall cost which consist of a vehicle and product related viewpoint (Hsiao, et al., 2017). In the operation of fresh food supply chains, cold chain plays important role to reducing food spoilage and guarantee food safety then has a research focus to find the optimization model to maximize the manufacturer’s profit and the retailer’s profit and then optimize decision about investment levels of cold chain construction and advertisement, and pricing decisions (Wang, M., Zhao, L., 2021) likewise the research using MILP to optimize the overall energy consumption throughout all stages of perishable supply chain and find the routes and transportation modes to save energy on the Silk Road Belt (Gallo, et al., 2017). About transportation and vehicles, cold chain logistics has grown rapidly since high consumption. Meanwhile, the grow-up of the cold chain logistics can generate more carbon emission. The company should be focus to reduce carbon emissions while maintain customer satisfaction so, in this paper use the vehicle routing optimization model to minimize the cost of a unit satisfied customer (Qin et al., 2019). There has another research related to transportation and vehicle in cold chain by using the vehicle routing problem (VRP) to design the appropriate routes for a different group of customers for vehicles to travel in an acceptable and controllable way and meet the constraints, under the condition like quantity, time limit, vehicle limit, etc. To achieve a certain objective like the least cost, the least time (Liu et al., 2018). For emergency cold chain to optimize distribution route for minimizing the loss cost and also consider the change of driving speed in different time periods by constructed the mathematical model that including loss of vehicle, refrigeration consumption and damage of goods over time (Qi, C.M., Hu, L.S., 2020) moreover to the extension of the VRP model by combining inventory allocation problem, vehicle routing problem, and cold supply chain (CSC) is formulated, denoted as IVRPCSC Model or inventory allocation with vehicle routing problem in the Cold Supply Chain system and almost all constraints, like sub-tour elimination, vehicle availability, and feasibility constraints to identify the routes, are categorized by these variables into six key categories: variables of pickup, distribution, use, inventory, deviation, and binary routing, for minimize transportation, penalty, and inventory costs (Al Theeb, et al., 2020). The last about the environmental issue there has research that want to minimize transportation cost and also environment cost by using mathematical model and using Generalized Reduced Gradient method for solving two main problems are location of distribution center and flow of product from supplier to consumers (Matskul V, et al., 2021).

2.4 Multi-criteria decision making (MCDM)

In India, around 30% of vegetables and fruits were spoiled and become wasted because of a lack of an efficient cold chain system. The third-party logistic providers play a significant role that makes the cold chain system more efficient. To select the third-party logistics or 3PL, they used a hybrid method of Fuzzy AHP and Fuzzy TOPSIS. The Fuzzy AHP is used to rate 3PLs selection parameters. Fuzzy TOPSIS used to identify the best performance of 3PLs (Singn, Gunasekaran, and Kumar 2018). The cold third-party logistics suppliers (CTPLs) are more important for food safety and effectiveness. They formulated the processes to minimize losses and enhance food losses by Fuzzy-DEMATEL. The Fuzzy-DEMATEL is used to measure the relative weights for CTPLs and used the Fuzzy-AHP for rating the appropriate CTLPs (Raut, Gardas, Narwane, and Narkhede 2019). The Fuzzy Interpretive Structure Modeling method (FISM) is used to establish the relationship between 13 inhibitors that used the brainstorming approach followed through semi-structured interviews. The brainstorming approach is to classify the products that include most categories of perishable items (Joshi, Banwet, and Shankar 2009).

2.5 Simulation

To study the temperature fluctuation that impacts on the shelf-life of frozen shrimps by evaluating the temperature condition in four main majors of Taiwan’s home delivery services. The Monte Carlo Simulation is used to calculate the shelf life with various scenarios by using the kinetic parameter and time-temperature variability as input data. This paper concluded that temperature -18 ± 3 °C is better to preserve the frozen shrimp's shelf life (Ndraha, Sung, and Hsiao 2019). The ways to study Chinese aquatic product cold supply chain logistics performance, this research uses the SISP (Subjects, Indexes, Standards, and Phases of performance evaluation) and ACSSN (Aquatic product, Customer, Supply chain, Society, and Node enterprises of the supply chain). After evaluating the performance indexes, they calculated the weights by ANP Fuzzy. Then, they use the Vensim software to construct the system-dynamic model. By the result, they concluded that the most negative Degree Celsius (30°C) that they simulated could make a higher revenue (Wu, Deng, and Zhang 2015).

Based on all the literature reviews, an issue related to this work is the optimization in the cold chain that is distribution planning for fulfilling the customer requirement and vehicle routing problem. However, the previous researches have never considered both storage and transportation at the same time. So, it has a research gap in terms of there is no suggested storage and transport planning in the supply chain to use cold chain in particular products. Then, the possible finding of this research or research opportunities that:

- The model suggested the supply chain stages use the cold chain, but in that region is undersupply. This research should suggest building cold supply capacity.
- However, a given area that has been oversupply should recommend a way to convince supply chain stages to use cold chain capacity.
- Identify the suitable products that are worth using the cold chain capacity. The model provides proper route, storage modes, and transportation modes to use in the supply chain stages to make a high overall profit and satisfies customer demand.

CHAPTER 3
METHODOLOGY

3.1 Generic cold chain network

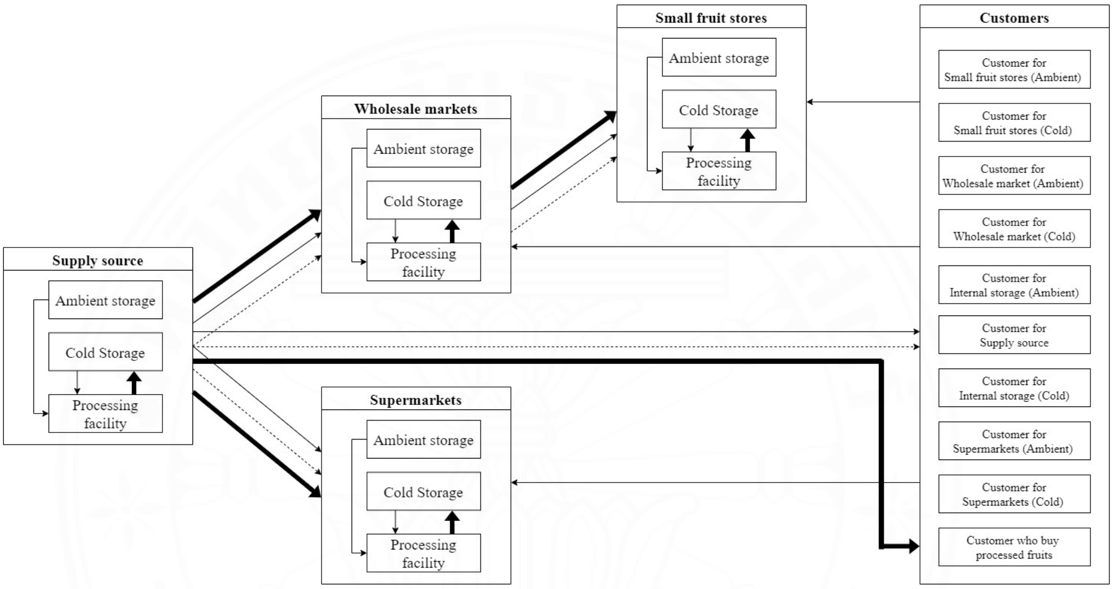


Figure 3.1 Generic cold chain network for fresh agricultural and processed fruit.

This study investigates cold chains of fruit products, including fresh fruits and some processed fruits. Processed fruits are ripe, peeled, unseeded, and ready-to-eat fruits that are packaged and usually kept cold or frozen to preserve their shelf lives. In some cases, they are further processed and filled with water, juice, and/or sweet syrups. Figure 3.1 illustrates a generic cold chain network that shows distribution of the products in common from a supply source to customers. The generic network is constructed from two sources of information, the general information on agricultural economy of each province (Official of Agricultural Economics, 2020) and in-depth interviews with supply chain members of various products. The network consists of five major groups of members: (1) supply sources, i.e., fruit farms, (2) wholesale markets, (3) supermarket, sometimes a section or department in large retail stores, (4) small (standalone) fruit stores, and (5) customers. At each node, there may be two storage modes: ambient and cold. An arc connecting any two nodes represents a transportation activity that may also be either ambient or cold. In addition, a line arc represents a flow of products at ambient temperature, while a dotted line arc is for a flow of products in a temperature-controlled environment.

The flow begins at a supply source, where fresh or processed fruits are stored in an ambient or cold storage located at the supply source before the fruits are sent to wholesale markets and supermarkets. In some cases, the supply source may send the fruits directly to these nodes without storage. Small fruit stores are local stores that do not have a direct contact with the supply source and, therefore, only purchase the fruits from the wholesale market. All nodes may sell the fruits directly to customers.

In this network, end customers (consumers) are separated into five groups: (1) customers in suburban and rural areas that purchase fresh fruit in a relatively small amount from small fruit stores, (2) customers in urban and suburban areas that purchase fresh fruit also in a small amount from supermarkets, (3) small group of customers that purchase fresh fruit in a larger amount from wholesale markets, (4) the smallest group of customers that purchase directly from the supply source and, lastly, (5) customers that purchase processed fruits. Each node may have either (or both) ambient and cold storage to store and sell the fruits to its customers according to their preference in terms.

3.2 Generic mathematical model

Model assumptions

1. Production capacity at the supply source is assumed to be a generic unit of one metric ton.
2. Storage capacity at the supply source, wholesale markets, supermarkets, and small fruit stores are unlimited.
3. In the base case scenario, customer demand of each group is estimated from in-depth interviews.
4. Wholesale markets and supermarkets do not pay for transportation costs of incoming and outgoing shipments. This is because the supply source delivers

the fruits to those nodes, and buyers from small fruit stores travel to buy the fruits from the wholesale markets.

