OPTIMIZATION FOR COLD CHAIN MANAGEMENT IN EASTERN THAILAND: A CASE STUDY IN MANGOSTEEN SUPPLY CHAIN

BY

MS. CHATSUDA JIARANAICHAROEN

AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)
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Member and Advisor ____________________
(Associate Professor Dr. Jirachai Buddhakulsomsiri, Ph.D.)

Member ____________________
(Associate Professor Dr. Pisal Yenradee, D.Eng.)

Director ____________________
(Professor Pruettha Nanakorn, D.Eng.)

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ABSTRACT

Nowadays, the quality of food, freshness, and food safety are getting more attention. Agricultural products have perishable characteristics, short shelf life, and temperature sensitivity. 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 eastern region of Thailand to maintain the quality and reduce loss and also increase the value of the product. The Mix-integer linear programming (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, Fruit supply 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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Ms. Chatsuda Jiaranaicharoen

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 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.

1.1 Problem statement

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 reduces 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 fruit supply chain in eastern region of Thailand while maintaining the quality of fresh and processed fruit as much as possible through the use of cold chain management.

1.2 Research objective

This article has a specific objective, as follows:

- To find a suitable fruit 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 fruit 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 fruits and processed fruit products that has the potential to use cold chain in the eastern region of Thailand by considering an aggregate plan to use the cold chain in the supply chain for fresh and processed agricultural products.

This article mentions in fruits and processed fruit products in the eastern region, the suitable fruit is mangosteen and can be processed into mangosteen cold-press juice.

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 Mangosteen

Eastern Thailand is already an important source of many agricultural products essential for fruits especially in Chanthaburi province because Chanthaburi is a province that is famous for producing and selling fruit and has a variety of agricultural products such as mangosteen. According to the Office of Agricultural Economics, the overall productivity of mangosteen in Thailand was 351,740 tons or 827 kilograms per rai and around 125,834 tons or 967 kilograms per rai in Chanthaburi province. The harvest season of mangosteen is from April to June. Shelf life in ambient temperature was 7 days but if we store in chilled temperature (13-15°C) product will keep for longer in 21 days. Unit cost at supply source is around 12.12 baht per kilogram and unit price is around 29.02-159 baht per kilogram.

Figure 1.1 Mangosteen

1.4.2 Mangosteen Cold-Press Juice

Mangosteen Cold-Press Juice is one of the processed products from mangosteen that is the process of taking mangosteen to make fruit juice. By using high pressure, squeeze or press the pulp to get the juice out. without causing heat in order to increase the value of the fruit. All flavors are made only from green veggies and fresh fruits carefully sourced from local producers without causing heat in order to increase the value of the fruit. The unit price will be around 150 baht per 220 milliliters or approximately 681.82 baht per kilogram.

Figure 1.2 Mangosteen Cold-Press Juice

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, the scope of research, and product overview.

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

Chapter 3 Methodology: represent the generic cold chain network and generic mathematical model followed by sets, parameters, and decision variables.

Chapter 4 Data collection and case study model: explained in the individual data collection of our case study and also the generic data, specific cold chain network and mathematical model for our product.

Chapter 5 Result and discussion: show the result from optimization 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

In this chapter explain the literature review of previous research related to this research topic, cold chain management. Classifying literature into 5 groups by the methodology, Firstly, a qualitative study is provided, followed by forecasting and data analysis, optimization model, multi-criteria decision making. Finally, the review related to simulation.

2.1 Qualitative study

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, et al., 2017). 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). 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 & 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, et al., 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 & 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 & 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, et al., 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, et al., 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 & 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 & 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 & 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 & 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, et al., 2013).

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 multiple linear regression in order to predict the demand for fresh food cold chain logistics (Hang & 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 & 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 & 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 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 focuses 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 consists of a vehicle and product-related viewpoint (Hsiao, et al., 2017). In the operation of fresh food supply chains, the cold chain plays an important role in 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 decisions about investment levels of cold chain construction and advertisement, and pricing decisions (Wang & Zhao, 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). Regarding 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 emissions. The company should be focus to reduce carbon emissions while maintaining customer satisfaction so, this paper uses 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 the 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 the 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 minimizing transportation, penalty, and inventory costs. (Al Theeb, et al., 2020). The last about the environmental issue there has research that wants to minimize transportation cost and also environment cost by using a mathematical model and using Generalized Reduced Gradient method for solving two main problems are the 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 is used to identify the best performance of 3PLs (Singn, et al., 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, et al., 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, et al., 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, et al.,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, et al.,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 fruit 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

This chapter describes the methodology of the research. First, the generic cold chain network of the fresh and processed fruit supply chain will be explained. Then, the generic mathematical model is described also the sets, parameters and decision variables are declared to use in the model.

3.1 Generic cold chain network

This study investigates cold chains of fruit products, including fresh fruits and processed fruits. Figure 3.1 illustrates a generic cold chain network that shows the 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 the 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.

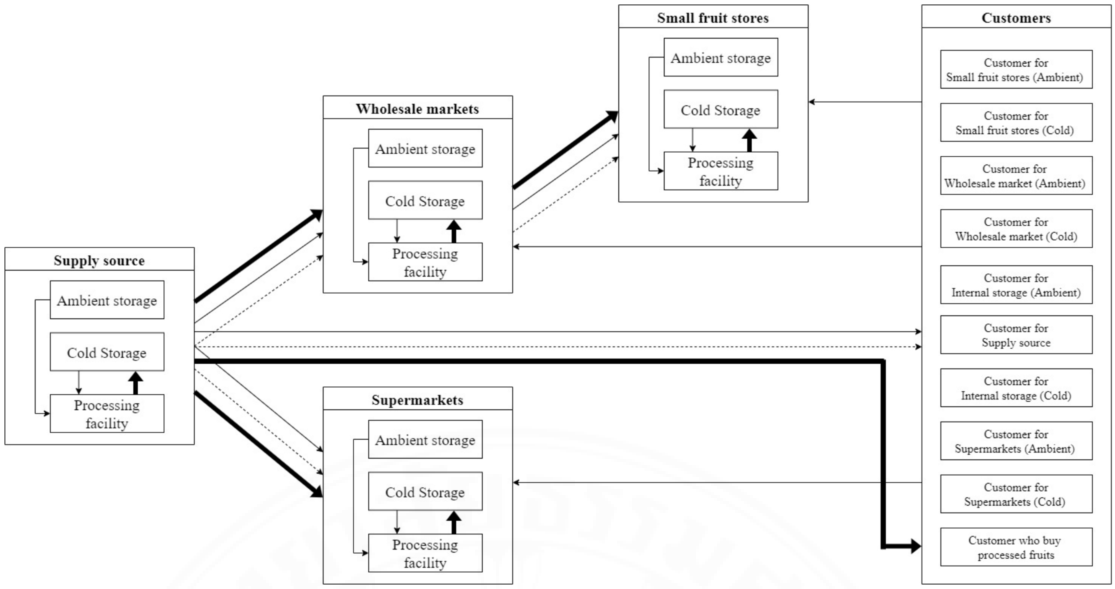

Figure 3.1 Generic cold chain network for fresh and processed fruit.

