OPTIMIZATION OF FRUIT COLD CHAIN MANAGEMENT: A CASE STUDY OF MAYONGCHID SUPPLY CHAIN IN CENTRAL THAILAND

BY

MS. PIMPITCHA THIENSIRI

AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER ENGINEERING (LOGISTIC AND SUPPLY CHAIN SYSTEMS ENGINEERING)

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ENTITLED

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

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Ms. Pimpitcha Thiensiri

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

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 products for a period while waiting to be transported to other members in the supply chain and customers. Cold transportation is responsible for transporting products from the origin node to the destination node. 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.

1.1 Problem statement

Thailand is an abundant country with a diverse geography and natural resources that make the area suitable for agriculture. Most of Thailand's labor is employed in agriculture. According to the Ministry of Agriculture and Cooperatives (2020), Thailand has 8,094,954 agriculturist households with 9,368,245 agriculturists. As for agricultural holdings in Thailand, the National Statistical Office (2018), there were approximately 112.8 million rai of agricultural area, which indicates that Thailand is an agricultural country. Thailand has many agricultural products such as fruits or vegetables, but Thailand is a country in Southeast Asia that is a tropical country. Heat and humidity can have an impact on these products, making them more susceptible to spoiling or deterioration, which decreases the opportunity for profit. However, producers must keep a product's quality as high as possible in order to maximize its value, sell it at a reasonable price, and satisfy customers. Therefore, it is necessary to apply an approach to help maintain the quality of the product for a long time before the producer can deliver the product to the customers. The suitable solution to solve this problem is cold chain management. Although, cold chain logistics in Thailand are at a low level but Thailand also has potential for the temperature-controlled in the food supply chain from the geographical and location advantages, according to an article published by the Board of Investment of Thailand (BOI 2017a). However, the main problem in Thailand is unbalanced supply and demand for cold storage and there might be a gap between producers transporting agricultural products to the customers. According to the supplier's point of view, it could lead to an oversupply. The cold storage might not be used efficiently scattered around places in Thailand. And for the demand side, there might not be enough cold storage. So, some entrepreneurs might need to invest more in the cold chain system. Furthermore, Buawat (2020) stated that there is only 10% of Thailand is using cold chains, but there is an increasing trend to use cold chains around 2019-2025. By having a cold chain both supply and demand can maintain quality, preventing spoilage, and also increasing the value of the product that is preferred to have the opportunity to sell more products at a higher price.

This research focuses on increasing the value of agricultural products by maximizing the overall profit of the supply chain and satisfying the customer demand in the supply chain of agriculture while maintaining the quality of the product as much as possible by using cold chain management and then using a mixed integer linear programming (MILP) model and excel (open solver) to solve the problem.

Also, this research involves a case study of the agriculture supply chain in the central region of Thailand. Consider using cold chains in fresh and processed fruits Furthermore, sensitivity analysis on some input parameters that affect the objective model is performed.

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 fresh and processed fruits in the central region of Thailand by considering an aggregate plan to use the cold chain in the supply chain for fresh and processed agricultural products. In the central region, the suitable fruit is mayongchid and can be processed into a ready to eat mayongchid that will peel and remove the seed.

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 facility 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 Mayongchid in the central region of Thailand.

The suitable product that is selected from Nakhon Nayok province in the central region of Thailand is Mayongchid, also known as Thai Plango in English, which is derived from the combination of plum and mango because Mayongchid has an orange and yellow color with a sweet and sour taste. According to the Office of Agricultural Economics (2019), the productivity of mayongchid is around 2,817.47 tons with an average of 382 kilogram per rai and Nakhon Nayok province has the highest productivity of mayongchid in Thailand with 1,074.10 tons or around 40% of the productivity of mayongchid in Thailand. Mayongchid has a high market demand, both domestic and international, and a relatively high selling price, which is considered a product that can provide income and profit for farmers in Nakhon Nayok province because it is a seasonal fruit that will be available only from January to March, but this type of fruit has a very short shelf life in the room temperature around 3-5 days.

Figure 1.1 Mayongchid in the central region of Thailand.

1.4.2 Ready to eat (peel mayongchid and remove seed)

Mayongchids are generally eaten fresh because they are the most delicious or when refrigerated, they will be more delicious with the taste of the fruit itself. So, ready to eat mayongchid product that will peel and remove the seed inside will increase and add more value to this agricultural product and the unit price will be around 500 Baht per kilogram that is more expensive than the unit price of raw material, but this product has to use a cold chain that will prevent spoilage because if the peel mayongchid is left overnight. The next day, there is a risk that it will be spoiled because the enzymes in the mayongchid will break down their own tissues and dehydrate. This will make the flavor less and eventually fade away. As a result, a cold chain is required to keep them longer and increase their shelf life along with increasing their profitability.

Figure 1.2 Ready to eat (peel mayongchid and remove seed)

1.5 Overview of research

The research is divided into six chapters, described as follows:

Chapter 1 Introduction: to introduce the overview of this research including problem statement, research objective, scope of research and product overview.

Chapter 2 Review of literature: review of the previous research literature that related to research topics that will help to identify the research gap of the research.

Chapter 3 Methodology: represent the generic cold chain network, model assumption and followed by mathematical models.

Chapter 4 Data collection and case study model: explained the data collection of the case study and the specific cold chain network and mathematical model for mayongchid in the central of Thailand.

Chapter 5 Result and discussion: show the result from optimization model and sensitivity analysis on some input parameters.

Chapter 6 Conclusions and recommendations: conclude the optimal solution that model recommends verbally to the user or supply chain member by word and recommendation to manage supply chain for the benefit of individual members also the benefit of the customer and recommend for further research.

CHAPTER 2
REVIEW OF LITERATURE

A brief overview of some recent papers about Cold chain management is discussed in this section and can be classified into five groups by the methodology. Firstly, a qualitative study is provided, followed by forecasting and data analysis, optimization model, multi-criteria decision making (MCDM) and simulation.

2.1 Qualitative study

The cold chain is an important issue in the food industry that use in maintaining the quality of the perishable product in many countries, also in India. Saurav et al. (2015), said that the Fruits and Vegetable market in India seems to be a very leading economy but India is one of the world's major trash producers because these items are perishable and have a short shelf life, so the cold chain will play an important part in the Indian supply chain by minimizing food losses and wastes to increase the revenue and improve the economy. For the same goal, Shashi et al. (2016) developed and analyzed ten sustainable cold chain management (SCCM) to identify the effective motivational indicators for the Indian Food Industry in sustainable cold-chain management by formulated a semi-structured questionnaire and sent out by postal to the member of perishable food products. Additionally, Rohit et al. (2010) use a survey method to approach and collect the data by using the questionnaire and then analyzed to the awareness and habit of consumers in India with the terms of handling the perishable product at homes. In the same field but different country and business, Salin et al. (2003) have provided the case study for the American Potato Trade Alliance (APTA) to examine the corporate partnerships used for exported goods to new developing countries and to enhance export opportunities for frozen potato products by using the method of on-site observations and analyze the result. Another country where generally an agricultural country been, which also produces a large number of perishable products in China. Hongxia et al. (2018) use an official report and made a survey to investigate the current situation for the cold chain in China and suggested that production in China is not effectively implemented since there are huge losses and waste, despite the fact that there is no way to estimate the quantity. Other researchers like Kelly et al. (2018) also applied value-chain analysis to analyze different three scenarios in China to construct the direction and policy for cold chain companies to see that the reason for food to be degraded is because of the broken cold chain. Additionally, Freiboth et al. (2013) studied the potential issue that is causing money to be lost during the broken fruit cold chain in Africa by analyzing the temperature of export fruits. For more literature about the Cold chain, Valentine et al. (2017) studied the temperature profile of the 24 hours after harvest of apples that affect the quality of apples by interviewing the three apple farms and use the iButton device to test the inside and outside temperature of the two different apples. Moreover, in New Zealand, James et al. (2018) studied the research and the current situation for the cold chain n in New Zealand because mainly export food products and 60% exported in refrigerated condition with regulation that will cover the standard temperature control for various food products. And also, Samuel et al. (2017) have studied the efficiency of cold storage in a food chain by review many recent developments articles and proposed the highlight of weakness in the cold chain system, accurate forecast in operating to decrease waste based on time and temperature and studied about cold chain systems in developing countries. Additionally, Gholamhassan et al. (2014) studied the quality of food and agricultural product depend on the temperature of the product, to ensure that the food safety and to preserve the product’s quality, it should trace and control the temperature and HEAP (2006) considered in a transport and storage of a perishable product and pharmaceutical issue of cold chain requirement that has to be a success and present about the weakness in cold chain environment issue, the emission of CO_2. Ilija et al. (2019) have recently analyzed the understanding of consistency in the apple fruit chain and measured it using the QFD approach, which is a technique to effectively convert the voice of the consumer into a product's engineering features.