5. Customers purchasing directly from the supply source pay for the transportation cost.
6. Customers of small fruit stores, wholesale markets, and supermarkets travel to those nodes to purchase fruits, therefore, transportation costs from those nodes and the customers are not considered.
7. Processed fruits do not have a loss from cold storage and cold transportation.
8. Customer demand for fruits kept in cold storage can only be satisfied by cold storage fruits, whereas customer demand for fruits kept at ambient temperature can be satisfied by both ambient and cold storage fruits.
9. For the total cost, the model considers only unit cost, transportation cost and storage cost.

Notation

Set of parameters

P = Set of fruits : $P = \{p_g, p_h\}$
where p_g denotes fresh fruit, and
p_h denotes processed fruits.

M = Set of transportation modes : $M = \{m_0, m_1, m_2\}$
where 0 denotes customers purchase by themselves, and
1 denotes ambient, and
2 denotes cold.

O = Set of supply source : $O = \{o\}$

S = Set of internal storage : $S = \{s_1, s_2\}$

W = Set of wholesale markets : $W = \{w_1, w_2\}$

R = Set of small fruit stores : $R = \{r_1, r_2\}$

K = Set of supermarkets : $K = \{k_1, k_2\}$

C = Set of customers : $C = \{c_{r,1}, c_{r,2}, c_{w,1}, c_{w,2}, c_{o,1}, c_{s,1}, c_{s,2}, c_{k,1}, c_{k,2}, c_{p_h}\}$

E = Set of processing facility : $E = \{e_o, e_w, e_r, e_k\}$

A = Set of transportation arcs

$$A = \left\{ \begin{matrix} (o, w_1), (o, w_2), (o, k_1), (o, k_2), (o, c_{o,1}), \\ (s_1, w_1), (s_1, w_2), (s_1, k_1), (s_1, k_2), (s_1, c_{s,1}), \\ (s_2, w_1), (s_2, w_2), (s_2, k_1), (s_2, k_2), (s_2, c_{s,1}), (s_2, c_{s,2}), (s_2, c_{p_h}), \\ (w_1, r_1), (w_1, r_2), (w_1, c_{w,1}), \\ (w_2, r_1), (w_2, r_2), (w_2, c_{w,1}), (w_2, c_{w,2}), (w_2, c_{p_h}), \\ (r_1, c_{r,1}), (r_2, c_{r,1}), (r_2, c_{r,2}), (r_2, c_{p_h}), \\ (k_1, c_{k,1}), (k_2, c_{k,1}), (k_2, c_{k,2}), (k_2, c_{p_h}) \end{matrix} \right\}$$

B = Set of transportation arcs for transportation loss between nodes.

$$B = \left\{ \begin{matrix} (o, w_1), (o, w_2), (o, k_1), (o, k_2), (o, c_{o,1}), \\ (s_1, w_1), (s_1, w_2), (s_1, k_1), (s_1, k_2), (s_1, c_{s,1}), \\ (s_2, w_1), (s_2, w_2), (s_2, k_1), (s_2, k_2), (s_2, c_{s,1}), (s_2, c_{s,2}) \\ (w_1, r_1), (w_1, r_2), (w_2, r_1), (w_2, r_2) \end{matrix} \right\}$$

N = Set of transportation arcs for transportation cost per unit between nodes.

$$N = \left\{ \begin{matrix} (o, w_1), (o, w_2), (o, k_1), (o, k_2), \\ (s_1, w_1), (s_1, w_2), (s_1, k_1), (s_1, k_2), \\ (s_2, w_1), (s_2, w_2), (s_2, k_1), (s_2, k_2), \\ (w_1, r_1), (w_1, r_2), (w_2, r_1), (w_2, r_2) \end{matrix} \right\}$$

V = Set of transportation arcs for fruit that transfer between nodes.

$$V = \left\{ \begin{matrix} (o, s_1), (o, s_2), (o, e_o), (w_1, e_w), (w_2, e_w), (r_1, e_r), (r_2, e_r), \\ (k_1, e_k), (k_2, e_k), (e_o, s_2), (e_w, w_2), (e_r, r_2), (e_k, k_2) \end{matrix} \right\}$$

Parameters

CAP_o = Capacity at a supply source o.

$D_{p,c}$ = Demand for fruit p of customer c

$L_{i,j,m}$ = Loss of fresh fruits during transportation from node i to node j with transportation mode m, $(i, j) \in B$.

l_s = Loss from storage at internal storage s.

l_w = Loss from storage at wholesale markets w.

l_r = Loss from storage at small fruit stores r.

l_k = Loss from storage at supermarkets k.

q_o = Conversion factor by weight from fresh fruit to processed fruit at supply source o.

q_w = Conversion factor by weight from fresh fruit to processed fruit at wholesale markets w.

q_r = Conversion factor by weight from fresh fruit to processed fruit at small fruit stores r.

q_k = Conversion factor by weight from fresh fruit to processed fruit at supermarkets k.

$T_{i,j,m}$ = Transportation cost per unit from node i to node j with transportation mode m, $(i,j) \in N$.

f_s = Storage cost per unit at internal storage s.

f_w = Storage cost per unit for using storage at wholesale markets w.

f_r = Storage cost per unit for using storage at small fruit stores r.

f_k = Storage cost per unit for using storage at supermarkets k.

u_o = Unit cost at supply source o.

$U_{p,i,j}$ = Unit price for fruits p from node i to node j, $(i,j) \in A$.

v = Unit cost for processing fruit.

Decision Variables

$X_{p,i,j,\mathrm{m}}$ = Amount of fruit p from node i to node j with transportation modes m, $(i,j) \in A$.

$Y_{p,i,j}$ = Amount of fruit p transfer between node i to node j , $(i,j) \in V$

$Z_{p,s}$ = Amount of fruit p that is stored at internal storages s.

$Z_{p,w}$ = Amount of fruit p that is stored at wholesale markets w.

$Z_{p,r}$ = Amount of fruit p that is stored at small fruit stores r.

$Z_{p,k}$ = Amount of fruit p that is stored at supermarkets k.

$$\text{Total profit} = \text{Total Revenue} - \text{Total Cost} \tag{1}$$

a) Supply Source

i) No storage

$$\begin{aligned}\text{Revenue} = {} & \textstyle\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \\ & \textstyle\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times \\ & X_{p_g,o,k,m}) + \textstyle\sum_{m=1}^{2}(L_{o,c_{o,1},m} \times U_{p_g,o,c_{o,1}} \times X_{p_g,o,c_{o,1},m})\end{aligned} \tag{2}$$

$$\begin{aligned}\text{Cost} = {} & \textstyle\sum_{w=1}^{2}\sum_{m=1}^{2}((u_o + T_{o,w,m}) \times X_{p_g,o,w,m}) + \\ & \textstyle\sum_{k=1}^{2}\sum_{m=1}^{2}((u_o + T_{o,k,m}) \times X_{p_g,o,k,m}) + \sum_{m=1}^{2}(u_o \times \\ & X_{p_g,o,c_{o,1},m}) + ((u_o + v) \times Y_{p_g,o,e_o})\end{aligned} \tag{3}$$

ii) Internal storage

$$\begin{aligned}\text{Revenue} = {} & \textstyle\sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times X_{p_g,s,w,m}) + \\ & \textstyle\sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \\ & \textstyle\sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,c_{s,1},m} \times U_{p_g,s,c_{s,1}} \times X_{p_g,s,c_{s,1},m}) + \\ & \textstyle\sum_{m=1}^{2}\left(L_{s_2,c_{s,2},m} \times U_{p_g,s_2,c_{s,2}} \times X_{p_g,s_2,c_{s,2},m}\right) + \\ & \left(U_{p_h,s_2,w_2} \times X_{p_h,s_2,w_2,m_2}\right) + \left(U_{p_h,s_2,k_2} \times X_{p_h,s_2,k_2,m_2}\right) + \\ & \left(U_{p_h,s_2,c_{p_h}} \times X_{p_h,s_2,c_{p_h},m_2}\right)\end{aligned} \tag{4}$$

$$\begin{aligned}\text{Cost} = {} & \textstyle\sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(T_{s,w,m} \times X_{p_g,s,w,m}) + \\ & \textstyle\sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(T_{s,k,m} \times X_{p_g,s,k,m}) + \sum_{s=1}^{2}((f_s + \\ & u_o) \times Z_{p_g,s}) + \left(f_{s_2} \times Z_{p_h,s_2}\right) + (T_{s_2,w_2,m_2} \times \\ & X_{p_h,s_2,w_2,m_2}) + (T_{s_2,k_2,m_2} \times X_{p_h,s_2,k_2,m_2})\end{aligned} \tag{5}$$

b) Wholesale markets

$$\begin{aligned}\text{Revenue} = {} & \textstyle\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}(U_{p_g,w,r} \times \\ & X_{p_g,w,r,m}) + \textstyle\sum_{w=1}^{2}(U_{p_g,w,c_{w,1}} \times X_{p_g,w,c_{w,1},m_0}) +\end{aligned} \tag{6}$$

$$(U_{p_g,w_2,c_{w,2}} \times X_{p_g,w_2,c_{w,2},m_0}) + (U_{p_h,w_2,r_2} \times X_{p_h,w_2,r_2,m_2}) + \left(U_{p_h,w_2,c_{p_h}} \times X_{p_h,w_2,c_{p_h},m_2}\right)$$

$$\text{Cost} = \sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times X_{p_g,s,w,m}) + \sum_{w=1}^{2}(f_w \times Z_{p_g,w}) + (f_{w_2} \times Z_{p_h,w_2}) + (U_{p_h,s_2,w_2} \times X_{p_h,s_2,w_2,m_2}) + \sum_{w=1}^{2}(Y_{p_g,w,e_w} \times v) \tag{7}$$