The flow begins at a supply source, where fresh or processed fruits are stored in 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).

3.2 Generic mathematical model

3.2.1 Model assumption

- Production capacity at the supply source is assumed to be a generic unit of one metric ton.
- Storage capacity at the supply source, wholesale markets, supermarkets, and small fruit stores are unlimited.
- In the base case scenario, customer demand of each group is estimated from in-depth interviews.
- 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.
- Customers purchasing directly from the supply source pay for the transportation cost.
- 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.
- Processed fruits do have a loss from cold storage and cold transportation.
- 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.
- For the total cost, the model considers only cost of goods sold, transportation cost and storage cost.

3.2.2 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

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

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.

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

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.

Total profit = Total Revenue -Total Cost (3.1)

a) Supply Source

i) No storage

$$\text{Revenue} = \sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}) + \sum_{m=1}^{2}(L_{o,c_{o,1},m} \times U_{p_g,o,c_{o,1}} \times X_{p_g,o,c_{o,1},m}) \quad (3.2)$$

$$\text{Cost} = \sum_{w=1}^{2}\sum_{m=1}^{2}((u_o + T_{o,w,m}) \times X_{p_g,o,w,m}) + \sum_{k=1}^{2}\sum_{m=1}^{2}((u_o + T_{o,k,m}) \times X_{p_g,o,k,m}) + \sum_{m=1}^{2}(u_o \times X_{p_g,o,c_{o,1},m}) + ((u_o + v) \times Y_{p_g,o,e_o}) \quad (3.3)$$

ii) Internal storage

$$\text{Revenue} = \sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times X_{p_g,s,w,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,c_{s,1},m} \times U_{p_g,s,c_{s,1}} \times X_{p_g,s,c_{s,1},m}) + \sum_{m=1}^{2}\left(L_{s_2,c_{s,2},m} \times U_{p_g,s_2,c_{s,2}} \times X_{p_g,s_2,c_{s,2},m}\right) + \left(U_{p_h,s_2,w_2} \times X_{p_h,s_2,w_2,m_2}\right) + \left(U_{p_h,s_2,k_2} \times X_{p_h,s_2,k_2,m_2}\right) + \left(U_{p_h,s_2,c_{p_h}} \times X_{p_h,s_2,c_{p_h},m_2}\right) \quad (3.4)$$

Cost = $\sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(T_{s,w,m} \times X_{p_g,s,w,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(T_{s,k,m} \times X_{p_g,s,k,m}) + \sum_{s=1}^{2}((f_s + u_o) \times Z_{p_g,s}) + \left(f_{s_2} \times Z_{p_h,s_2}\right) + (T_{s_2,w_2,m_2} \times X_{p_h,s_2,w_2,m_2}) + (T_{s_2,k_2,m_2} \times X_{p_h,s_2,k_2,m_2})$ (3.5)

b) Wholesale markets

Revenue = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}(U_{p_g,w,r} \times X_{p_g,w,r,m}) + \sum_{w=1}^{2}(U_{p_g,w,c_{w,1}} \times X_{p_g,w,c_{w,1},m_0}) + (U_{p_g,w_2,c_{w,2}} \times X_{p_g,w_2,c_{w,2},m_0}) + \left(U_{p_h,w_2,r_2} \times X_{p_h,w_2,r_2,m_2}\right) + \left(U_{p_h,w_2,c_{p_h}} \times X_{p_h,w_2,c_{p_h},m_2}\right)$ (3.6)

Cost = $\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times X_{p_g,s,w,m}) + \sum_{w=1}^{2}(f_w \times Z_{p_g,w}) + \left(f_{w_2} \times Z_{p_h,w_2}\right) + \left(U_{p_h,s_2,w_2} \times X_{p_h,s_2,w_2,m_2}\right) + \sum_{w=1}^{2}(Y_{p_g,w,e_w} \times v)$ (3.7)

c) Small fruit stores

Revenue = $\sum_{r=1}^{2}(U_{p_g,r,c_{r,1}} \times X_{p_g,r,c_{r,1},m_0}) + \left(U_{p_g,r_2,c_{r,2}} \times X_{p_g,r_2,c_{r,2},m_0}\right) + \left(U_{p_h,r_2,c_{p_h}} \times X_{p_h,r_2,c_{p_h},m_0}\right)$ (3.8)

Cost = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}((T_{w,r,m} + U_{p_g,w,r}) \times X_{p_g,w,r,m}) + \sum_{r=1}^{2}(f_r \times Z_{p_g,r}) + \left(f_{r_2} \times Z_{p_h,r_2}\right) + ((T_{w_2,r_2,m_2} + U_{p_h,w_2,r_2}) \times X_{p_h,w_2,r_2,m_2}) + \sum_{r=1}^{2}(Y_{p_g,r,e_r} \times v)$ (3.9)

d) Supermarkets

Revenue = $\sum_{k=1}^{2}(U_{p_g,k,c_{k,1}} \times X_{p_g,k,c_{k,1},m_0}) + \left(U_{p_g,k_2,c_{k,2}} \times X_{p_g,k_2,c_{k,2},m_0}\right) + \left(U_{p_h,k_2,c_{p_h}} \times X_{p_h,k_2,c_{p_h},m_0}\right)$ (3.10)

$$\text{Cost} = \sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \sum_{k=1}^{2}(f_k \times Z_{p_g,k}) + \left(f_{k_2} \times Z_{p_h,k_2}\right) + \left(U_{p_h,s_2,k_2} \times X_{p_h,s_2,k_2,m_2}\right) + \sum_{k=1}^{2}(Y_{p_g,k,e_k} \times v) \quad (3.11)$$