2.2 Forecasting and data analysis

According to Tongjuan et al. (2017) considering in Beijing-Tianjin-Hebei integration with analyzing the development and forecast strategy of cold chain logistic demand of agricultural products to analyze on development agricultural of cold chain logistic by using PEST analysis, SWOT analysis, and strategic combination of cold chain logistic development and to analyze to predict the demand of the agricultural product in three areas mentioned above by using exponential smoothing method. Yin et al. (2014) mentioned that efficient fresh food in cold chain logistics is important to meet customer demands. So, this paper will investigate bottlenecks, predict, and analyze the demand for cold chain logistics. They need to be considered to predict demand by using a comparison of prediction methods and the conclusion is multiple linear regression. Leila et al. (2020) identifies there are temperature breaks and spikes in navel orange exported from South Africa to the United States of America by monitors and analyzing the temperature inside the oranges and temperature inside cartons by using temperature monitors, iButtons to record both temperature data every 30 min during the export cold chain. Through evaluating the shortage and demand forecast of capabilities for refrigerated conditions in South Korea, Chang-Hyo Son (2012) used basic data and survey data for long-term development prediction. Lan et al. (2013) analyzes the demand status for the food cold chain (warehouse and transportation) and forecast the demand for cold chain by this paper investigated 152 cold chain logistics companies in Beijing. The analysis shows that the demand for the food chain is increasing dramatically. However, the capacity of cold chain storage and logistics is not sufficient for the demand.

2.3 Optimization model

Other researchers studied the optimization in the Cold supply chain by using mathematical modeling to analyze and solve the terminal logistic distribution problem based on a joint distribution node and involve VRP or vehicle routing problem that design the proper routes for a different group of customers like Liu et al. (2018). In the same field, Al et al. (2020) have provided an extension for the VRP by including many constraints for the Cold supply chain system to the model like various capacities, speeds, and quantities to transportation of chilled products in different commodities, periods, fixed cost and demand for the customer, and the model that these authors use is inventory allocation with VRP in the cold supply chain system (IVRPCSC), it shares almost all constraints with the classical VRP to identify the routes for reducing the overall cost, including transportation, fine, and inventory costs. To achieve the same objective, Accorsi et al. (2017) suggested using the mixed-integer linear programming (MILP) model for product packaging, refrigerated storage, and delivery. Similarly, Gallo et al. (2017), also use the MILP model with a different objective that is to optimize the total consumption of energy in all processes of the supply chain, including the process from the product start to transportation activities. Additionally, Yang et al. (2017) studied a model to determine a suitable temperature in the refrigerator storage and transport and also calculated the optimal maximum profit through a math model. Another research project, Hsiao et al. (2017) focuses on distribution planning to formulate a mathematical model to generate a distribution plan for fulfilling the customer requirements for various foods with quality concern by adapting biogeography-based optimization (BBO) to solve the problem and also applying the genetic algorithm (GA) to be a benchmarking method to minimize the overall cost, which consists of a vehicle and product related viewpoint. Because of its high consumption, cold chain logistics has grown rapidly in terms of transportation and vehicles. Meanwhile, the growing-up of cold chain logistics could generate more carbon emissions and cause the environmental issue. Qin et al. (2019) suggest that the company should be focus to reduce carbon emissions while maintain customer satisfaction by using the vehicle routing optimization model to minimize the cost of a unit satisfied customer and Matskul et al. (2021) 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. Currently, Wang and Zhao (2021) want to optimize profitability for supply chain participants, an optimization model for a food supply chain has been developed. Because they believe that cold chains are a significant investment that must consider both cost and benefit, which will be a significant part in decreasing wastage and ensuring food quality in supply chains. Qi and Hu (2021) optimize distribution routes to minimize the loss cost and also consider the change of driving speed in different time periods by constructing a mathematical model that includes loss of vehicle, refrigeration consumption and damage of goods over time.

2.4 Multi-criteria decision making (MCDM)

Some research implies that instead of optimizing the cold chain, it is better to use Multiple-criteria decision analysis to identify and selection of third-party logistic providers (3PLs) for the cold chain because, in the cold chain management, 3PL will be operated in completely unpredictable and fuzzy circumstances. According to Singh et al. (2018), the hybrid method composed of Fuzzy AHP and Fuzzy TOPSIS is used for the collection of 3PLs in a cold chain system. Fuzzy AHP is applied to rate various 3PLs selection parameters, and then Fuzzy TOPSIS is applied to identify the highest performance-based of 3PLs. Joshi et al. (2009) studied the inhibitors of the productive cold chain and developed the inhibitor relationship and dependence by using the Fuzzy Interpretive Structure Modeling (FISM) method. Recently, Raut et al. (2019) have proposed a model of Fuzzy-DEMATEL which is used to measure the equivalent sizing of the different variables for third-party logistic providers in the cold supply chain management and Fuzzy AHP to minimize losses in the fruits and vegetable.

2.5 Simulation

Nodali et al. (2019) conducted to discover and analyze the temperature fluctuation's effect on the temperature's residual shelf life that is suitable for maintaining the quality of frozen shrimp during the shipment because the temperature control throughout shipment can increase and maintain the food quality. Therefore, in this research, four major home delivery service companies in Taiwan have evaluated the temperature situation. Additionally, Wu et al. (2015), combined the cold chain logistics with the traditional performance by using the SISP model and ACSSN model to evaluate all indexes and performance and use ANP-fuzzy to evaluate operational performance and to develop cold chain logistics in China due to the impact on the aquatic products.

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 research has 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 and the possible finding of this research are described as follows:

- The research suggested the supply chain members use the cold chain. If there is an undersupply in that area, this research would suggest building more cold supply capacity. However, if the given area has been oversupply, this research would recommend a way to convince supply chain members to use cold chain instead of the normal or ambient supply chain.
- Identify the suitable products that are worth using the cold chain. The model provides proper route, storage modes, and transportation modes to use in the supply chain to make maximum overall profit and satisfies the customer demand.

CHAPTER 3
METHODOLOGY

3.1 Generic cold chain network

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 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 of fruit storage temperature and forms of fruit (fresh, ready-to-eat, or processed).

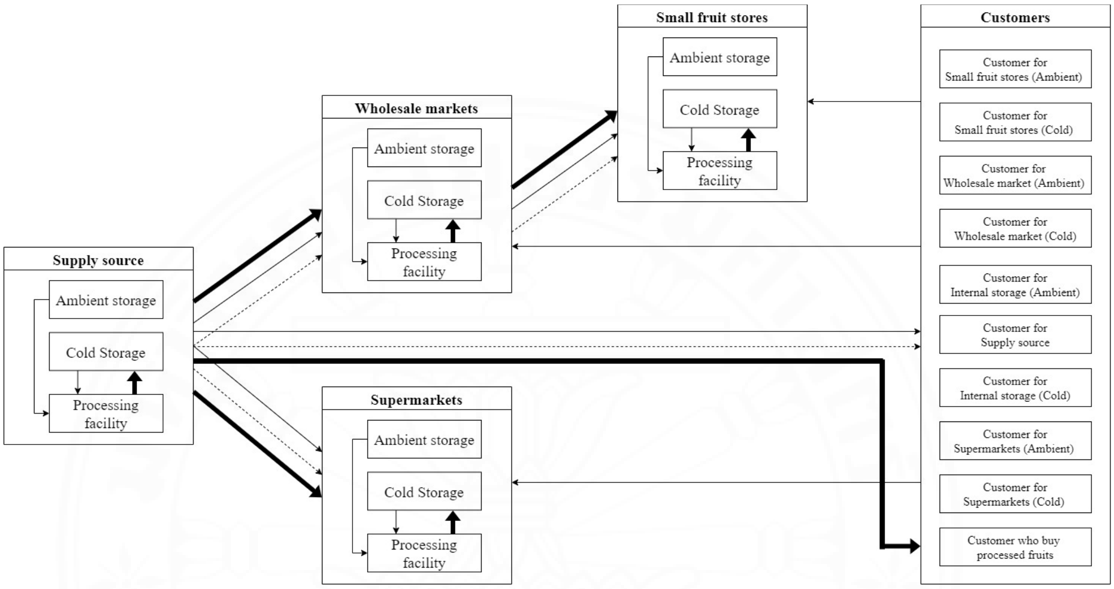

Figure 3.1 Generic cold chain network for fresh agricultural and processed products.