c) Small fruit stores

$$\text{Revenue} = \sum_{r=1}^{2}(U_{p_g,r,c_{r,1}} \times X_{p_g,r,c_{r,1},m_0}) + \left(U_{p_g,r_2,c_{r,2}} \times X_{p_g,r_2,c_{r,2},m_0}\right) + \left(U_{p_h,r_2,c_{p_h}} \times X_{p_h,r_2,c_{p_h},m_0}\right) \tag{8}$$

$$\text{Cost} = \sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}((T_{w,r,m} + U_{p_g,w,r}) \times X_{p_g,w,r,m}) + \sum_{r=1}^{2}(f_r \times Z_{p_g,r}) + (f_{r_2} \times Z_{p_h,r_2}) + ((T_{w_2,r_2,m_2} + U_{p_h,w_2,r_2}) \times X_{p_h,w_2,r_2,m_2}) + \sum_{r=1}^{2}(Y_{p_g,r,e_r} \times v) \tag{9}$$

d) Supermarkets

$$\text{Revenue} = \sum_{k=1}^{2}(U_{p_g,k,c_{k,1}} \times X_{p_g,k,c_{k,1},m_0}) + \left(U_{p_g,k_2,c_{k,2}} \times X_{p_g,k_2,c_{k,2},m_0}\right) + \left(U_{p_h,k_2,c_{p_h}} \times X_{p_h,k_2,c_{p_h},m_0}\right) \tag{10}$$

$$\text{Cost} = \sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \sum_{k=1}^{2}(f_k \times Z_{p_g,k}) + (f_{k_2} \times Z_{p_h,k_2}) + (U_{p_h,s_2,k_2} \times X_{p_h,s_2,k_2,m_2}) + \sum_{k=1}^{2}(Y_{p_g,k,e_k} \times v) \tag{11}$$

Constraint 1: Flow balance (the in-flow and out-flow must be equal)

$$\begin{aligned}&\sum_{s=1}^{2} Y_{p_g,o,s} + \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,o,w,m} + \sum_{m=1}^{2} X_{p_g,o,c_{o,1},m} + \\ &\sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,o,k,m} + Y_{p_g,o,e_o} = CAP_o\end{aligned} \tag{12}$$

$$q_o \times Y_{p_g,o,e_o} = Y_{p_h,e_o,s_2} \tag{13}$$

$$Y_{p_g,o,s} = Z_{p_g,s} \text{ , } \forall_s \tag{14}$$

$$Y_{p_h,e_o,s_2} = Z_{p_h,s_2} \tag{15}$$

$$\begin{aligned}&l_{s_1} \times Z_{p_g,s_1} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,w,m} + \sum_{m=1}^{2} X_{p_g,s_1,c_{s,1},m} + \\ &\sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,k,m}\end{aligned} \tag{16}$$

$$\begin{aligned}&l_{s_2} \times Z_{p_g,s_2} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,w,m} + \\ &\sum_{m=1}^{2} X_{p_g,s_2,c_{s,1},m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,2},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,k,m}\end{aligned} \tag{17}$$

$$Z_{p_h,s_2} = X_{p_h,s_2,w_2,m_2} + X_{p_h,s_2,k_2,m_2} + X_{p_h,s_2,c_{p_h},m_2} \tag{18}$$

$$\sum_{m=1}^{2}(L_{o,w,m} \times X_{p_g,o,w,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times X_{p_g,s,w,m}) = Z_{p_g,w} \text{ , } \forall_w \tag{19}$$

$$X_{p_h,s_2,w_2,m_2} + Y_{p_h,e_w,w_2} = Z_{p_h,w_2} \tag{20}$$

$$l_{w_1} \times Z_{p_g,w_1} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_1,r,m} + X_{p_g,w_1,c_{w,1},m_0} + Y_{p_g,w_1,e_w} \tag{21}$$

$$\begin{aligned}&l_{w_2} \times Z_{p_g,w_2} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_2,r,m} + X_{p_g,w_2,c_{w,1},m_0} + X_{p_g,w_2,c_{w,2},m_0} + \\ &Y_{p_g,w_2,e_w}\end{aligned} \tag{22}$$

$$Z_{p_h,w_2} = X_{p_h,w_2,r_2,m_2} + X_{p_h,w_2,c_{p_h},m_0} \tag{23}$$

$$q_w \times \sum_{w=1}^{2} Y_{p_g,w,e_w} = Y_{p_h,e_w,w_2} \tag{24}$$

$$\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{w,r,m} \times X_{p_g,w,r,m}) = Z_{p_g,r} \text{ , } \forall_r \tag{25}$$

$$X_{p_h,w_2,r_2,m_2} + Y_{p_h,e_r,r_2} = Z_{p_h,r_2} \tag{26}$$

$$l_{r_1} \times Z_{p_g,r_1} = X_{p_g,r_1,c_{r,1},m_0} + Y_{p_g,r_1,e_r} \tag{27}$$

$$l_{r_2} \times Z_{p_g,r_2} = X_{p_g,r_2,c_{r,1},m_0} + X_{p_g,r_2,c_{r,2},m_0} + Y_{p_g,r_2,e_r} \tag{28}$$

$$Z_{p_h,r_2} = X_{p_h,r_2,c_{p_h},m_0} \tag{29}$$

$$q_r \times \sum_{r=1}^{2} Y_{p_g,r,e_r} = Y_{p_h,e_r,r_2} \tag{30}$$

$$\sum_{m=1}^{2}(L_{o,k,m} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times X_{p_g,s,k,m}) = Z_{p_g,k} \text{ , } \forall_k \tag{31}$$

$$X_{p_h,s_2,k_2 m_2} + Y_{p_h,e_k,k_2} = Z_{p_h,k_2} \tag{32}$$

$$l_{k_1} \times Z_{p_g,k_1} = X_{p_g,k_1,c_{k,1},m_0} + Y_{p_g,k_1,e_k} \tag{33}$$

$$l_{k_2} \times Z_{p_g,k_2} = X_{p_g,k_2,c_{k,1},m_0} + X_{p_g,k_2,c_{k,2},m_0} + Y_{p_g,k_2,e_k} \tag{34}$$

$$Z_{p_h,k_2} = X_{p_h,k_2,c_{p_h},m_0} \tag{35}$$

$$q_k \times \sum_{k=1}^{2} Y_{p_g,k,e_k} = Y_{p_h,e_k,k_2} \tag{36}$$

Constraint 2: Requirements must be fulfilled.

$$X_{p_g,r_1,c_{r,1},m_0} + X_{p_g,r_2,c_{r,1},m_0} \ \leq \ D_{p_g,c_{r,1}} \tag{37}$$

$$X_{p_g,r_2,c_{r,2},m_0} \ \leq \ D_{p_g,c_{r,2}} \tag{38}$$

$$X_{p_g,w_1,c_{w,1},m_0} + X_{p_g,w_2,c_{w,1},m_0} \ \leq \ D_{p_g,c_{w,1}} \tag{39}$$

$$X_{p_g,w_2,c_{w,2},m_0} \ \leq \ D_{p_g,c_{w,2}} \tag{40}$$

$$\sum_{m=1}^{2} (L_{o,c_{o,1},m} \times X_{p_g,o,c_{o,1},m}) \ \leq \ D_{p_g,c_{o,1}} \tag{41}$$

$$\sum_{m=1}^{2} (L_{s_1,c_{s,1},m} \times X_{p_g,s_1,c_{s,1},m}) + \sum_{m=1}^{2} (L_{s_2,c_{s,1},m} \times X_{p_g,s_2,c_{s,1},m}) \ \leq \ D_{p_g,c_{s,1}} \tag{42}$$

$$\sum_{m=1}^{2} (L_{s_2,c_{s,2},m} \times X_{p_g,s_2,c_{s,2},m}) \ \leq \ D_{p_g,c_{s,2}} \tag{43}$$

$$X_{p_g,k_1,c_{k,1},m_0} + X_{p_g,k_2,c_{k,1},m_0} \ \leq \ D_{p_g,c_{k,1}} \tag{44}$$

$$X_{p_g,k_2,c_{k,2},m_0} \ \leq \ D_{p_g,c_{k,2}} \tag{45}$$

$$X_{p_h,s_2,c_{p_h},m_2} + X_{p_h,w_2,c_{p_h},m_0} + X_{p_h,r_2,c_{p_h},m_0} + X_{p_h,k_2,c_{p_h},m_0} \leq \ D_{p_h,c_{p_h}} \tag{46}$$

Constraint 3: Non-negativity constraints

All decision variables ≥ 0 (47)

In the model, the objective function, Equation (1), maximizes the total profit for all supply chain members. The profit is computed as the difference between revenue and cost, which includes the cost of the supply source, the cost of the processing fruits, storage costs, and transportation costs, as specified by Equation (2) – (11). The revenue and cost of supply source are calculated by adding the revenue in Equations (2) and (4) and the cost in Equations (3) and (5) for no storage and internal storage, respectively. Constraints (12) - (36) are flow balance between flow in and flow out. The flow of incoming shipments must be equal to the amount of fruits stored at the stage. The amount of fruits after storage loss and/or processing conversion factor must be equal to the total amount of fruits that are transported out of the stage. Constraints (37) - (46) are customer requirements that must be fulfilled. Because of storage and transportation losses, customers may receive the amount of fruits that are less than or equal to their demand. Constraints (47) are non-negativity constraints.