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

$$\sum_{s=1}^{2} Y_{p_g,o,s} + \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,o,w,m} + \sum_{m=1}^{2} X_{p_g,o,c_{o,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,o,k,m} + Y_{p_g,o,e_o} = CAP_o \quad (3.12)$$

$$q_o \times Y_{p_g,o,e_o} = Y_{p_h,e_o,s_2} \quad (3.13)$$

$$Y_{p_g,o,s} = Z_{p_g,s}\ ,\forall_s \quad (3.14)$$

$$Y_{p_h,e_o,s_2} = Z_{p_h,s_2} \quad (3.15)$$

$$l_{s_1} \times Z_{p_g,s_1} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,w,m} + \sum_{m=1}^{2} X_{p_g,s_1,c_{s,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,k,m} \quad (3.16)$$

$$l_{s_2} \times Z_{p_g,s_2} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,w,m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,1},m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,2},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,k,m} \quad (3.17)$$

$$Z_{p_h,s_2} = X_{p_h,s_2,w_2,m_2} + X_{p_h,s_2,k_2,m_2} + X_{p_h,s_2,c_{p_h},m_2} \quad (3.18)$$

$$\sum_{m=1}^{2}(L_{o,w,m} \times X_{p_g,o,w,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times X_{p_g,s,w,m}) = Z_{p_g,w}\ ,\forall_w \quad (3.19)$$

$$X_{p_h,s_2,w_2,m_2} + Y_{p_h,e_w,w_2} = Z_{p_h,w_2} \quad (3.20)$$

$$l_{w_1} \times Z_{p_g,w_1} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_1,r,m} + X_{p_g,w_1,c_{w,1},m_0} + Y_{p_g,w_1,e_w} \quad (3.21)$$

$$l_{w_2} \times Z_{p_g,w_2} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_2,r,m} + X_{p_g,w_2,c_{w,1},m_0} + X_{p_g,w_2,c_{w,2},m_0} + Y_{p_g,w_2,e_w} \quad (3.22)$$

$$Z_{p_h,w_2} = X_{p_h,w_2,r_2,m_2} + X_{p_h,w_2,c_{p_h},m_0} \quad (3.23)$$

$$q_w \times \sum_{w=1}^{2} Y_{p_g,w,e_w} = Y_{p_h,e_w,w_2} \quad (3.24)$$

$$\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{w,r,m} \times X_{p_g,w,r,m}) = Z_{p_g,r}\ ,\forall_r \quad (3.25)$$

$$X_{p_h,w_2,r_2,m_2} + Y_{p_h,e_r,r_2} = Z_{p_h,r_2} \quad (3.26)$$

$$l_{r_1} \times Z_{p_g,r_1} = X_{p_g,r_1,c_{r,1},m_0} + Y_{p_g,r_1,e_r} \quad (3.27)$$

$$l_{r_2} \times Z_{p_g,r_2} = X_{p_g,r_2,c_{r,1},m_0} + X_{p_g,r_2,c_{r,2},m_0} + Y_{p_g,r_2,e_r} \quad (3.28)$$

$$Z_{p_h,r_2} = X_{p_h,r_2,c_{p_h},m_0} \tag{3.29}$$

$$q_r \times \sum_{r=1}^{2} Y_{p_g,r,e_r} = Y_{p_h,e_r,r_2} \tag{3.30}$$

$$\sum_{m=1}^{2}(L_{o,k,m} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times X_{p_g,s,k,m}) = Z_{p_g,k}\ , \forall_k \tag{3.31}$$

$$X_{p_h,s_2,k_2 m_2} + Y_{p_h,e_k,k_2} = Z_{p_h,k_2} \tag{3.32}$$

$$l_{k_1} \times Z_{p_g,k_1} = X_{p_g,k_1,c_{k,1},m_0} + Y_{p_g,k_1,e_k} \tag{3.33}$$

$$l_{k_2} \times Z_{p_g,k_2} = X_{p_g,k_2,c_{k,1},m_0} + X_{p_g,k_2,c_{k,2},m_0} + Y_{p_g,k_2,e_k} \tag{3.34}$$

$$Z_{p_h,k_2} = X_{p_h,k_2,c_{p_h},m_0} \tag{3.35}$$

$$q_k \times \sum_{k=1}^{2} Y_{p_g,k,e_k} = Y_{p_h,e_k,k_2} \tag{3.36}$$

Constraint 2: Requirements must be fulfilled.

$$X_{p_g,r_1,c_{r,1},m_0} + X_{p_g,r_2,c_{r,1},m_0} \le D_{p_g,c_{r,1}} \tag{3.37}$$

$$X_{p_g,r_2,c_{r,2},m_0} \le D_{p_g,c_{r,2}} \tag{3.38}$$

$$X_{p_g,w_1,c_{w,1},m_0} + X_{p_g,w_2,c_{w,1},m_0} \le D_{p_g,c_{w,1}} \tag{3.39}$$

$$X_{p_g,w_2,c_{w,2},m_0} \le D_{p_g,c_{w,2}} \tag{3.40}$$

$$\sum_{m=1}^{2}(L_{o,c_{o,1},m} \times X_{p_g,o,c_{o,1},m}) \le D_{p_g,c_{o,1}} \tag{3.41}$$

$$\sum_{m=1}^{2}(L_{s_1,c_{s,1},m} \times X_{p_g,s_1,c_{s,1},m}) + \sum_{m=1}^{2}(L_{s_2,c_{s,1},m} \times X_{p_g,s_2,c_{s,1},m}) \le D_{p_g,c_{s,1}} \tag{3.42}$$

$$\sum_{m=1}^{2}(L_{s_2,c_{s,2},m} \times X_{p_g,s_2,c_{s,2},m}) \le D_{p_g,c_{s,2}} \tag{3.43}$$

$$X_{p_g,k_1,c_{k,1},m_0} + X_{p_g,k_2,c_{k,1},m_0} \le D_{p_g,c_{k,1}} \tag{3.44}$$

$$X_{p_g,k_2,c_{k,2},m_0} \le D_{p_g,c_{k,2}} \tag{3.45}$$

$$X_{p_h,s_2,c_{p_h},m_2} + X_{p_h,w_2,c_{p_h},m_0} + X_{p_h,r_2,c_{p_h},m_0} + X_{p_h,k_2,c_{p_h},m_0} \le D_{p_h,c_{p_h}} \tag{3.46}$$

Constraint 3: Non-negativity constraints

All decision variables ≥ 0 (3.47)

In the model, the objective function, Equation (3.1), 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 (3.2) – (3.11). The revenue and cost of the supply source are calculated by adding the revenue in Equations (3.2) and (3.4) and the cost in Equations (3.3) and (3.5) for no storage and internal storage, respectively. Constraints (3.12) - (3.36) are flow balance between flow in and flow out. The flow of incoming shipments must be equal to the number of fruits stored at the stage. The number 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 (3.37) - (3.46) are customer requirements that must be fulfilled. Because of storage and transportation losses, customers may receive the number of fruits that are less than or equal to their demand. Constraints (3.47) are non-negativity constraints.