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

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

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

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

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

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

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

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

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.

Objective function

Total profit = Total Revenue -Total Cost (1)

a) Supply Source

i) No storage

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

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

ii) Internal storage

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

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

b) Wholesale markets

Revenue = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}(U_{p_g,w,r} \times X_{p_g,w,r,m}) + \sum_{w=1}^{2}(U_{p_g,w,c_{w,1}} \times X_{p_g,w,c_{w,1},m_0}) + (U_{p_g,w_2,c_{w,2}} \times X_{p_g,w_2,c_{w,2},m_0}) + \left(U_{p_h,w_2,r_2} \times X_{p_h,w_2,r_2,m_2}\right) + \left(U_{p_h,w_2,c_{p_h}} \times X_{p_h,w_2,c_{p_h},m_2}\right)$ (6)

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

c) Small fruit stores

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

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

d) Supermarkets

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

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

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

$$\sum_{s=1}^{2} Y_{p_g,o,s} + \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,o,w,m} + \sum_{m=1}^{2} X_{p_g,o,c_{o,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,o,k,m} + Y_{p_g,o,e_o} = CAP_o \quad (12)$$

$$q_o \times Y_{p_g,o,e_o} = Y_{p_h,e_o,s_2} \quad (13)$$

$$Y_{p_g,o,s} = Z_{p_g,s} \text{ , } \forall_s \quad (14)$$

$$Y_{p_h,e_o,s_2} = Z_{p_h,s_2} \quad (15)$$

$$l_{s_1} \times Z_{p_g,s_1} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,w,m} + \sum_{m=1}^{2} X_{p_g,s_1,c_{s,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,k,m} \quad (16)$$

$$l_{s_2} \times Z_{p_g,s_2} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,w,m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,1},m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,2},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,k,m} \quad (17)$$

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

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

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

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

$$l_{w_2} \times Z_{p_g,w_2} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_2,r,m} + X_{p_g,w_2,c_{w,1},m_0} + X_{p_g,w_2,c_{w,2},m_0} + Y_{p_g,w_2,e_w} \quad (22)$$

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

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

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

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

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

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

$$Z_{p_h,r_2} = X_{p_h,r_2,c_{p_h},m_0} \quad (29)$$

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

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

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

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

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

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

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

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 AND CASE STUDY MODEL

4.1 Data collection

This research collected data from both online and onsite information. For the reliable and official data sources are given in Table 4.1, the agricultural fruits information from the Official of Agricultural Economics (2019). The Department of Industrial Works (2020) provides lists of cold chain companies in Thailand. The financial statement data comes from the Department of Business Development (2020). The Food and Agriculture Organization of the United Nations (2011) provides information on the loss rate of agricultural products that are given in Table 4.3.

However, some additional data are given in Table 4.2 that cannot be found in the official data source can be collected from supply chain members directly. Transportation and storage cost information is obtained from third party logistics providers such as SCG Logistic, BI Logistics and Inter Express company and other third-party logistics providers.

Table 4.1 Official data sources

No.	Data source	Provides information about:
1	Office of Agricultural Economics	Agricultural production information
2	Department of Industrial works	A list of cold chain companies in Thailand
3	Department of Business Development	Financial statement information
4	Food and Agriculture Organization of the United Nations	Loss rate for agricultural products
5	Economic Research Institute for ASEAN and East Asia	Research project report about cold chain for agri-food products in ASEAN

Table 4.2 Additional data sources

No.	Data source		Provides information about:
1	Supply sources	Farmers in Nakhon Nayok Province	Agricultural production information
2	Wholesale markets	Talaad Thai and Simummuang market	
3	Small fruit stores	Local markets and social media platforms	
4	Supermarkets	Tops, Villa market, Lotus and Big C	
5	Third-party logistic providers	SCG Logistic, BI Logistics and Inter Express company	Fixed cost for transportation and storage

Table 4.3 Loss rate for storage and transportation in agricultural products

Types	Percentage of Losses (%)	
	Storage	Transportation
Ambient	9%	10%
Cold	1%	0.001%

4.2 Case study for mayongchid in the central region of Thailand

4.2.1 Data for the optimization model

Buawat (2020) indicate the estimates of Thailand for cold chain logistics account will be approximately 5-7% of the total logistics market in 2017 but in 2019-2025, the world market forecast that it will increase up to 18%. So, the demand will be set as approximately 20% for cold mode. The initial capacity at supply source will be assumed to be 1,000 kg.

In addition, the demand for mayongchid in each market channel will be separated by the proportion of customer demand into five types of customers, depending on the market channel. There are customers for supply sources, wholesale markets, small fruit stores, supermarkets and customers who buy processed fruits. The optimization model that includes the fresh and processed mayongchid assumes that the proportion of demand are given in Table 4.4.

Table 4.4 The proportion of demand for fresh and processed mayongchid.

Demand for ambient: 50%			
Origin	Destination	Proportion (%)	Quantity (kg.)
Small fruit stores	Customer for small fruit store	40%	200
Wholesale markets	Customer for wholesale market	15%	75
Supply source	Customer for supply source	10%	50
Internal ambient storages	Customer for internal storage	10%	50
Supermarkets	Customer for supermarket	25%	125
Demand for cold: 30%			
Origin	Destination	Proportion (%)	Quantity (kg.)
Small fruit stores	Customer for small fruit store	40%	120
Wholesale markets	Customer for wholesale market	15%	45
Internal cold storages	Customer for internal storage	20%	60
Supermarkets	Customer for supermarket	25%	75
Demand for processed fruit: 20%			
Origin	Destination	Proportion (%)	Quantity (kg.)
Small fruit stores with cold storage	Customer who buys processed product	20%	200
Wholesale markets with cold storage			
Internal cold storages			
Supermarkets with cold storage			

The parameters used in the optimization model for mayongchid in the central region are shown in Table 4.5. The capacity will be unlimited in all nodes except for the initial capacity at the supply source that will be set at 1,000 kilograms. The unit cost, that is the planting cost for mayongchid, is 92.38 Baht per kilogram. The cost for processed fruit that will consist of material cost and labor cost is 19.15 Baht per kilogram and the unit price, are given in Table 1, sells from the origin node to the destination node and the range for the unit price is between 144.11 to 399 Baht per kilogram and the unit price for processed fruit will be 500 Baht per kilogram, There are storage costs at the origin node, divided into cold mode (1.8 Baht per kilogram) and ambient mode (0.294 Baht per kilogram) that are obtained from SCG Logistic and Inter Express Logistic. The transportation cost from the origin node to the destination node, divided into cold mode (12.14 Baht per kilogram) and ambient mode (3.50 Baht per kilogram) that obtained from Thailand Post, BI Logistics, and Inter Express Logistic. For the processed fruit, the model needs to add the conversion factor that refers to the amount of agricultural product that will be left after the process and for the processed fruit of mayongchid that is ready to eat, which is peeled and removed seed from the mayongchid, the conversion factor is 90% for this processed fruit.

Table 4.5 Parameters in the optimization model for mayongchid in the central region.