CHAPTER 4
DATA COLLECTION

This research collected data from both online and onsite information. For the reliable sources data, the agricultural fruits information from the Official of Agricultural Economics. The Department of Industrial Works provides lists of cold chain companies in Thailand. The financial statement data comes from the Department of Business Development. The Food and Agriculture Organization of the United Nations provides information on the loss rate of agricultural products. This research shows the loss rate of ambient storage is 9%, and transportation is 10%. It is 1% and 0.001% for cold storage and transportation, respectively (FAO, 2018).

In addition, additional information that cannot be obtained from official websites can be collected from supply chain members directly. Transportation and storage cost information is obtained from logistics providers such as Thai post, SCG express, Inter Express Company, and other third-party logistics providers. The ambient storage cost of the Inter Express company is 0.294 Baht per kilogram. The SCG company charges 1.800 Baht per kilogram for cold storage.

4.1 Case study for mangosteen

For the optimization model of fresh fruit, the model will set the proportion demand by 80% demand for ambient product, and 20% demand for cold product. The demand that assumes the characteristics of customer behavior for mangosteen products includes the processed products, peeled mangosteen, in each market channel are separated by five different types of customers depending on the origin nodes. The proportion of customers at small fruit stores is 30%, for wholesale markets 10%, for supply source and internal storages 25%, and for supermarkets 35%.

The parameters that are used in the optimization model for mangosteen products are given in Table 4.1. Fresh and processed product unit prices range from 29.00 to 1,346.15 Baht per kilogram from origin nodes to destination nodes. The planting cost at the supply source is 15.33 Baht per kilogram. The supply source delivered product to wholesale markets and supermarkets.at the same rate at ambient 4.00 Baht per kilogram from the Sisahy Transport. For cold transport from the Sicha group is 6.20 Baht per kilogram. The transportation costs from the wholesale markets to small fruit stores are 2.00 and 5.00 Baht per kilogram from Deliveree company in ambient and cold modes, respectively. The capacity at the supply source will be limited to 1,000 kilograms. However, the other nodes have unlimited capacity. In addition, the cost for processing consisted of material cost, labor cost, packaging cost is 22.62 Baht per kilogram. The conversion factor for the processed product is 39%.

Table 4.1 Parameters in the optimization model for mangosteen in the southern region.

Origin	Destination	Unit price (Baht/kg.)
Supply source	Wholesale market	29.00
	Supermarkets	30.00
	Customer for supply source (No storage)	75.00
Internal storage	Wholesale market	29.00
	Supermarkets	30.00
	Customer for internal storage (Ambient)	75.00
	Customer for internal storage (Cold)	85.00
	Customer who buys processed product	1,346.15
Wholesale market	Small fruit stores	45.00
	Customer for wholesale market (Ambient)	60.00
	Customer for wholesale market (Cold)	70.00
Small fruit stores	Customer for small fruit stores (Ambient)	70.00
	Customer for small fruit stores (Cold)	80.00
Supermarkets	Customer for supermarkets (Ambient)	159.00
	Customer for supermarkets (Cold)	159.00

4.2 Specific cold chain network for mangosteen

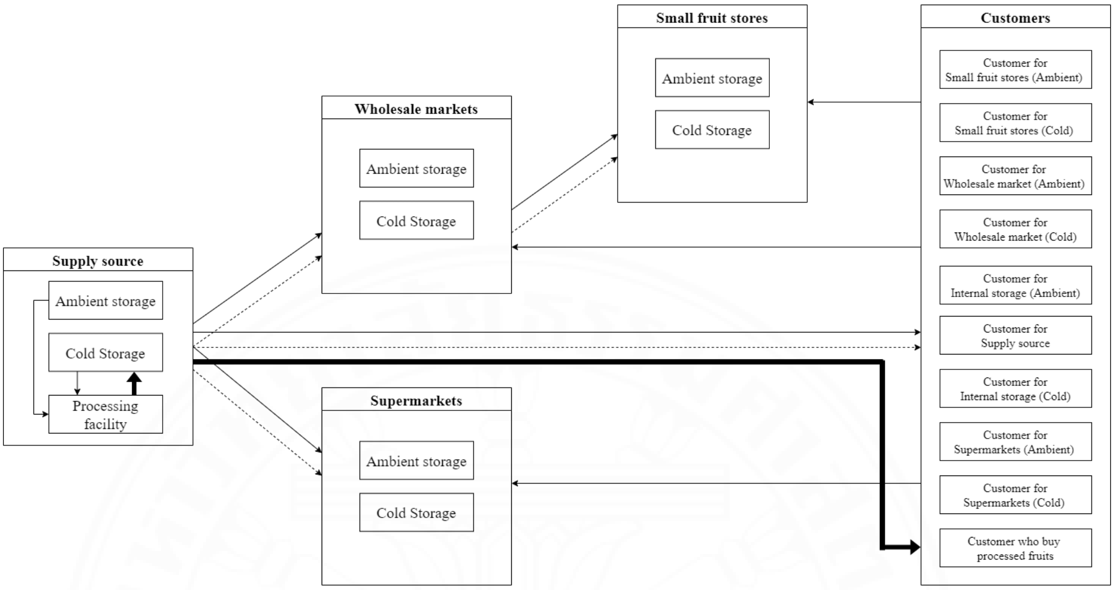


Figure 4.1 Supply chain network for fresh and processed mangosteen in the southern region.

Mangosteen is easy to buy from wholesale markets, small fruit stores, and supermarkets during harvest season. When the farmer harvested, the raw fruits mixed up with fresh ripe fruits. The fresh ripe mangosteen can be shipped to other stages on the supply chain and customer directly. The near ripe fruits should be stored in the internal storage before sending to others. Every stage in the network for the fresh fruit is necessary for mangosteen.

The farmer uses the raw mangosteen without a vein on the surface of the mangosteen for processing the peeled mangosteen. The peeled mangosteen is only processed in the supply source in Nakhon Sri Thammarat province. After they are processed and delivered for customers who buys the processed fruit (C_{ph}) directly or stored in the cold internal storage before selling to customers.

Figure 4.1 illustrates the cold chain network of mangosteen in the southern region. The network is similar to the generic network as shown in Figure 3.1. However, for the processed fruit of mangosteen, they only process at supply source and store it in internal storage before shipping to customer (C_{ph}).

4.3 Specific cold chain mathematical model for mangosteen

Additional model assumptions for mangosteen in the southern region.

1. The processed mangosteen (Peeled mangosteen) is processing at the supply source only and stored in the cold internal storage.

Notation

Set of parameters

P = Set of fruits : $P = \{p_g, p_h\}$
where p_g denotes fresh fruit, and
p_h denotes processed fruits.
M = Set of transportation modes : $M = \{m_0, m_1, m_2\}$
where 0 denotes customers purchase by themselves, and
1 denotes ambient, and
2 denotes cold.
O = Set of supply source : $O = \{o\}$
S = Set of internal storage : $S = \{s_1, s_2\}$
W = Set of wholesale markets : $W = \{w_1, w_2\}$
R = Set of small fruit stores : $R = \{r_1, r_2\}$
K = Set of supermarkets : $K = \{k_1, k_2\}$
C = Set of customers : $C = \{c_{r,1}, c_{r,2}, c_{w,1}, c_{w,2}, c_{o,1}, c_{s,1}, c_{s,2}, c_{k,1}, c_{k,2}, c_{p_h}\}$
E = Set of processing facility : $E = \{e_o\}$

A = Set of transportation arcs

$$A = \left\{ \begin{matrix} (o,w_1),(o,w_2),(o,k_1),(o,k_2),\left(o,c_{o,1}\right), \\ (s_1,w_1),(s_1,w_2),(s_1,k_1),(s_1,k_2),(s_1,c_{s,1}), \\ (s_2,w_1),(s_2,w_2),(s_2,k_1),(s_2,k_2),(s_2,c_{s,1}),(s_2,c_{s,2}),(s_2,c_{p_h}), \\ (w_1,r_1),(w_1,r_2),(w_1,c_{w,1}), \\ (w_2,r_1),(w_2,r_2),(w_2,c_{w,1}),(w_2,c_{w,2}), \\ (r_1,c_{r,1}),(r_2,c_{r,1}),(r_2,c_{r,2}), \\ (k_1,c_{k,1}),(k_2,c_{k,1}),(k_2,c_{k,2}) \end{matrix} \right\}$$

B = Set of transportation arcs for transportation loss between nodes.

$$B = \left\{ \begin{matrix} (o,w_1),(o,w_2),(o,k_1),(o,k_2),\left(o,c_{o,1}\right), \\ (s_1,w_1),(s_1,w_2),(s_1,k_1),(s_1,k_2),(s_1,c_{s,1}), \\ (s_2,w_1),(s_2,w_2),(s_2,k_1),(s_2,k_2),(s_2,c_{s,1}),(s_2,c_{s,2}) \\ (w_1,r_1),(w_1,r_2),(w_2,r_1),(w_2,r_2) \end{matrix} \right\}$$

N = Set of transportation arcs for transportation cost per unit between nodes.

$$N = \left\{ \begin{matrix} (o,w_1),(o,w_2),(o,k_1),(o,k_2), \\ (s_1,w_1),(s_1,w_2),(s_1,k_1),(s_1,k_2), \\ (s_2,w_1),(s_2,w_2),(s_2,k_1),(s_2,k_2), \\ (w_1,r_1),(w_1,r_2),(w_2,r_1),(w_2,r_2) \end{matrix} \right\}$$

V = Set of transportation arcs for fruit that transfer between nodes.

$$V = \{(o,s_1),(o,s_2),(o,e_o),(e_o,s_2)\}$$

Parameters

CAP_o = Capacity at a supply source o.