CHAPTER 4
DATA COLLECTION AND CASE STUDY MODEL

Presented in this chapter are the data collection for analyzing in the optimization model to be used for determining total cost, revenue, and profit. The data collection and case study model consist of two main parts which are data collection and case study model of mangosteen in eastern region. In the case study model described also the data for optimization, a specific cold chain network, and modified mathematical model that fit the framework of the product in the case study.

4.1 Data collection

Data were collected from both online and onsite information. For the data that are from reliable sources or official websites are given in Table 4.1. For additional information that could not be obtained from the website or official data can be collected from supply sources or farmers directly, wholesalers or Talaad Thai, large retailers such as supermarkets like tops and small retailers such as local markets and on social media platforms such as Facebook, Instagram, Shopee, and Lazada. In addition, fixed costs for transportation and storage are obtained from the suppliers like Thai Post, SCG, and Inter Express company. The ambient storage cost is from Inter Express logistics company and cold storage cost is from SCG Express logistics company as can be seen in Table 4.2. Additional information such as loss rate for transportation and loss for storage in agricultural products for either ambient or cold mode are given in Table 4.3.

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 sources

No.	Data source		Provides information about:
1	Supply sources	Farmers	Agricultural production information
2	Wholesalers	Talaad Thai	
3	Small Retailer	Local markets and social media platforms	
4	Large Retailer	Supermarkets	
5	Third-party logistics	Thai Post, SCG 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 model for mangosteen in eastern region

4.2.1 Data for the optimization model

For the optimization model. The parameters that are used in the optimization model for mangosteen supply chain include the customer demand, unit cost, unit price, transportation cost, and storage cost. The assumed demand in base case without processed product will be set as approximately 20% for cold mode and 80% for ambient mode and assumed demand in base case with processed product will be set as 10% for cold mode, 80% for ambient mode and 10% for the processed product based on the current situation. The initial capacity at supply source will be assumed to be 1,000 kilograms and set capacity at other nodes to be unlimited capacity. In addition, the proportion of the demand will be set according to the market channel by 40% for small fruit stores, 15% for wholesale market, 10% for directly from supply sources, 10% for internal storage ambient, 20% for internal storage cold, and 25% for supermarkets.

The unit cost or planting cost at the supply source for mangosteen in eastern region is 12.12 baht per kilogram and the unit selling price for selling fresh and processed product from origin node to other destination nodes is given in Table 4.4. Storage cost with ambient mode is 0.294 baht per kilogram obtained from Inter Express Logistic and cold mode is 1.80 baht per kilogram form SCG Logistic. Transportation cost, the supply source and internal storage delivered product to wholesale market and supermarket at the same rate at an ambient 0.88 baht per kilogram obtained from Tawetruck. For cold transport from Sicha Transport is 4.90 baht per kilogram, same with the transportation costs from the wholesale market to a small fruit store, respectively. In addition, the cost for processed product, mangosteen cold-press juice that will consist of material cost, packaging cost and labor cost is 15.88 baht per kilogram. The processed product will be sold from supply source to customers. Unit price for processed product is also given and the unit price is 150 baht per 220 milliliter or 681.82 baht per kilogram and the additional transportation cost with the cold transportation mode. For the processed product, we need to add the conversion factor that refers to the proportion of fresh agricultural product that will be transferred to the process and for the processed product of mangosteen, the conversion factor is 22% for this processed product.

Table 4.4 Parameters in the optimization model for mangosteen in eastern region.

Origin	Destination	Unit price (baht/kg)
Supply source	Wholesale market	29.02
	Supermarkets	33.83
	Customer for supply source (No storage)	90.00
Internal storage	Wholesale market	29.02
	Supermarkets	33.83

	Customer for internal storage (Ambient)	90.00
	Customer for internal storage (Cold)	120.00
	Customer who buys processed product	681.82
Wholesale market	Small fruit stores	48.33
	Customer for wholesale market (Ambient)	65.00
	Customer for wholesale market (Cold)	75.00
Small fruit stores	Customer for small fruit stores (Ambient)	70.00
	Customer for small fruit stores (Cold)	85.00
Supermarkets	Customer for supermarkets (Ambient)	159.00
	Customer for supermarkets (Cold)	159.00

4.2.2 Specific cold chain network for mangosteen in eastern region

Nowadays, Demand for fresh mangosteen in the country trends to increase and productivity per rai has increased as well. Mangosteen is easy to buy from wholesale markets, small fruit stores, and supermarkets during harvest season. After harvested, 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 because if mangosteen is stored at ambient temperature, it can be stored for seven days and deteriorate, causing less product to sell and the product is low quality, which means temperature affects the quality of the product.

In addition, producers also want to add value to their products by bringing fresh fruit to be processed in order to have more value that can be sold at a higher price, as in the case of mangosteen in Chanthaburi, bringing it to make Mangosteen Cold-Press Juice, is only processed in the supply source. Then, they will process and pack for customers or store in the internal storage before selling to customers. The cold chain network for fresh mangosteen together with processed mangosteen is shown in Figure 4.1. The network is similar to the generic cold chain network for fresh agricultural and processed products 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. However, only the supply source has the processing facility to do the processed fruit before shipping to customers.

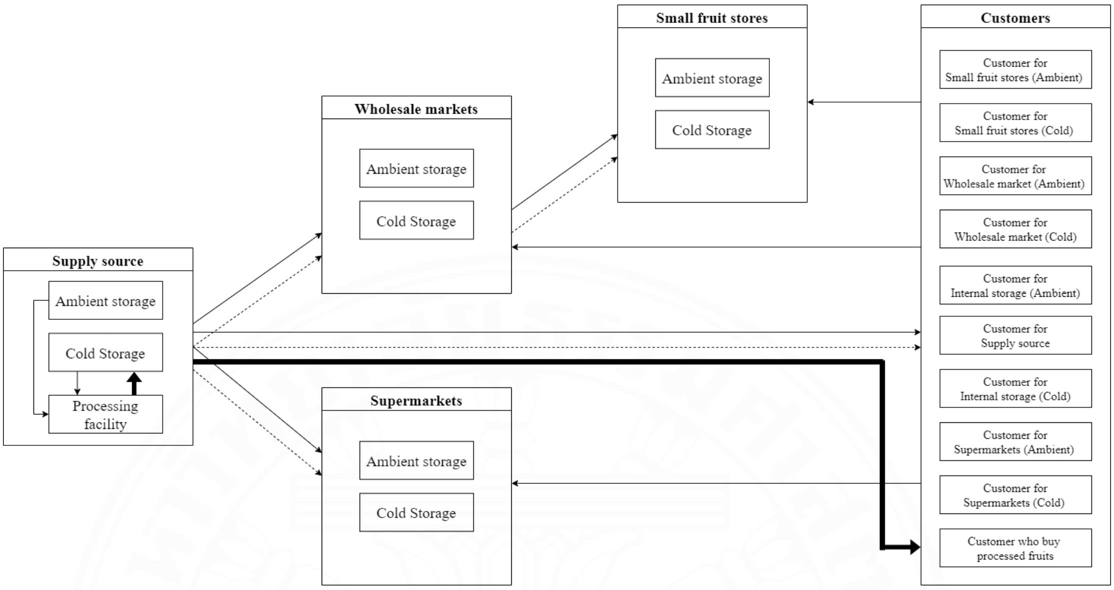

Figure 4.1 Supply chain network for fresh and processed mangosteen in the eastern region.