Origin	Destination	Unit price (Baht/kg.)
Supply source	Wholesale market	144.11
	Supermarkets	144.11
	Customer for supply source (No storage)	268.75
Internal storage	Wholesale market	144.11
	Supermarkets	144.11
	Customer for internal storage (Ambient)	268.75
	Customer for internal storage (Cold)	290.00
	Customer who buys processed fruits	500.00
Wholesale market	Small fruit stores	197.56
	Customer for wholesale market (Ambient)	250.00
	Customer for wholesale market (Cold)	285.00
	Customer who buys processed fruits	500.00
Small fruit stores	Customer for small fruit stores (Ambient)	350.00
	Customer for small fruit stores (Cold)	385.00
	Customer who buys processed product	500.00
Supermarkets	Customer for supermarkets (Ambient)	399.00
	Customer for supermarkets (Cold)	399.00
	Customer who buys processed fruits	500.00

4.2.2 Specific cold chain network for mayongchid.

Mayongchid is a seasonal fruit that well-known at Nakhon Nayok province and will be available only from January to March. Generally, the farmer or supply source will sell mayongchids to the wholesale markets, and some retailers directly and then they will distribute the produce throughout the country and sell it to the end customers through various panels. Because mayongchid does not have a high productivity, but it has a high demand every year, most farmers will only sell it to customers who come to buy it every year or sell it in front of their garden.

Mayongchid is generally delicious when refrigerated after peeling and removing the seed inside. So, ready-to-eat mayongchid is the best processed product that will make value added to the producers and convenience for the customers, but this product has a short shelf life. So, the producers must peel and remove the seed at the final stage before sending it to the customer, which means there will be a process facility in all stages of the supply chain.

Figure 4.1 illustrates a specific cold chain network for fresh and processed mayongchid in the central region of Thailand that shows distribution of the mayongchid in common from a supply source to the end customers. This network in Figure 4.1 is similar to the generic cold chain network for fresh and processed fruits in Figure 3.1 that consists of five major groups of members and end customers; there may be two storage and transportation modes: ambient and cold in each node and arc.

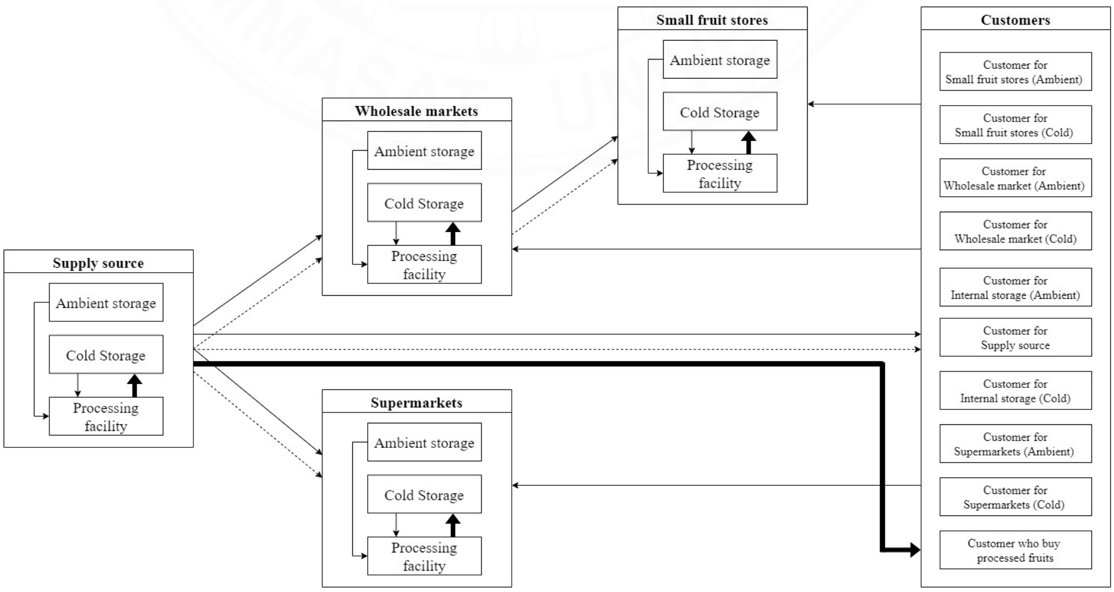

Figure 4.1 Specific cold chain network for fresh and processed mayongchid

4.2.3 Specific mathematical model for mayongchid.

Additional model assumptions for mayongchid.

1. Processed fruits will only be sold to customer who buy processed fruits and will not be sold to other nodes in the supply chain because of their short shelf life.
2. For processed fruits, all nodes have the same unit price (500 Baht per kilogram).

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

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

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

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

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

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

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

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

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.

Objective function

Total profit = Total Revenue -Total Cost (48)

a) Supply Source

i) No storage

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

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

ii) Internal storage

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

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

b) Wholesale markets

Revenue = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}(U_{p_g,w,r} \times X_{p_g,w,r,m}) + \sum_{w=1}^{2}(U_{p_g,w,c_{w,1}} \times X_{p_g,w,c_{w,1},m_0}) + (U_{p_g,w_2,c_{w,2}} \times X_{p_g,w_2,c_{w,2},m_0}) + \left(U_{p_h,w_2,c_{p_h}} \times X_{p_h,w_2,c_{p_h},m_2}\right)$ (53)

Cost = $\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times X_{p_g,s,w,m}) + \sum_{w=1}^{2}(f_w \times Z_{p_g,w}) + \left(f_{w_2} \times Z_{p_h,w_2}\right) + \sum_{w=1}^{2}(Y_{p_g,w,e_w} \times v)$ (54)

c) Small fruit stores

Revenue = $\sum_{r=1}^{2}(U_{p_g,r,c_{r,1}} \times X_{p_g,r,c_{r,1},m_0}) + \left(U_{p_g,r_2,c_{r,2}} \times X_{p_g,r_2,c_{r,2},m_0}\right) + \left(U_{p_h,r_2,c_{p_h}} \times X_{p_h,r_2,c_{p_h},m_0}\right)$ (55)

Cost = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}((T_{w,r,m} + U_{p_g,w,r}) \times X_{p_g,w,r,m}) + \sum_{r=1}^{2}(f_r \times Z_{p_g,r}) + \left(f_{r_2} \times Z_{p_h,r_2}\right) + \sum_{r=1}^{2}(Y_{p_g,r,e_r} \times v)$ (56)

d) Supermarkets

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

Cost = $\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \sum_{k=1}^{2}(f_k \times Z_{p_g,k}) + \left(f_{k_2} \times Z_{p_h,k_2}\right) + \sum_{k=1}^{2}(Y_{p_g,k,e_k} \times v)$ (58)

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

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

$$q_o \times Y_{p_g,o,e_o} = Y_{p_h,e_o,s_2} \quad (60)$$

$$Y_{p_g,o,s} = Z_{p_g,s}, \forall_s \quad (61)$$

$$Y_{p_h,e_o,s_2} = Z_{p_h,s_2} \quad (62)$$

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

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

$$Z_{p_h,s_2} = X_{p_h,s_2,c_{p_h},m_2} \quad (65)$$

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

$$Y_{p_h,e_w,w_2} = Z_{p_h,w_2} \quad (67)$$

$$l_{w_1} \times Z_{p_g,w_1} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_1,r,m} + X_{p_g,w_1,c_{w,1},m_0} + Y_{p_g,w_1,e_w} \quad (68)$$

$$l_{w_2} \times Z_{p_g,w_2} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_2,r,m} + X_{p_g,w_2,c_{w,1},m_0} + X_{p_g,w_2,c_{w,2},m_0} + Y_{p_g,w_2,e_w} \quad (69)$$

$$Z_{p_h,w_2} = X_{p_h,w_2,c_{p_h},m_0} \quad (70)$$

$$q_w \times \sum_{w=1}^{2} Y_{p_g,w,e_w} = Y_{p_h,e_w,w_2} \quad (71)$$

$$\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{w,r,m} \times X_{p_g,w,r,m}) = Z_{p_g,r}, \forall_r \quad (72)$$

$$Y_{p_h,e_r,r_2} = Z_{p_h,r_2} \quad (73)$$

$$l_{r_1} \times Z_{p_g,r_1} = X_{p_g,r_1,c_{r,1},m_0} + Y_{p_g,r_1,e_r} \quad (74)$$

$$l_{r_2} \times Z_{p_g,r_2} = X_{p_g,r_2,c_{r,1},m_0} + X_{p_g,r_2,c_{r,2},m_0} + Y_{p_g,r_2,e_r} \quad (75)$$