$D_{p,c}$ = Demand for fruit p of customer c

$L_{i,j,m}$ = Loss of fresh fruits during transportation from node i to node j with transportation mode m, $(i,j) \in B$.

l_s = Loss from storage at internal storage s.

l_w = Loss from storage at wholesale markets w.

l_r = Loss from storage at small fruit stores r.

l_k = Loss from storage at supermarkets k.

q_o = Conversion factor by weight from fresh fruit to processed fruit at supply source o.

$T_{i,j,m}$ = Transportation cost per unit from node i to node j with transportation mode m, $(i,j) \in N$.

f_s = Storage cost per unit at internal storage s.

f_w = Storage cost per unit for using storage at wholesale markets w.

f_r = Storage cost per unit for using storage at small fruit stores r.

f_k = Storage cost per unit for using storage at supermarkets k.

u_o = Unit cost at supply source o.

$U_{p,i,j}$ = Unit price for fruits p from node i to node j, $(i,j) \in A$.

v = Unit cost for processing fruit

Decision Variables

$X_{p,i,j,\mathrm{m}}$ = Amount of fruit p from node i to node j with transportation modes m, $(i,j) \in A$.

$Y_{p,i,j}$ = Amount of fruit p transfer between node i to node j , $(i,j) \in V$

$Z_{p,s}$ = Amount of fruit p that is stored at internal storages s.

$Z_{p,w}$ = Amount of fruit p that is stored at wholesale markets w.

$Z_{p,r}$ = Amount of fruit p that is stored at small fruit stores r.

$Z_{p,k}$ = Amount of fruit p that is stored at supermarkets k.

Mathematical model

$$\text{Total profit} = \text{Total Revenue -Total Cost} \tag{48}$$

a) Supply Source

i) No storage

$$\text{Revenue} = \sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}) + \sum_{m=1}^{2}(L_{o,c_{o,1},m} \times U_{p_g,o,c_{o,1}} \times X_{p_g,o,c_{o,1},m}) \tag{49}$$

$$\begin{aligned}\text{Cost} \quad = \quad & \sum_{w=1}^{2}\sum_{m=1}^{2}((u_o + T_{o,w,m}) \times X_{p_g,o,w,m}) + \\ & \sum_{k=1}^{2}\sum_{m=1}^{2}((u_o + T_{o,k,m}) \times X_{p_g,o,k,m}) + \sum_{m=1}^{2}(u_o \times \\ & X_{p_g,o,c_{o,1},m}) + ((u_o + v) \times Y_{p_g,o,e_o}) \end{aligned} \qquad (50)$$

ii) Internal storage

$$\begin{aligned}\text{Revenue} = \quad & \sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times X_{p_g,s,w,m}) + \\ & \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \\ & \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,c_{s,1},m} \times U_{p_g,s,c_{s,1}} \times X_{p_g,s,c_{s,1},m}) + \\ & \sum_{m=1}^{2}\left(L_{s_2,c_{s,2},m} \times U_{p_g,s_2,c_{s,2}} \times X_{p_g,s_2,c_{s,2},m}\right) + \\ & \left(U_{p_h,s_2,c_{p_h}} \times X_{p_h,s_2,c_{p_h},m_2}\right) \end{aligned} \qquad (51)$$

$$\begin{aligned}\text{Cost} \quad = \quad & \sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(T_{s,w,m} \times X_{p_g,s,w,m}) + \\ & \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(T_{s,k,m} \times X_{p_g,s,k,m}) + \sum_{s=1}^{2}((f_s + \\ & u_o) \times Z_{p_g,s}) + \left(f_{s_2} \times Z_{p_h,s_2}\right) \end{aligned} \qquad (52)$$

b) Wholesale markets

$$\begin{aligned}\text{Revenue} = \quad & \sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}(U_{p_g,w,r} \times \\ & X_{p_g,w,r,m}) + \sum_{w=1}^{2}(U_{p_g,w,c_{w,1}} \times X_{p_g,w,c_{w,1},m_0}) + \\ & (U_{p_g,w_2,c_{w,2}} \times X_{p_g,w_2,c_{w,2},m_0}) \end{aligned} \qquad (53)$$

$$\begin{aligned}\text{Cost} \quad = \quad & \sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \\ & \sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times \\ & X_{p_g,s,w,m}) + \sum_{w=1}^{2}(f_w \times Z_{p_g,w}) \end{aligned} \qquad (54)$$

c) Small fruit stores

$$\begin{aligned}\text{Revenue} = \quad & \sum_{r=1}^{2}(U_{p_g,r,c_{r,1}} \times X_{p_g,r,c_{r,1},m_0}) + \left(U_{p_g,r_2,c_{r,2}} \times \\ & X_{p_g,r_2,c_{r,2},m_0}\right) \end{aligned} \qquad (55)$$

Cost =

$$\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}((T_{w,r,m} + U_{p_g,w,r}) \times X_{p_g,w,r,m}) + \sum_{r=1}^{2}(f_r \times Z_{p_g,r}) \tag{56}$$

d) Supermarkets

Revenue =

$$\sum_{k=1}^{2}(U_{p_g,k,c_{k,1}} \times X_{p_g,k,c_{k,1},m_0}) + \left(U_{p_g,k_2,c_{k,2}} \times X_{p_g,k_2,c_{k,2},m_0}\right) \tag{57}$$

Cost =

$$\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \sum_{k=1}^{2}(f_k \times Z_{p_g,k}) \tag{58}$$

Constraint 1: Flow balance (the in-flow and out-flow must be equal)

$$\sum_{s=1}^{2} Y_{p_g,o,s} + \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,o,w,m} + \sum_{m=1}^{2} X_{p_g,o,c_{o,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,o,k,m} + Y_{p_g,o,e_o} = CAP_o \tag{59}$$

$$q_o \times Y_{p_g,o,e_o} = Y_{p_h,e_o,s_2} \tag{60}$$

$$Y_{p_g,o,s} = Z_{p_g,s} \text{ , } \forall_s \tag{61}$$

$$Y_{p_h,e_o,s_2} = Z_{p_h,s_2} \tag{62}$$

$$l_{s_1} \times Z_{p_g,s_1} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,w,m} + \sum_{m=1}^{2} X_{p_g,s_1,c_{s,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,k,m} \tag{63}$$

$$l_{s_2} \times Z_{p_g,s_2} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,w,m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,1},m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,2},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,k,m} \tag{64}$$

$$Z_{p_h,s_2} = X_{p_h,s_2,c_{p_h},m_2} \tag{65}$$

$$\sum_{m=1}^{2}(L_{o,w,m} \times X_{p_g,o,w,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times X_{p_g,s,w,m}) = Z_{p_g,w} \text{ , } \forall_w \tag{66}$$

$$l_{w_1} \times Z_{p_g,w_1} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_1,r,m} + X_{p_g,w_1,c_{w,1},m_0} \tag{67}$$

$$l_{w_2} \times Z_{p_g,w_2} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_2,r,m} + X_{p_g,w_2,c_{w,1},m_0} + X_{p_g,w_2,c_{w,2},m_0} \tag{68}$$

$$\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{w,r,m} \times X_{p_g,w,r,m}) = Z_{p_g,r} \text{ , } \forall_r \tag{69}$$

$$l_{r_1} \times Z_{p_g,r_1} = X_{p_g,r_1,c_{r,1},m_0} \tag{70}$$

$$l_{r_2} \times Z_{p_g,r_2} = X_{p_g,r_2,c_{r,1},m_0} + X_{p_g,r_2,c_{r,2},m_0} \tag{71}$$

$$\sum_{m=1}^{2}(L_{o,k,m} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times X_{p_g,s,k,m}) = Z_{p_g,k} \text{ , } \forall_k \tag{72}$$

$$l_{k_1} \times Z_{p_g,k_1} = X_{p_g,k_1,c_{k,1},m_0} \tag{73}$$

$$l_{k_2} \times Z_{p_g,k_2} = X_{p_g,k_2,c_{k,1},m_0} + X_{p_g,k_2,c_{k,2},m_0} \tag{74}$$

Constraint 2: Requirements must be fulfilled.

$$X_{p_g,r_1,c_{r,1},m_0} + X_{p_g,r_2,c_{r,1},m_0} \le D_{p_g,c_{r,1}} \tag{75}$$

$$X_{p_g,r_2,c_{r,2},m_0} \le D_{p_g,c_{r,2}} \tag{76}$$

$$X_{p_g,w_1,c_{w,1},m_0} + X_{p_g,w_2,c_{w,1},m_0} \le D_{p_g,c_{w,1}} \tag{77}$$

$$X_{p_g,w_2,c_{w,2},m_0} \le D_{p_g,c_{w,2}} \tag{78}$$

$$\sum_{m=1}^{2}(L_{o,c_{o,1},m} \times X_{p_g,o,c_{o,1},m}) \le D_{p_g,c_{o,1}} \tag{79}$$

$$\sum_{m=1}^{2}(L_{s_1,c_{s,1},m} \times X_{p_g,s_1,c_{s,1},m}) + \sum_{m=1}^{2}(L_{s_2,c_{s,1},m} \times X_{p_g,s_2,c_{s,1},m}) \le D_{p_g,c_{s,1}} \tag{80}$$

$$\sum_{m=1}^{2}(L_{s_2,c_{s,2},m} \times X_{p_g,s_2,c_{s,2},m}) \le D_{p_g,c_{s,2}} \tag{81}$$

$$X_{p_g,k_1,c_{k,1},m_0} + X_{p_g,k_2,c_{k,1},m_0} \le D_{p_g,c_{k,1}} \tag{82}$$

$$X_{p_g,k_2,c_{k,2},m_0} \le D_{p_g,c_{k,2}} \tag{83}$$

$$X_{p_h,s_2,c_{p_h},m_2} \le D_{p_h,c_{p_h}} \tag{84}$$

Constraint 3: Non-negativity constraints

$$\text{All decision variables} \ge 0 \tag{85}$$

In the model, the objective function, Equation (48), maximizes the total profit for all supply chain members. The profit is computed as the difference between revenue and cost, which includes the cost of the supply source, the cost of the processing fruits, storage costs, and transportation costs, as specified by Equation (49) – (58). The revenue and cost of supply source are calculated by adding the revenue in Equations (49) and (51) and the cost in Equations (50) and (52) for no storage and internal storage, respectively. Constraints (59) - (74) are flow balance between flow in and flow out. The flow of incoming shipments must be equal to the amount of fruits stored at the stage.