4.2.3 Specific mathematical model for mangosteen in eastern region

Additional model assumptions for mangosteen in the eastern region.

- The processed mangosteen (Mangosteen Cold-Press Juice) 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

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

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

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

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.

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

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.

Total profit = Total Revenue -Total Cost (4.1)

a) Supply Source

iii) No storage

Revenue = $\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}) + \sum_{m=1}^{2}(L_{o,c_{o,1},m} \times U_{p_g,o,c_{o,1}} \times X_{p_g,o,c_{o,1},m})$ (4.2)

Cost = $\sum_{w=1}^{2}\sum_{m=1}^{2}((u_o + T_{o,w,m}) \times X_{p_g,o,w,m}) + \sum_{k=1}^{2}\sum_{m=1}^{2}((u_o + T_{o,k,m}) \times X_{p_g,o,k,m}) + \sum_{m=1}^{2}(u_o \times X_{p_g,o,c_{o,1},m}) + ((u_o + v) \times Y_{p_g,o,e_o})$ (4.3)

iv) Internal storage

Revenue = $\sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times X_{p_g,s,w,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,c_{s,1},m} \times U_{p_g,s,c_{s,1}} \times X_{p_g,s,c_{s,1},m}) + \sum_{m=1}^{2}\left(L_{s_2,c_{s,2},m} \times U_{p_g,s_2,c_{s,2}} \times X_{p_g,s_2,c_{s,2},m}\right) + \left(U_{p_h,s_2,c_{p_h}} \times X_{p_h,s_2,c_{p_h},m_2}\right)$ (4.4)

Cost = $\sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(T_{s,w,m} \times X_{p_g,s,w,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(T_{s,k,m} \times X_{p_g,s,k,m}) + \sum_{s=1}^{2}((f_s + u_o) \times Z_{p_g,s}) + \left(f_{s_2} \times Z_{p_h,s_2}\right)$ (4.5)

b) Wholesale markets

Revenue = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}(U_{p_g,w,r} \times X_{p_g,w,r,m}) + \sum_{w=1}^{2}(U_{p_g,w,c_{w,1}} \times X_{p_g,w,c_{w,1},m_0}) + (U_{p_g,w_2,c_{w,2}} \times X_{p_g,w_2,c_{w,2},m_0})$ (4.6)

Cost = $\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \sum_{s=1}^{2}\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times U_{p_g,s,w} \times X_{p_g,s,w,m}) + \sum_{w=1}^{2}(f_w \times Z_{p_g,w})$ (4.7)

c) Small fruit stores

Revenue = $\sum_{r=1}^{2}(U_{p_g,r,c_{r,1}} \times X_{p_g,r,c_{r,1},m_0}) + \left(U_{p_g,r_2,c_{r,2}} \times X_{p_g,r_2,c_{r,2},m_0}\right)$ (4.8)

Cost = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}((T_{w,r,m} + U_{p_g,w,r}) \times X_{p_g,w,r,m}) + \sum_{r=1}^{2}(f_r \times Z_{p_g,r})$ (4.9)

d) Supermarkets

Revenue = $\sum_{k=1}^{2}(U_{p_g,k,c_{k,1}} \times X_{p_g,k,c_{k,1},m_0}) + \left(U_{p_g,k_2,c_{k,2}} \times X_{p_g,k_2,c_{k,2},m_0}\right)$ (4.10)

Cost = $\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times U_{p_g,s,k} \times X_{p_g,s,k,m}) + \sum_{k=1}^{2}(f_k \times Z_{p_g,k})$ (4.11)

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

$\sum_{s=1}^{2} Y_{p_g,o,s} + \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,o,w,m} + \sum_{m=1}^{2} X_{p_g,o,c_{o,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,o,k,m} + Y_{p_g,o,e_o} = CAP_o$ (4.12)

$q_o \times Y_{p_g,o,e_o} = Y_{p_h,e_o,s_2}$ (4.13)

$Y_{p_g,o,s} = Z_{p_g,s}\ , \forall_s$ (4.14)

$Y_{p_h,e_o,s_2} = Z_{p_h,s_2}$ (4.15)

$l_{s_1} \times Z_{p_g,s_1} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,w,m} + \sum_{m=1}^{2} X_{p_g,s_1,c_{s,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_1,k,m}$ (4.16)

$l_{s_2} \times Z_{p_g,s_2} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,w,m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,1},m} + \sum_{m=1}^{2} X_{p_g,s_2,c_{s,2},m} + \sum_{k=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,k,m}$ (4.17)

$$Z_{p_h,s_2} = X_{p_h,s_2,c_{p_h},m_2} \quad (4.18)$$

$$\sum_{m=1}^{2}(L_{o,w,m} \times X_{p_g,o,w,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,w,m} \times X_{p_g,s,w,m}) = Z_{p_g,w} \text{ , } \forall_w \quad (4.19)$$

$$l_{w_1} \times Z_{p_g,w_1} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_1,r,m} + X_{p_g,w_1,c_{w,1},m_0} \quad (4.20)$$

$$l_{w_2} \times Z_{p_g,w_2} = \sum_{r=1}^{2}\sum_{m=1}^{2} X_{p_g,w_2,r,m} + X_{p_g,w_2,c_{w,1},m_0} + X_{p_g,w_2,c_{w,2},m_0} \quad (4.21)$$

$$\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{w,r,m} \times X_{p_g,w,r,m}) = Z_{p_g,r} \text{ , } \forall_r \quad (4.22)$$

$$l_{r_1} \times Z_{p_g,r_1} = X_{p_g,r_1,c_{r,1},m_0} \quad (4.23)$$

$$l_{r_2} \times Z_{p_g,r_2} = X_{p_g,r_2,c_{r,1},m_0} + X_{p_g,r_2,c_{r,2},m_0} \quad (4.24)$$

$$\sum_{m=1}^{2}(L_{o,k,m} \times X_{p_g,o,k,m}) + \sum_{s=1}^{2}\sum_{m=1}^{2}(L_{s,k,m} \times X_{p_g,s,k,m}) = Z_{p_g,k} \text{ , } \forall_k \quad (4.25)$$

$$l_{k_1} \times Z_{p_g,k_1} = X_{p_g,k_1,c_{k,1},m_0} \quad (4.26)$$

$$l_{k_2} \times Z_{p_g,k_2} = X_{p_g,k_2,c_{k,1},m_0} + X_{p_g,k_2,c_{k,2},m_0} \quad (4.27)$$