$$Z_{p_h,r_2} = X_{p_h,r_2,c_{p_h},m_0} \quad (76)$$

$$q_r \times \sum_{r=1}^{2} Y_{p_g,r,e_r} = Y_{p_h,e_r,r_2} \quad (77)$$

$$\sum_{m=1}^{2}(L_{o,k,m} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times X_{p_g,s,k,m}) = Z_{p_g,k}, \forall_k \quad (78)$$

$$Y_{p_h,e_k,k_2} = Z_{p_h,k_2} \quad (79)$$

$$l_{k_1} \times Z_{p_g,k_1} = X_{p_g,k_1,c_{k,1},m_0} + Y_{p_g,k_1,e_k} \quad (80)$$

$$l_{k_2} \times Z_{p_g,k_2} = X_{p_g,k_2,c_{k,1},m_0} + X_{p_g,k_2,c_{k,2},m_0} + Y_{p_g,k_2,e_k} \tag{81}$$

$$Z_{p_h,k_2} = X_{p_h,k_2,c_{p_h},m_0} \tag{82}$$

$$q_k \times \sum_{k=1}^{2} Y_{p_g,k,e_k} = Y_{p_h,e_k,k_2} \tag{83}$$

Constraint 2: Requirements must be fulfilled.

$$X_{p_g,r_1,c_{r,1},m_0} + X_{p_g,r_2,c_{r,1},m_0} \leq D_{p_g,c_{r,1}} \tag{84}$$

$$X_{p_g,r_2,c_{r,2},m_0} \leq D_{p_g,c_{r,2}} \tag{85}$$

$$X_{p_g,w_1,c_{w,1},m_0} + X_{p_g,w_2,c_{w,1},m_0} \leq D_{p_g,c_{w,1}} \tag{86}$$

$$X_{p_g,w_2,c_{w,2},m_0} \leq D_{p_g,c_{w,2}} \tag{87}$$

$$\sum_{m=1}^{2}(L_{o,c_{o,1},m} \times X_{p_g,o,c_{o,1},m}) \leq D_{p_g,c_{o,1}} \tag{88}$$

$$\sum_{m=1}^{2}(L_{s_1,c_{s,1},m} \times X_{p_g,s_1,c_{s,1},m}) + \sum_{m=1}^{2}(L_{s_2,c_{s,1},m} \times X_{p_g,s_2,c_{s,1},m}) \leq D_{p_g,c_{s,1}} \tag{89}$$

$$\sum_{m=1}^{2}(L_{s_2,c_{s,2},m} \times X_{p_g,s_2,c_{s,2},m}) \leq D_{p_g,c_{s,2}} \tag{90}$$

$$X_{p_g,k_1,c_{k,1},m_0} + X_{p_g,k_2,c_{k,1},m_0} \leq D_{p_g,c_{k,1}} \tag{91}$$

$$X_{p_g,k_2,c_{k,2},m_0} \leq D_{p_g,c_{k,2}} \tag{92}$$

$$X_{p_h,s_2,c_{p_h},m_2} + X_{p_h,w_2,c_{p_h},m_0} + X_{p_h,r_2,c_{p_h},m_0} + X_{p_h,k_2,c_{p_h},m_0} \leq D_{p_h,c_{p_h}} \tag{93}$$

Constraint 3: Non-negativity constraints

All decision variables ≥ 0 (94)

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) - (83) 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 (84) - (93) 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 (94) are non-negativity constraints.

CHAPTER 5
RESULT AND DISCUSSION

5.1 Result for fresh mayongchid.

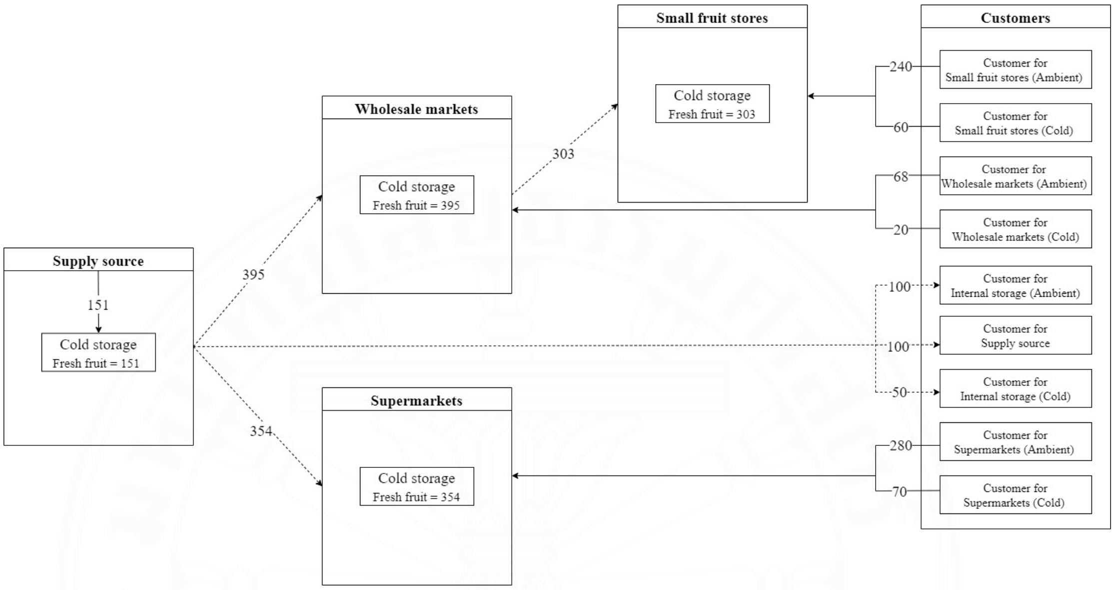

Figure 5.1 Network of fresh mayongchid in the supply chain

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

Stages in supply chain	Revenue	Cost	Profit
Supply source	169,711.88	102,295.44	67,416.44
Wholesale market	115,059.43	79,703.72	35,355.71
Small fruit stores	142,800.00	85,455.39	57,344.61
Supermarkets	99,750.00	36,845.96	62,904.04
Total	527,321.32	304,300.52	223,020.80

Table 5.2 Satisfied demand of fresh mayongchid in each market channel

Origin	Destination	Actual demand	Satisfied demand	
		(Kg.)	(Kg.)	(%)
Supply source	Customer for supply source (No storage)	80	80	100%
Internal storage	Customer for internal storage (Ambient)	80	80	100%
	Customer for internal storage (Cold)	40	40	100%
Wholesale market	Customer for wholesale market (Ambient)	120	107	89%
	Customer for wholesale market (Cold)	30	30	100%
Small fruit stores	Customer for small fruit stores (Ambient)	320	320	100%
	Customer for small fruit stores (Cold)	80	80	100%
Supermarkets	Customer for supermarkets (Ambient)	200	200	100%
	Customer for supermarkets (Cold)	50	50	100%

Discussion

This optimization model for fresh mayongchid in the central region of Thailand. The model assumes that the customer demand for ambient fresh fruit is 80% and for cold fresh fruit is 20%. After performing the experiment for fresh mayongchid by mixed integer linear programming in the Excel Open Solver, the model suggested routes and modes of storage and transportation, as shown in Figure 5.1. The route began with the supply source sending fresh mayongchid to store in the internal cold storage by the amount of 121 kilograms and sent through the wholesale market for 546 kilograms and supermarkets for 253 kilograms by cold transportation mode. Then, the small fruit stores will receive fresh mayongchid in the amount of 404 kilograms from the wholesale market by cold transportation mode and all stages will send fresh mayongchid to the end customers depending on their demand by using cold transportation mode. Since all the nodes in the supply chain use cold storage and cold transportation modes that have a very low loss rate, this is the reason why it didn't affect the amount of fresh mayongchid that is sent through the whole supply chain.

According to the demand satisfaction shown in Table 5.2, the result indicates that the initial capacity at supply source (1,000 kg.) can mostly satisfy the customers except the customer from the wholesale market with ambient demand ($C_{w,1}$) that can be satisfied only 89% because the wholesale market has to send the fresh mayongchid to both small fruit stores and customer. So, the wholesale market cannot satisfy their demand and there also have some losses that occur in the storage and transportation process. Since the model limited the capacity of the supply source and the model suggested to satisfy customer demand for cold mode first because it will make a higher profit than customer demand for ambient mode.