The amount of fruits after storage loss and/or processing conversion factor must be equal to the total amount of fruits that are transported out of the stage. Constraints (75) - (84) are customer requirements that must be fulfilled. Because of storage and transportation losses, customers may receive the amount of fruits that are less than or equal to their demand. Constraints (85) are non-negativity constraints.

CHAPTER 5
RESULT AND DISCUSSION

5.1 Result and discussion for fresh mangosteen

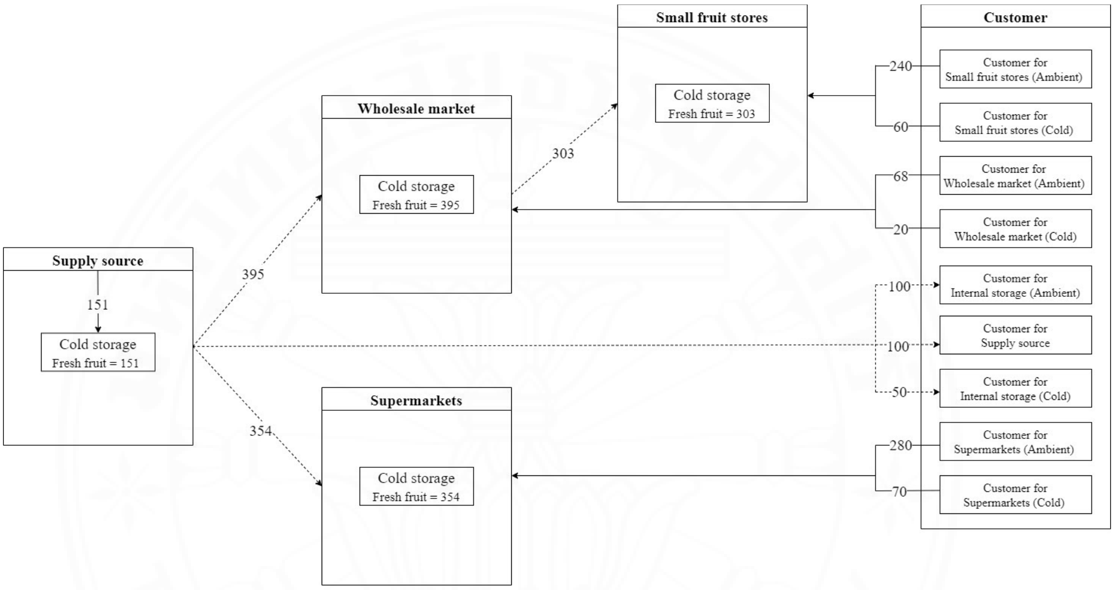


Figure 5.1 Network of fresh mangosteen in the supply chain.

Table 5.1 Data of revenue, cost, and profit for fresh mangosteen in the supply chain.

Stages in supply chain	Total revenue	Total cost	Total profit
Supply source	41,309.31	20,243.32	21,065.99
Wholesale market	19,113.91	12,164.14	6,949.77
Small fruit stores	21,600.00	15,697.12	5,902.88
Supermarkets	55,650.00	11,242.42	44,407.58
Total	137,673.21	59,347.00	78,326.21

Table 5.2 Satisfied demand of fresh mangosteen in each market channel.

Origin	Destination	Actual demand (kg.)	Satisfied demand	
			(kg.)	(%)
Supply source	Customer for supply source (No storage)	100	100	100%
Internal storages	Customer for internal storage (Ambient)	100	100	100%
	Customer for internal storage (Cold)	50	50	100%
Wholesale markets	Customer for wholesale market (Ambient)	80	68	85%
	Customer for wholesale market (Cold)	20	20	100%
Small fruit stores	Customer for small fruit store (Ambient)	240	240	100%
	Customer for small fruit store (Cold)	60	60	100%
Supermarkets	Customer for supermarket (Ambient)	280	280	100%
	Customer for supermarket (Cold)	70	70	100%

Discussion

After we performed the experiment for a fresh fruit by mixed-integer linear programming in the Excel Open Solver, the model suggested routes and modes of storage and transportation, as shown in the Figure 5.1 above. The supply source sent the fresh mangosteen to the cold internal storage by 151 kilograms, wholesaler markets by 395 kilograms, and supermarkets by 354 kilograms with cold transportation mode including customers that received 100 kilograms of fresh mangosteen from the supply source directly. The cold internal storage delivers 100 kilograms to customers for internal storage in ambient mode and another 25 kilograms for customers in cold demand mode. Small fruit stores received 303 kilograms of fresh fruit from the wholesale markets with cold transportation. Cold transport is used to deliver fresh mangosteens. The loss of cold transportation is only 0.001%, so the amount of fresh fruits that remain in storage is almost the same. According to the model assumptions, customers of small fruit stores, wholesale markets, and supermarkets travel to those nodes to purchase fruits, so the amount of product that is sent to the customer can be satisfied by almost all customer demand except for wholesale markets in ambient mode that can be satisfied only 85% as shown in the Table 5.2. Since we had losses during storage and transport and limited the capacity of the supply source. The model suggested to satisfy the demand of customers for wholesale markets in the cold mode because it makes a higher profit.

Table 5.1 shows the data of revenue, cost, and profit for fresh mangosteen in the supply chain. The revenue of the overall supply chain is 137,673.21 Baht, while the cost is 59,347.00 Baht that makes a maximum total profit of 78,326.21 Baht in the overall supply chain stage. Supermarkets are the stage that has the highest revenue and profit which are 55,650.00 Baht and 44,407.58 Baht, respectively. Since, this stage has the highest customer demand and unit price. The highest cost is 20,243.32 Baht from the supply source stage because wholesale markets and supermarkets do not pay for incoming fruits from the supply source. The total cost, revenue, and profit of wholesale markets, small fruit stores are also shown in a summary Table 5.1 above.

5.2 Result and discussion for fresh and processed mangosteen

For the optimization of the extension model for fresh fruit and processed fruit, the model will set the proportion demand by 80% demand for ambient product, 10% demand for cold product, and 10% demand for processed fruit.

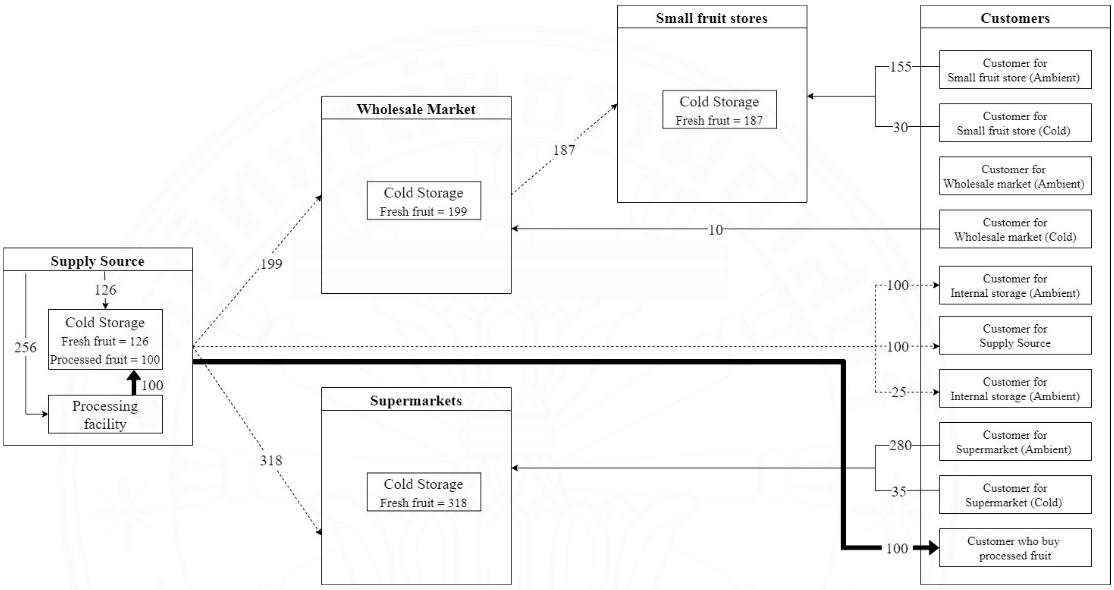


Figure 5.2 Network of fresh and processed mangosteen in the supply chain.

Table 5.3 Data of revenue, cost, and profit for fresh and processed mangosteen in the supply chain.

Stages in supply chain	Total revenue	Total cost	Total profit
Supply source	167,060.45	24,744.69	142,315.76
Wholesale market	9,121.59	6,133.45	2,988.15
Small fruit stores	13,269.12	9,694.18	3,574.94
Supermarkets	50,085.00	10,118.18	39,966.82
Total	239,536.17	50,690.50	188,845.66

Table 5.4 Satisfied demand of fresh and processed mangosteen in each market channel.