Constraint 2: Requirements must be fulfilled.

$$X_{p_g,r_1,c_{r,1},m_0} + X_{p_g,r_2,c_{r,1},m_0} \leq D_{p_g,c_{r,1}} \quad (4.28)$$

$$X_{p_g,r_2,c_{r,2},m_0} \leq D_{p_g,c_{r,2}} \quad (4.29)$$

$$X_{p_g,w_1,c_{w,1},m_0} + X_{p_g,w_2,c_{w,1},m_0} \leq D_{p_g,c_{w,1}} \quad (4.30)$$

$$X_{p_g,w_2,c_{w,2},m_0} \leq D_{p_g,c_{w,2}} \quad (4.31)$$

$$\sum_{m=1}^{2}(L_{o,c_{o,1},m} \times X_{p_g,o,c_{o,1},m}) \leq D_{p_g,c_{o,1}} \quad (4.32)$$

$$\sum_{m=1}^{2}(L_{s_1,c_{s,1},m} \times X_{p_g,s_1,c_{s,1},m}) + \sum_{m=1}^{2}(L_{s_2,c_{s,1},m} \times X_{p_g,s_2,c_{s,1},m}) \leq D_{p_g,c_{s,1}} \quad (4.33)$$

$$\sum_{m=1}^{2}(L_{s_2,c_{s,2},m} \times X_{p_g,s_2,c_{s,2},m}) \leq D_{p_g,c_{s,2}} \quad (4.34)$$

$$X_{p_g,k_1,c_{k,1},m_0} + X_{p_g,k_2,c_{k,1},m_0} \leq D_{p_g,c_{k,1}} \quad (4.35)$$

$$X_{p_g,k_2,c_{k,2},m_0} \leq D_{p_g,c_{k,2}} \quad (4.36)$$

$$X_{p_h,s_2,c_{p_h},m_2} + X_{p_h,w_2,c_{p_h},m_0} + X_{p_h,r_2,c_{p_h},m_0} + X_{p_h,k_2,c_{p_h},m_0} \leq D_{p_h,c_{p_h}} \quad (4.37)$$

Constraint 3: Non-negativity constraints

All decision variables ≥ 0 (4.38)

In the model, the objective function, Equation (4.1), 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 (4.2) – (4.11). The revenue and cost of the supply source are calculated by adding the revenue in Equations (4.2) and (4.4) and the cost in Equations (4.3) and (4.5) for no storage and internal storage, respectively. Constraints (4.12) - (4.27) are flow balance between flow in and flow out. The flow of incoming shipments must be equal to the number of fruits stored at the stage. The number 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 (4.28) - (4.37) are customer requirements that must be fulfilled. Because of storage and transportation losses, customers may receive the number of fruits that are less than or equal to their demand. Constraints (4.38) are non-negativity constraints.

CHAPTER 5
RESULT AND DISCUSSION

This chapter shows the optimal solution of decision variables from solving the mathematical model in fresh mangosteen model and fresh and processed mangosteen, and also a summary of the revenue, cost, and profit of each stage in the supply chain and also the total revenue, cost and profit of whole supply chain then, show the suggested plan for using cold chain management in the supply chain and sensitivity analysis will be provided at the end of the chapter.

5.1 Result for fresh mangosteen (Base case)

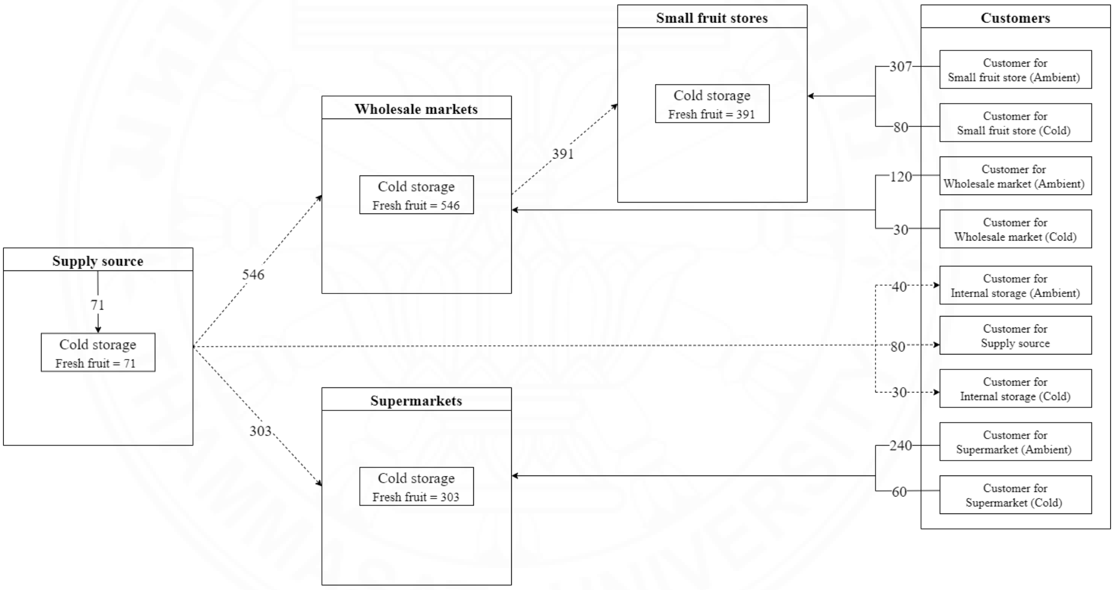

Figure 5.1 Result network of fresh mangosteen in the supply chain.