Data of cost, revenue, and profit in all stages of the supply chain are given in Table 5.1. The total profit in the overall supply chain stage is 223,020.80 Baht. The supply source was the node that had the highest profit with the highest revenue.

From the result, the model will suggest that fresh mayongchid can be more profitable and extend their shelf life by using cold chain in both storage and transportation because they can provide more product to sale and the percentage for loss of transportation (0.001%) and storage (1%) are very low, which can prevent the spoilage. To summarize, all the nodes need cold storage and cold transportation to satisfy the customer demand and to maximize the overall profit in the supply chain.

5.2 Result for fresh and processed mayongchid

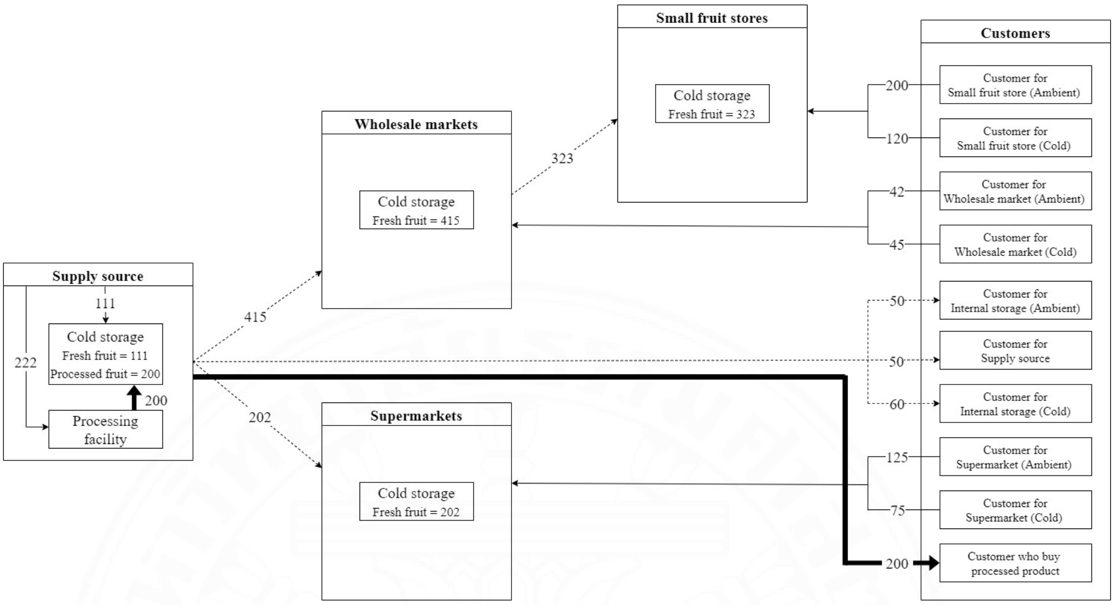

Figure 5.2 Network of fresh and processed mayongchid in the supply chain

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

Stages in supply chain	Total revenue	Total cost	Total profit
Supply source	233,141.71	104,681.87	128,459.84
Wholesale market	87,247.60	60,499.93	26,747.67
Small fruit stores	116,200.00	68,364.32	47,835.68
Supermarkets	79,800.00	29,476.77	50,323.23
Total	516,389.31	263,022.88	253,366.43

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

Origin	Destination	Actual demand	Satisfied demand	
		(Kg.)	(Kg.)	(%)
Supply source	Customer for supply source (No storage)	50	50	100%
Internal storage	Customer for internal storage (Ambient)	50	50	100%
	Customer for internal storage (Cold)	60	60	100%
Wholesale market	Customer for wholesale market (Ambient)	75	42	56%
	Customer for wholesale market (Cold)	45	45	100%
Small fruit stores	Customer for small fruit stores (Ambient)	200	200	100%
	Customer for small fruit stores (Cold)	120	120	100%
Supermarkets	Customer for supermarkets (Ambient)	125	125	100%
	Customer for supermarkets (Cold)	75	75	100%
All nodes	Customer who buys processed fruits	200	200	100%

Discussion

This optimization model for fresh mayongchid and processed fruit that is ready to eat mayongchid that will peel and remove their seeds in the central region of Thailand. The model assumes that the proportion of customer demand is 50% for ambient mode, 30% for cold mode, and 20% for processed fruit. After performing the experiment for fresh mayongchid by mixed integer linear programming in the Excel Open Solver, the model suggested routes and modes of storage and transportation, as shown in Figure 5.1. This is the extension model that will include the processed fruit and the suggested routes and modes of storage and transportation for both fresh mayongchid and processed fruit are shown in Figure 5.2.

The route began with the supply source sending fresh mayongchid to store in the internal cold storage by the amount of 111 kilograms and sent through the wholesale market for 415 kilograms and supermarkets for 202 kilograms by cold transportation mode. Then, the small fruit stores will receive fresh mayongchid in the amount of 323 kilograms from the wholesale market by cold transportation mode and all stages will send fresh mayongchid to the end customers depending on their demand by using cold transportation mode. For the processed fruit, all of the nodes in the supply chain will send fresh mayongchid to the processing facility to peel and remove the seed, then send the processed fruit or ready to eat mayongchid to the customer who buys the processed fruit. From the model, the suggested node that is the suitable node to have the processing facility inside is the supply source because there is the lowest unit price for fresh fruit to be processed and a high unit price for the processed fruit. So, the supply source will send the fresh mayongchid to the processing facility for 222 kilograms and there will process the fresh mayongchid to become the ready to eat mayongchid with 200 kilograms and store it inside the cold internal storage before sending it to the end customer. Since all the nodes in the supply chain use cold storage and cold transportation modes that have a very low loss rate, this is the reason why it did not affect the amount of fresh mayongchid that is sent through the whole supply chain.

According to the demand satisfaction shown in Table 5.4, it indicates that the initial capacity at the supply source (1,000 kilograms) can mostly satisfy the customers, except for the customer from the wholesale market with ambient demand ($C_{w,1}$) that can satisfy only 56% because the wholesale market has to send the product to both small fruit stores and customers, so they can not satisfy the demand and there is also some loss in the storage and transportation process. This optimization model limited the capacity of the supply source and suggested satisfying customer demand for the cold mode first because it made a higher profit than the customer's demand for the ambient mode.

Data of cost, revenue, and profit in all stages of the supply chain are given in Table 5.3. The total profit in the overall supply chain stage is 253,366.43 Baht, which is higher than the total profit for the previous case that consisted only of the fresh mayongchid. The supply source was the node that had the highest profit with the highest revenue. Since, this is the only node that has the processing facility to peel and remove the seed of the mayongchid before sending it to the customer. As a result, the processed fruit can make the fresh mayongchid become more profitable and the model also suggests that fresh mayongchid can extend their shelf life by using cold chain in both storage and transportation because they can provide more product for sale and the percentage of loss of transportation (0.001%) and storage (1%) are very low, which can prevent the spoilage. To summarize, all the nodes need cold storage and cold transportation to satisfy the customer demand and to maximize the overall profit in the supply chain.

5.3 Sensitivity analysis

Sensitivity analysis is performed to evaluate the input parameter that affects the optimal solution. In this research, the sensitivity analysis will include the extreme case of ambient spectrum that is no cold allowed, demand and price for both fresh fruits and processed fruits, loss for storage, and loss for transportation are considered.

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

When comparing the total profit of the base case for fresh mayongchid and the extreme case of ambient spectrum with no cold allowed, as shown in Figure 5.3. The total profit in the extreme case of ambient spectrum is less than the total profit in the base case due to the high loss rate of ambient storage and transportation. This situation will reduce the amount of products for sale and unit price. If there is a cold chain in the system for both cold storage and cold transportation, the profit will increase because the cold chain can help to maintain the quality of the fresh perishable products and extend their shelf life, including value-added to the product.

Based on Figure 5.3 and Table 5.5, the highest amount of difference in profit between base case and extreme case of ambient spectrum is on the supply source nodes for mayongchid in the central region of Thailand.