Origin	Destination	Actual demand (kg.)	Satisfied demand	
			(kg.)	(%)
Supply source	Customer for supply source (No storage)	100	100	100%
Internal storages	Customer for internal storage (Ambient)	100	100	100%
	Customer for internal storage (Cold)	25	25	100%
Internal storage with cold storage	Customer who buys processed fruit	100	100	100%
Wholesale markets	Customer for wholesale market (Ambient)	80	0	0%
	Customer for wholesale market (Cold)	10	10	100%
Small fruit stores	Customer for small fruit store (Ambient)	240	155	65%
	Customer for small fruit store (Cold)	30	30	100%
Supermarkets	Customer for supermarket (Ambient)	280	280	100%
	Customer for supermarket (Cold)	35	35	100%

Discussion

After applying the data from Table 4.1 to the extension model by using mixed linear programming in the Excel Solver, the model suggested the routes, storage and transportation mode for the fresh and processed fruit model. Figure 5.2 illustrates that the supply source transports the fresh mangosteen for wholesale markets by 199 kilograms and supermarkets 318 kilograms in cold transportation mode. Likewise, small fruit stores transport 187 kilograms with cold transportation. The supply source stores the fresh mangosteen at the cold internal storage for 126 kilograms and processing for 256 kilograms. To process the peeled mangosteen, the conversion factor is 39%. After processing, 100 kilograms of processed fruits are kept in the cold storage. The customer receives 100 kilograms of fresh fruit directly from the supply source with cold transportation mode. Cold internal storage delivers 100 kilograms to customers for ambient demand, 25 kilograms to customers for cold demand, and lastly, 100 kilograms for processed fruit of customers who buy processed fruit by cold transportation. Wholesale markets, small fruit stores, and supermarkets stored the product in the cold mode of storage. This model can satisfy all customers including the customer who buys the processed product. From table 5.4, the model cannot satisfy the demand of customers for wholesale markets in ambient mode at all and satisfy the customer for small fruit stores in ambient mode only 65%. According to the limitation of capacity at the supply source, the model suggested satisfying the customer who buys processed fruit first because the unit price of selling processed fruit is high and makes more profit to the supply chain.

Table 5.3 distributes the data of revenue, cost, profit for fresh mangosteen and processed fruit in the supply chain. The total revenue from overall stages is 239,536.17 Baht, while the cost is 50,690.50 Baht that makes the overall profit is 188,845.66 Baht. According to the peeled mangosteen that processes at the supply source stage, this stage makes the maximum revenue and profit which are 167,060.45 Baht, and 142,315.76 Baht. However, the supply source is the stage that has the highest cost because the supply source transports fresh fruit to wholesale markets and supermarkets. So, the cost at the supply source is higher than other stages of the supply chain which is 24,744.69 Baht.

In summary, the model suggested that cold transportation and storage be used to increase profitability. In addition, the use of proper cold chain systems can extend the shelf life and maintain the quality of fresh mangosteen. However, the cold chain systems still have a loss from transport and storage but less than in ambient mode. Therefore, the processed fruit must be stored and transported in cold mode, so the proper cold chain system should be provided to support all the supply chain members to maximize the overall total profit. In this case, the model limited the capacity of the supply source to be 1,000 kilograms, the number in the model is sufficient to support in the cold storages and also the cold transportation.

5.3 Sensitivity analysis for fresh mangosteen

5.3.1 The comparison of total profit between base case and extreme case of ambient spectrum

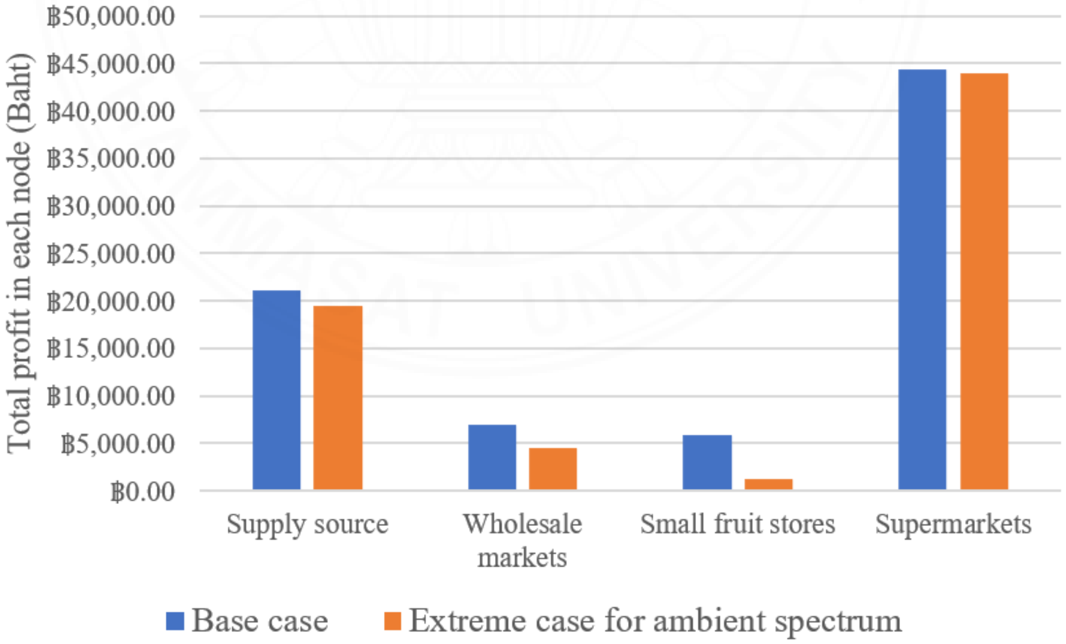
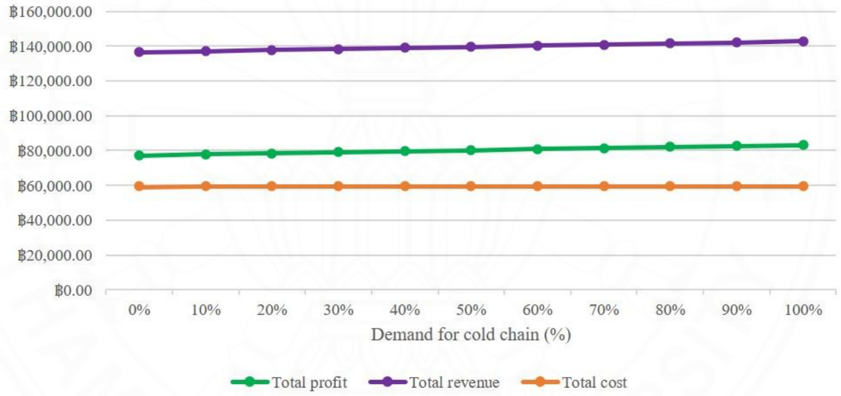


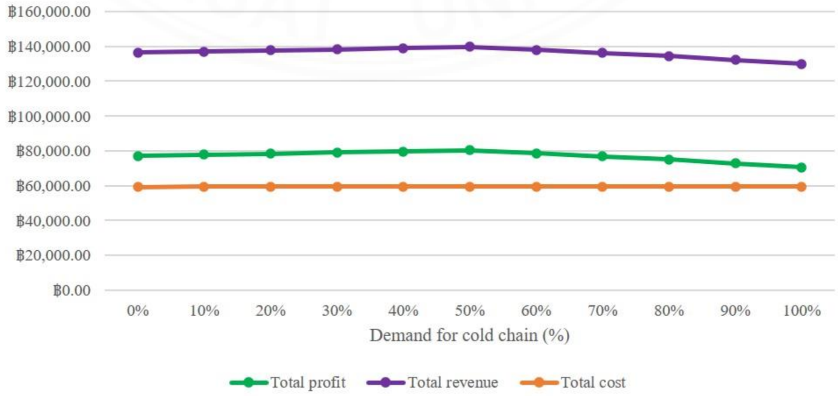
Figure 5.3 Comparison of the total profit between base case and extreme case of ambient spectrum in each node of the supply chain.

When comparing the total profit of the base case of fresh fruit and extreme case of ambient spectrum (no cold allowed) in each node as shown above. The total profit in case no cold is allowed in the network is less than the profit in base case because the product will be wasted from both storage and transportation there will be fewer products left for sale and selling products at a low price and if there is a cold chain in the system (cold storage and cold transport) the profit will increase because the cold chain can help to maintain the quality of the fresh fruits and extend the shelf life including value-added to the product. Based on each graph in Figure 5.3 above, the highest profit is on the supermarket nodes.

5.3.2 Sensitivity analysis of demand and price



Sensitivity analysis of demand
Mangosteen (Southern region)
(a)



Sensitivity analysis of demand and price
Mangosteen (Southern region)
(b)

Figure 5.4 Sensitivity analysis of demand and price for fresh mangosteen.

According to the Figure 5.4 (a) demonstrates the relationship between the adjustable percentage of demand sensitivity from 0% to 100 % compared with the total profit, revenue, and cost for fresh mangosteen in southern region. The trend of total profit seems to be gradually increasing from the demand of 0% to 100% for cold chains, which means if the demand of mangosteen that uses the cold chain system is increased, the total cost will increase. Meanwhile, the unit price of selling cold products is higher than ambient products, which means the overall revenue and profit will also be increased. The models suggest using both cold storage and cold transport in every scenario for fresh mangosteen.

Then, we will consider the sensitivity of price for fresh fruit demand as shown in Figure 5.4 (b), if there is more demand in the cold chain, the supply of fresh products should increase, but the unit price will be decrease at the end of the supply chain toward the customer. Next, we try to adjust the data to be more reasonable in the case of sensitivity analysis of price for demand by assuming that if demand for cold chain rises to 60%, cold product prices will decrease linearly until cold demand for cold chain reaches 100%. Unit prices for cold product will be equal to unit price for ambient product at all stages, apart from supermarkets, where cold and ambient prices have been equal since the beginning. After that total revenue and total profit tend to decrease because we sell the product at lower unit price.