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	40,503.77	16,408.80	24,094.96
Wholesale market	28,936.89	16,835.51	12,101.38
Small fruit stores	28,281.48	21,505.17	6,776.31
Supermarkets	47,700.00	10,796.97	36,903.03
Total	145,422.13	65,546.45	79,875.69

Table 5.2 Satisfied demand of mangosteen in each market channel

Origin	Destination	Actual demand (kg)	Satisfied demand	
			(kg)	(%)
Supply source	Customer for supply source (No storage)	80	80	100%
Internal storages	Customer for internal storage (Ambient)	40	40	100%
	Customer for internal storage (Cold)	30	30	100%
Wholesale markets	Customer for wholesale market (Ambient)	120	120	100%
	Customer for wholesale market (Cold)	30	30	100%
Small fruit stores	Customer for small fruit store (Ambient)	320	307	96%
	Customer for small fruit store (Cold)	80	80	100%
Supermarkets	Customer for supermarket (Ambient)	240	240	100%
	Customer for supermarket (Cold)	60	60	100%

Discussion

After we applying all data in the base case model without the demand of the processed product, we assume the ambient products demand for 80% and cold products demand 20% and then perform an experiment for fresh mangosteen supply chain by mixed-integer linear programming and using Excel Open Solver to solve the problem and find the optimal solution in order to find the appropriate route, storage mode and, transportation mode and then make a maximum profit in each of supply chain members also the whole supply chain of the fresh mangosteen. The model will generate the suggested result as shown in Figure 5.1 above. All nodes in the network store the product in cold mode. The transportation between which nodes in the network are only in cold mode as well as the storage. The number of products is stored in each node and the number of products is transported between nodes as shown in Figure 5.1. The capacity at the supply source starts with 1,000 kilograms. The route began with the supply source sending mangosteen to store in the cold storage of the internal storage and sent through the wholesale market and supermarket by cold transportation mode. Then, the small fruit stores will receive the product from the wholesale market by cold transportation mode and in the supply source node will send mangosteen to the end customer but in other stages, the customer will come and buy it.

The finding results. Consist of cost, revenue, and profit in all stages of the supply chain are given in Table 5.1. The total profit in the whole mangosteen supply chain stage is 79,875.69 baht. And most of the profit and revenue come from supermarkets because this stage has the highest selling price.

According to the demand satisfaction shown in Table 5.2 can indicates that the initial capacity at the supply source (1,000 kg) can mostly satisfy the customer demand except for the customer from a small fruit stores with ambient demand that can satisfy 96% because the small fruit stores did not receive enough product to meet the demand from the wholesale market due to we limited the capacity of the supply source and the model suggested to satisfy customer demand for cold mode before ambient mode because the cold product makes a higher profit than an ambient product.

5.2 Result for fresh and processed mangosteen (Base case with processed fruit)

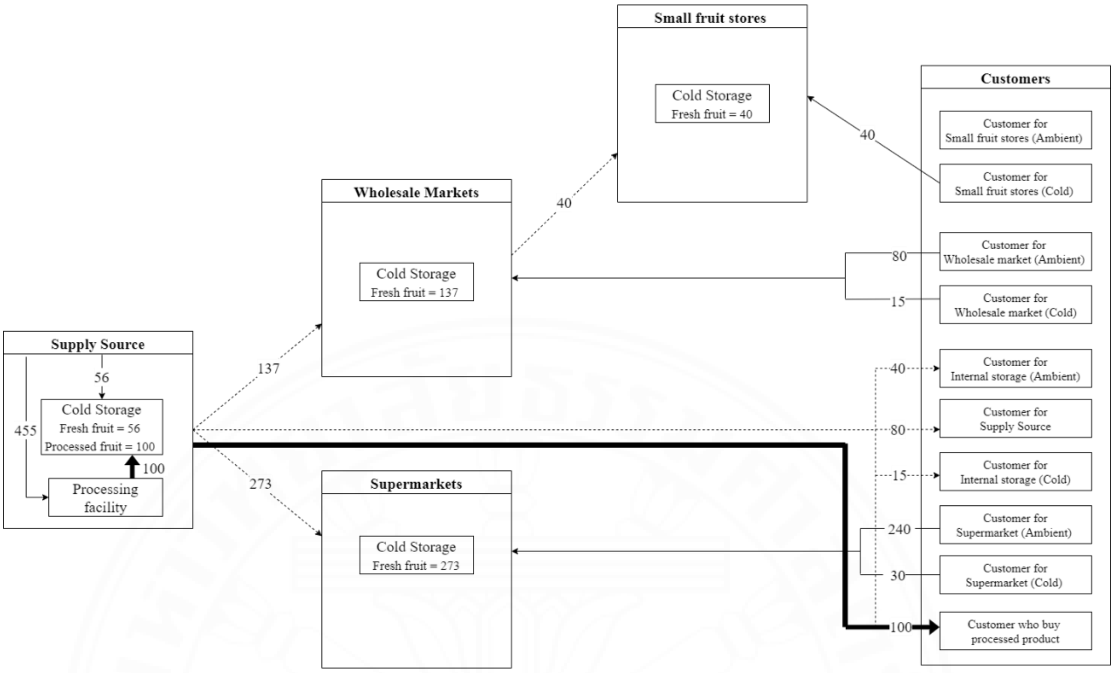

Figure 5.2 Result network of fresh and processed mangosteen in the supply chain.

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	93,988.93	21,626.68	72,362.25
Wholesale market	8,303.11	4,227.46	4,075.64
Small fruit stores	3,400.00	2,223.46	1,176.54
Supermarkets	42,930.00	9,717.27	33,212.73
Total	148,622.04	37,794.87	110,827.16

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)	80	80	100%

Internal storages	Customer for internal storage (Ambient)	40	40	100%
	Customer for internal storage (Cold)	15	15	100%
Internal storage with cold storage	Customer who buys processed fruit	100	100	100%
Wholesale markets	Customer for wholesale market (Ambient)	120	80	67%
	Customer for wholesale market (Cold)	15	15	100%
Small fruit stores	Customer for small fruit store (Ambient)	320	0	0%
	Customer for small fruit store (Cold)	40	40	100%
Supermarkets	Customer for supermarket (Ambient)	240	240	100%
	Customer for supermarket (Cold)	30	30	100%

Discussion

Extended the model from the base case model without the demand for processed products. This optimization model is for fresh mangosteen and processed mangosteen products, mangosteen cold-press juice in Thailand's eastern region. Assuming the ambient products demand 80% and cold products demand for 10%, and 10% for the processed product then perform an experiment for fresh and processed mangosteen supply chain by mixed-integer linear programming and using Excel Open Solver to solve the problem and find the optimal solution in order to find the appropriate route, storage mode, and transportation mode and then make a maximum profit in each of supply chain members also the whole supply chain of the mangosteen. The model will generate the suggested result as shown in the Figure 5.2 above. All nodes in the network store the product in cold mode. The transportation between which nodes in the network are only in cold mode as well as the storage. The number of products is stored in each node and the number of products is transported between nodes as shown in Figure 5.2.