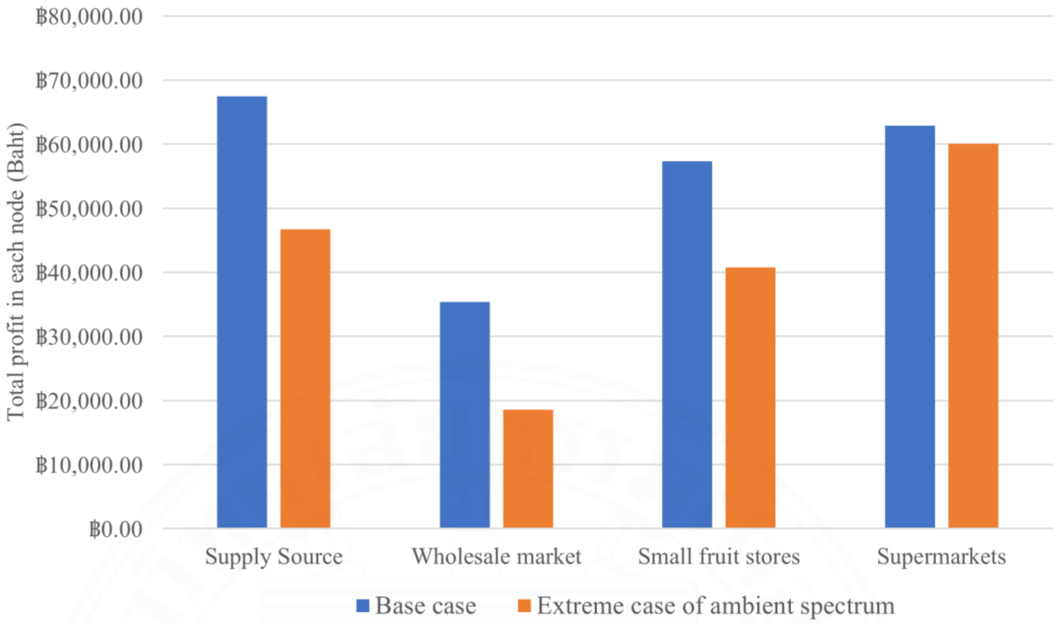

Figure 5.3 Comparison of the total profit between base case and extreme case of ambient spectrum in each node of the supply chain.

Table 5.5 The summary table for comparison of total profit between base case and extreme case of ambient spectrum.

Case	Supply source	Wholesale markets	Small fruit stores	Super markets	Total profit
Base case	67,416.44	35,355.71	57,344.61	62,904.04	223,020.80
Extreme case of ambient spectrum	46,671.89	18,581.91	40,785.54	60,078.57	166,117.91
The difference in profit	20,744.55	16,773.80	16,559.07	2,825.47	56,902.89

5.3.2 Sensitivity analysis of demand and price in the fresh fruit.

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

Then, the model will consider the sensitivity of demand and unit price for fresh fruit. If there is more demand in the cold chain, the supply of fresh products should increase, but the unit price will decrease at the end of the supply chain toward the customer. Next, adjust the data to be more reasonable by assuming that if demand for the cold chain rises to 60%, cold product prices will fall linearly until cold demand for the cold chain reaches 100%. Unit prices for cold products will be equal to the unit price for ambient products at all stages, apart from supermarkets that the unit price will be reduced in both ambient and cold demand, because cold and ambient prices for supermarket have been equal since the beginning. As a result, total revenue and total profit tend to decrease due to the lower unit price.

When adjusted for the unit price of cold products, 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, the use of a cold chain is still slightly reduced, which means the cold chain is robust.

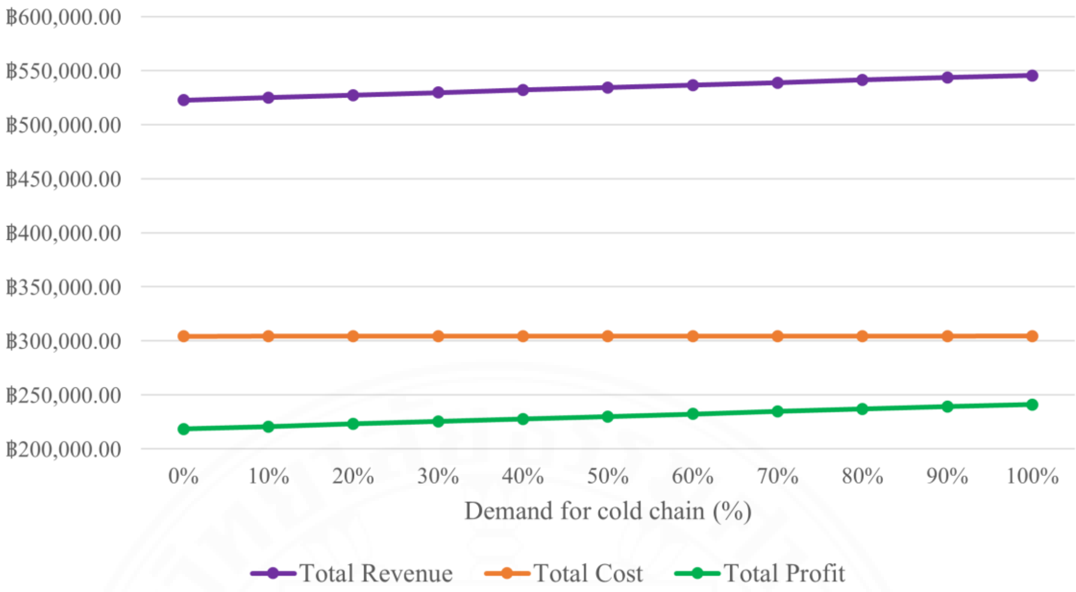

Figure 5.4 Sensitivity analysis of demand in the fresh fruit.

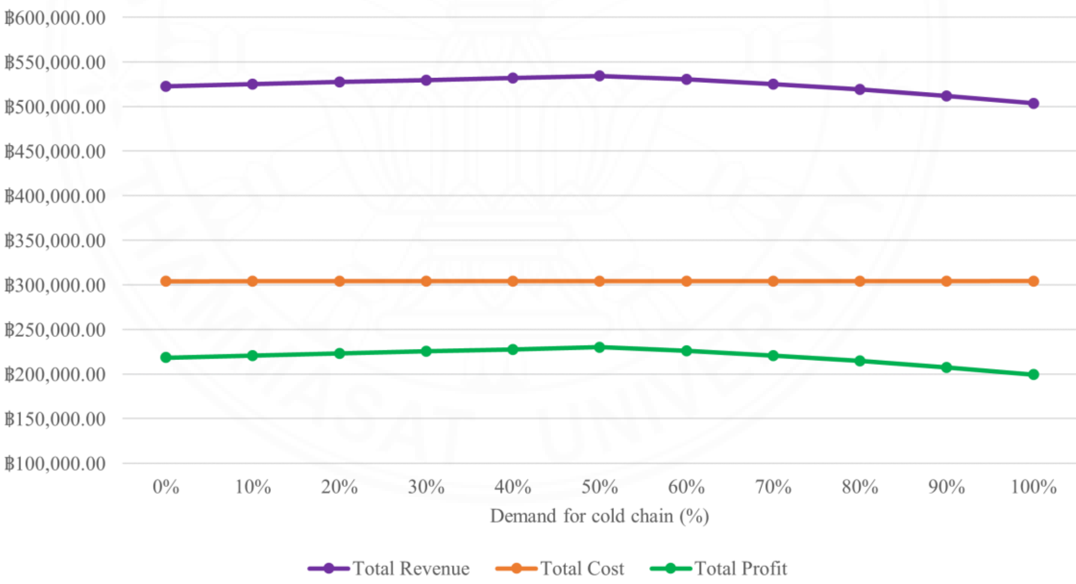

Figure 5.5 Sensitivity analysis of demand and price in the fresh fruit.

5.3.3 Sensitivity analysis for loss storage

The sensitivity analysis for loss rate in storage with ambient mode of mayongchid is shown in Figure 5.6. This relationship between ambient storage loss compared with the amounts that are stored in both cold and ambient modes can state that when the loss rate of ambient storage increases, the model will change the decision from the ambient mode to use the cold mode instead, because when stored in the cold mode, they can provide more product to sale due to the low loss rate of storage. The graph in Figure 5.6 shows that when the storage loss rate is around 1.7%, mayongchid will change the mode of storage from using ambient mode to using cold mode instead to keep the quality or freshness of the product when stored in the storage.