When we adjusted the unit price of cold products, we discovered that the model still recommends the same decision in every scenario that includes both cold storage and cold transportation in the supply chain. Although the unit price for cold products is reduced to the same as the unit price for ambient products and the use of a cold chain may be slightly reduced, but the model still uses a cold chain, which means the cold chain is robust.

5.3.3 Sensitivity analysis of loss storage

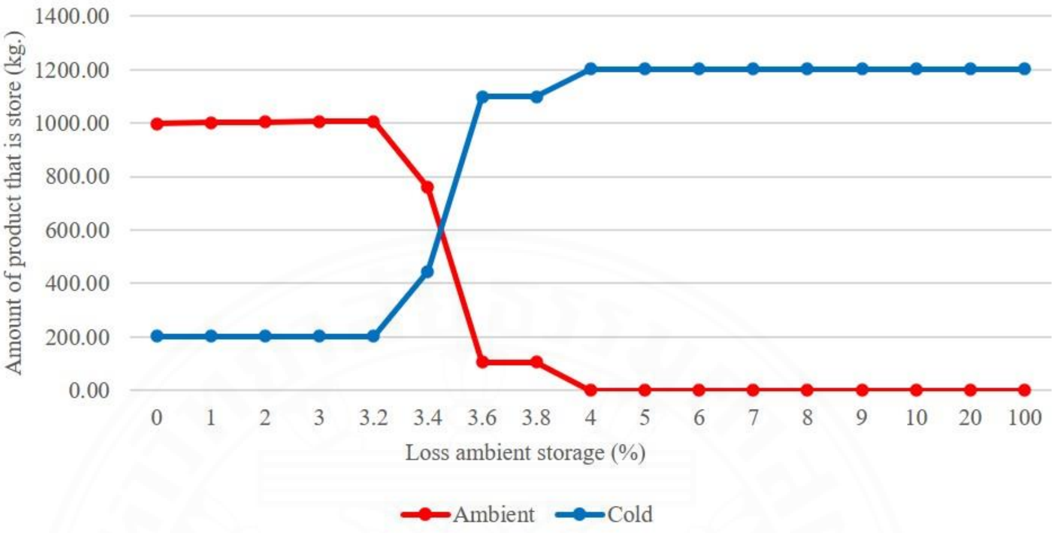


Figure 5.5 Sensitivity analysis of loss storage for fresh mangosteen.

For the sensitivity analysis of loss rate in storage with ambient mode for fresh mangosteen as shown in Figure 5.5 above. This relationship between ambient storage loss compared with amounts that are stored in both cold and ambient modes can state that when the loss rate increases, the model will change the decision from the ambient mode to use the cold mode instead, because when stored in the ambient mode, the cost of storage is lower than in the cold mode. From the graph shows that when storage loss rate is 3.4% for mangosteen, there will change the decision in mode of storage that changes from using ambient mode to using the cold storage instead to keep the quality or freshness of the product when stored in the storage. Therefore, the figure above can conclude that the model suggests storing the product in a cold chain system when it reaches the proper ambient storage loss for fresh mangosteen.

5.3.4 Sensitivity analysis of loss transportation

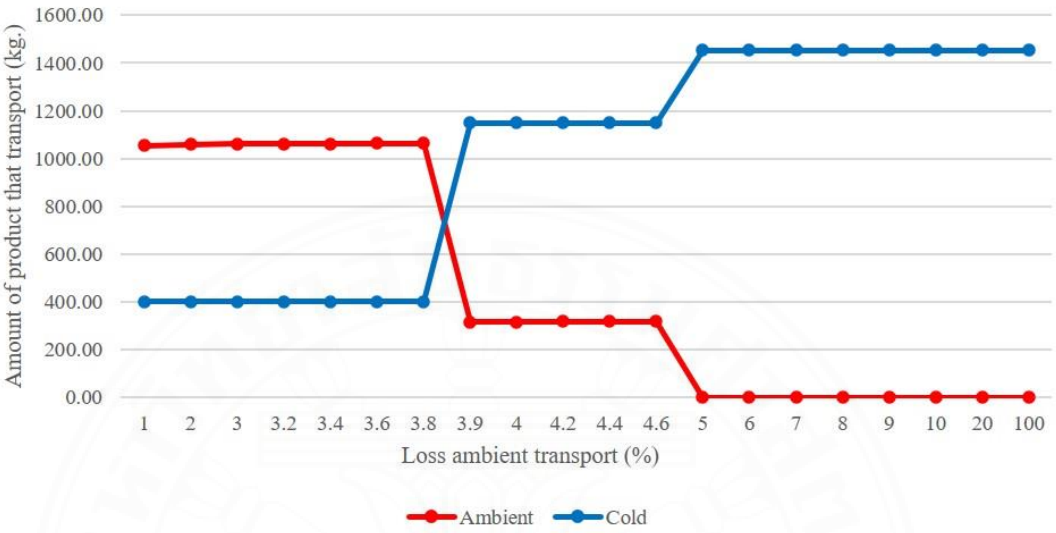


Figure 5.6 Sensitivity analysis of loss transportation for fresh mangosteen.

From Figure 5.6 above, this relationship between the amount of product that is transported (X) and the loss rate for ambient transportation can state that when the loss rate is increased, the model will change the decision from the ambient mode to use the cold mode instead. The value that makes the decision change for fresh mangosteen from 3.8% to 1%, there will be more products delivered in the ambient rather than in a cold transportation mode. From the base case model, we used the transportation loss of the ambient model for 10%. The model suggested delivering the product in a cold chain system.

5.4 Sensitivity analysis for processed mangosteen

5.4.1 Sensitivity analysis of processed price

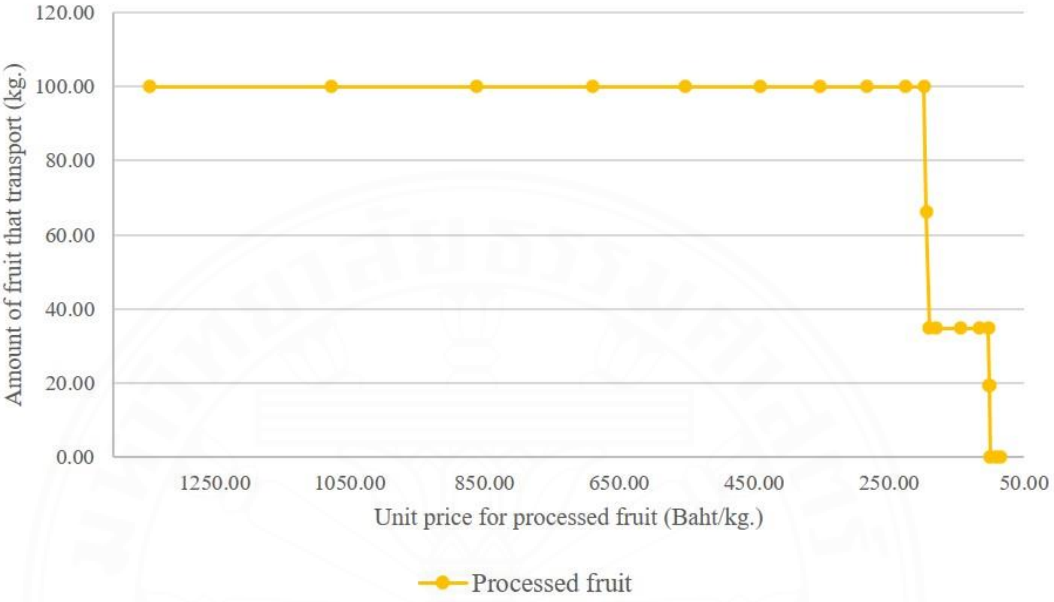


Figure 5.7 Sensitivity analysis of price for processed mangosteen.

Figure 5.7 illustrates the sensitivity analysis of price for processed fruit or peeled mangosteen. The model suggests to satisfy the demand of customers who buy processed fruit when the unit price for selling peeled mangosteen is 1,346.15 Baht per kilogram until the price is decreased to 198.00 Baht per kilogram. When the unit price was less than 198.00 baht per kilogram, the model suggested processing the fruit at only 66.28 kilograms. Whenever the unit price is reduced to 190.00 Baht per kilogram, the supply source will process the fruit for 34.77 kilograms. However, the model would not suggest processing the fresh fruit, if the unit price for processed fruit reduced to 100.00 Baht per kilogram. The model indicates that the unit price for processed mangosteen should not be less than 198.00 baht per kilogram because processing the fresh fruit has higher cost and the conversion factor of 39%. It is not worthwhile to process fresh fruit if the price is less than 198.00 Baht per kilogram.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In this study, cold chain implementation will provide more benefits to supply chain members by increasing the value added to agricultural products and aiming to maximize the total profit of the entire agricultural supply chain. A mixed integer linear programming model has been developed to suggest a plan for using cold chain management for both storage and transportation. In addition, the model can suggest which area or stage should be used for the cold chain in both storage and transportation by showing the route as decision making, and if there is no service provider for the cold chain in the suggested area, there will be a chance to increase capacity to gain more profit for the supply chain members. After optimizing the model for fresh agricultural products, we extended the model by optimizing the processed products that aim to make agricultural products more marketable and attractive to potential customers and using cold chains to extend their shelf life and maintain the quality of the processed product.

In order to gain the maximum total profit and maintain the quality of the product, the result of fresh mangosteen suggest that we should use cold chain management in the supply chain.

6.2 Recommendation

Based on the results, if supply chain members invest more in the cold chain, they will be able to provide a higher quality product available to customers and the products with high quality will be more expensive. This research can help convince and encourage them to use the proper cold chain systems in order to maintain the product quality, reduce perishables and increase the value of agricultural products.

For further research direction, extend the scope of the problem by adding more factors or information that is related to the supply chain problem to make the model more realistic and study various products with a high potential to involve cold chain management in their system.

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