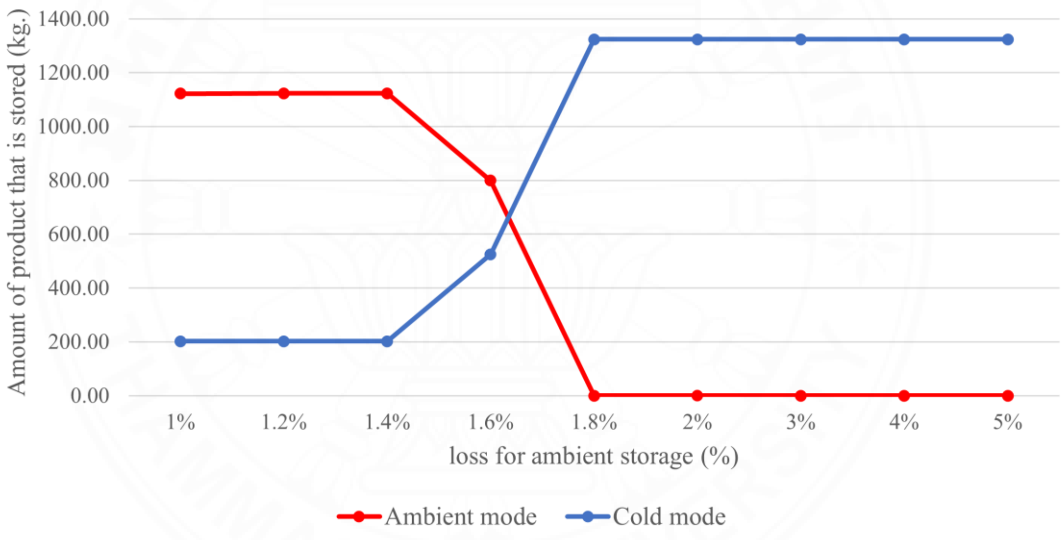

Figure 5.6 Sensitivity analysis of loss storage

5.3.4 Sensitivity analysis for loss transportation

The sensitivity analysis for loss rate in transportation with ambient mode of mayongchid is shown in Figure 5.7. This relationship between ambient transportation loss compared with the amounts of product that is transported in both cold and ambient modes can state that when the loss rate of ambient transportation mode increases, the model will change the decision from the ambient mode to use the cold mode instead, because when transport in the cold mode, they can provide more product to sale due to the low loss rate of transportation. The graph in Figure 5.7 shows that when the transportation loss rate is around 3.5%, mayongchid will change the mode of transportation from using ambient mode to using cold mode instead.

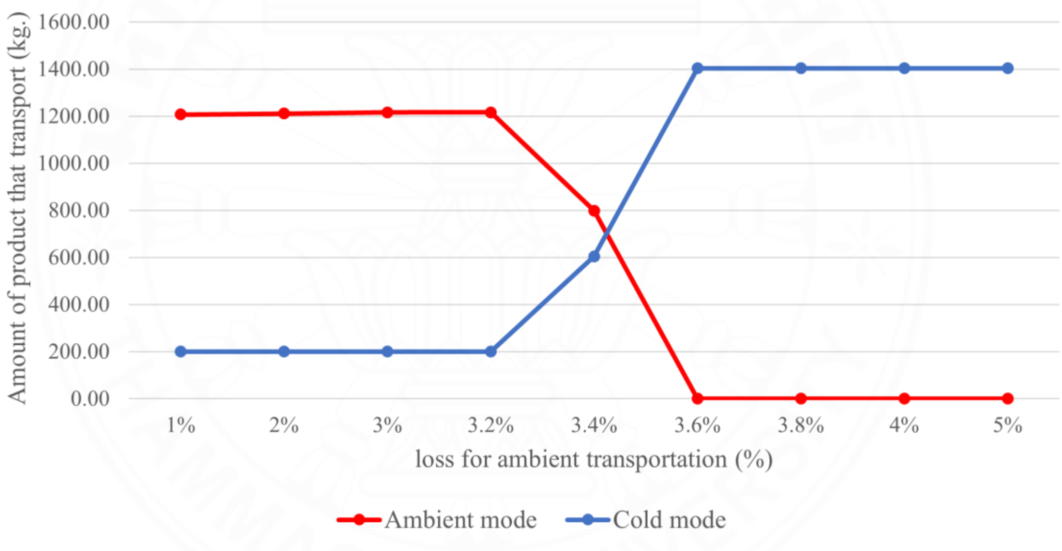

Figure 5.7 Sensitivity analysis of loss transportation

5.3.5 Sensitivity analysis of price in the processed fruit.

The sensitivity analysis for the value or unit price of processed mayongchid (ready to eat mayongchid) is shown in Figure 5.8. The graph shows the relationship between the unit price for processed fruit that will drop until the demand is not worth selling the processed fruit and the amount of processed fruit that is sent to the end customers. The unit price of processed mayongchid is 500 Baht per kilogram and the amount of processed mayongchid that can be sold is 200.00 kilograms, which is the amount that can satisfy the demand for customers who want to buy processed fruits. However, the model indicates that the unit price for processed mayongchid should not be less than 300 baht per kilogram because the amount of processed mayongchid will be reduced to 170.23 kilograms, which cannot satisfy the demand for customers who want to buy processed fruits.

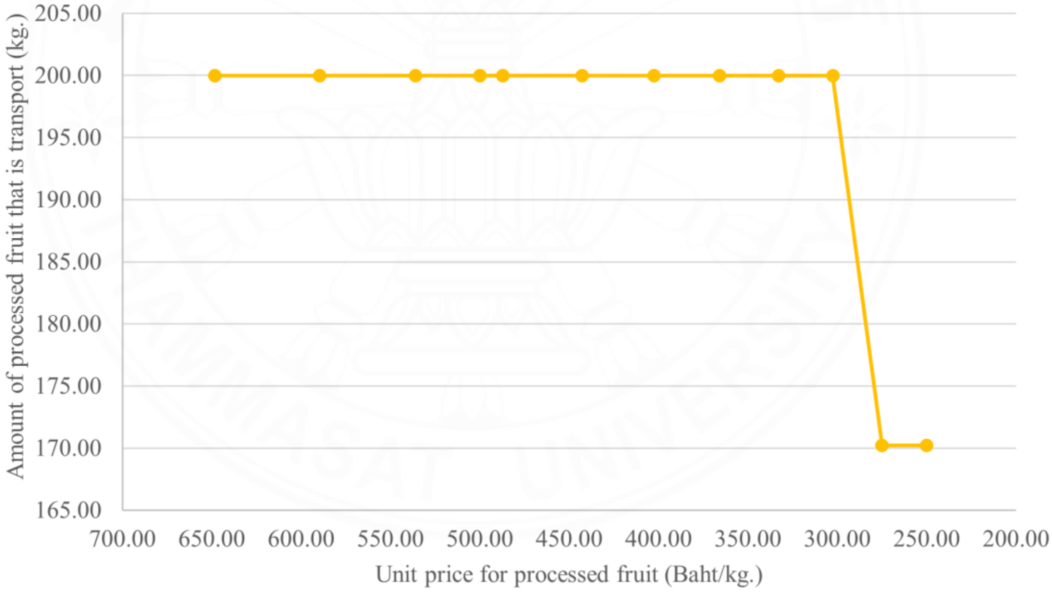

Figure 5.8 Sensitivity analysis of price in the processed fruit.

CHAPTER 6
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, the model was expanded to include processed products with the goal of making agricultural products more marketable and attractive to potential consumers, as well as the use of cold chains to increase shelf life and maintain quality.

The results of the study suggest that mayongchid supply chain should use cold chain management in the whole supply chain for both fresh and processed fruits. According to the Department of Industrial Works (2020), Nakhon Nayok province has only 2 companies with cold storage that are undersupply for this optimization model that suggests using a cold chain for the whole supply chain. From the results, this research suggests increasing by building more cold supply capacity in each member of supply chain to satisfy the customer demand and maximize the overall profit.

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 study 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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