Starting from 1,000 kilograms of fresh mangosteen at supply source then transport into the fresh product or processed into mangosteen cold-press juice to different stages. The route of fresh mangosteen began with the supply source sending mangosteen to store in the cold storage of the internal storage and sent through wholesale markets and supermarkets by cold transportation mode. Then, the small fruit store will receive the product from the wholesale market by cold transportation mode and in the supply source stage will send mangosteen directly to the end customer but in other stages, the customer will come and buy it. On the processed product side, the route of processed mangosteen began with the supply source sending fresh mangosteen to the processed stage at the supply source and then process it to the mangosteen cold-press juice and then sending mangosteen cold-press juice to store in the cold internal storage before sending to the customer or direct to the end customer.

The finding results. Consist of cost, revenue, and profit in all stages of the supply chain are given in Table 5.3. The total profit in the whole mangosteen supply chain stage is 110,827.16 baht. Most of the profit comes from the supply source stage because this stage has the sale of both the fresh and processed products and the processed products will generate the highest selling price that causes the highest profit.

According to the demand satisfaction as shown in Table 5.4 can indicate that the initial capacity at supply source (1,000 kg) can mostly satisfy the customer demand except for demand of customers for a small fruit stores in ambient mode at all and satisfy the customer for the wholesale market in ambient mode only 67% because we limited the capacity of the supply source the model suggest satisfy the demand for the processed product first because the unit of the selling price is high that can make more profit to the supply chain and in order to satisfy the demand for cold and ambient product respectively.

However, cold chain systems still have a loss from transport and storage but less than in ambient mode. So, both models suggest that cold storage and cold transportation are used in the fresh and processed mangosteen supply chain indicate that cold chain management is necessary in order to maintain the quality and freshness and also extend the shelf life of the product causing more products to be sold then generate the maximum profit moreover if we add the value in the product to be more value-added like the processed product cold chain is even more necessary to maintain the quality of the product and prevent the loss of the product.

From the result, the required cold storage capacity at each location can be determined. The number of products stored in each storage that obtains from the model will be the maximum storage capacity at each location for initial capacity at the supply source in this case for 1,000 kilograms but with a larger initial capacity, the model also suggests the suitable capacity as well as the transportation, the number of products are transported between node shown on the arc it also becomes the maximum transport capacity in each route in the network model. These two values, storage, and transport capacity can be used to plan to use cold storage or build up cold storage in a particular region and can be used to calculate the number of vehicles used in transportation and planning transportation as well.

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 the ambient spectrum that is no cold allowed, demand, price elasticity for both fresh fruits and processed fruits, loss for storage, and loss for transportation are considered.

5.3.1 Comparison of the total profit between base case and extreme case of ambient spectrum (No cold allowed)

When comparing the total profit of the base case of fresh fruits and extreme case of ambient spectrum (no cold allowed) in each node as shown in Table 5.5. 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 Figure 5.3, the highest profit is on the supermarket nodes.

Table 5.5 The comparison of total profit between base case and extreme case of ambient spectrum in each node for mangosteen.

Case	Supply source	Wholesale markets	Small fruit stores	Supermarkets	Total profit
Base case	24,094.96	12,101.38	6,776.31	36,903.03	79,875.69
Extreme case of the ambient spectrum (No cold allowed)	21,700.52	9,514.06	2,721.27	29,160.26	63,096.11
The difference in profit	2,394.44	2,587.32	4,055.04	7,742.77	16,779.57

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

5.3.2 Sensitivity analysis for demand and price

According to Figure 5.4 demonstrates the relationship between the adjustable percentage of demand sensitivity from 0% to 100 % compared with the total profit, revenue, and cost. The trend of total profit seems to be gradually increasing from the demand of 0% to 100% for cold chains, which means when the demand of mangosteen that uses the cold chain system is increased, the total cost will increase but total revenue increase more, resulting in greater total profits as well. 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.

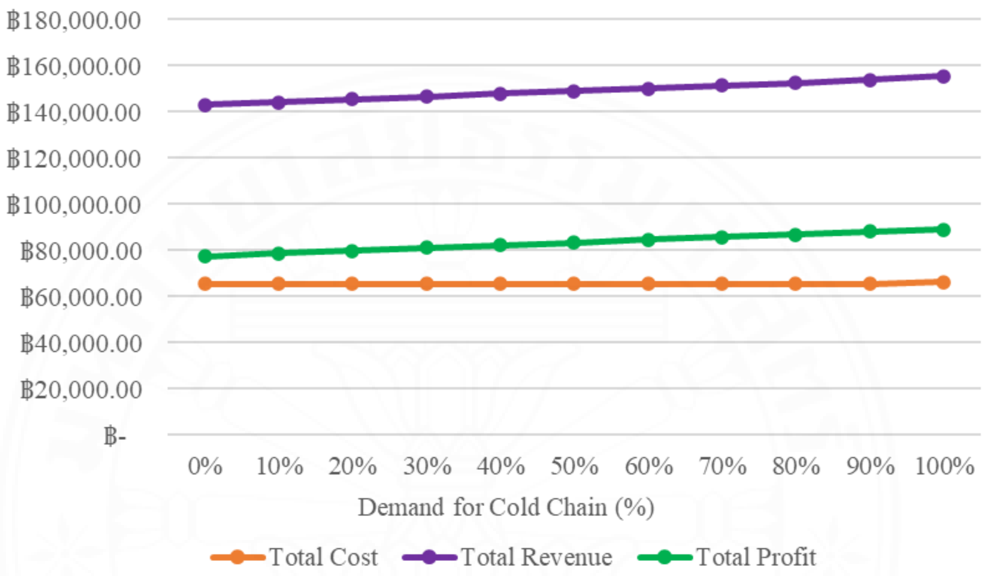

Figure 5.4 Sensitivity analysis for demand

Then, consider the demand and price in terms of if have more demand in the cold chain that means the supply of fresh product will be available more, price should be reduced also at the end of the supply chain toward the customer's hand. Then, try to adjust the data to be more reasonable in the case of price elasticity of demand by assuming that when the demand for product increases, the price of product little reduce because of the more supply and adapt in the cold product by if cold demand increases to 60%, the cold product prices will decrease linearly until cold demand reaches 100% the unit price for the cold product will be equal to the unit price for ambient product ambient in every stage expect in large retailer because the cold and ambient price are equal since the beginning.

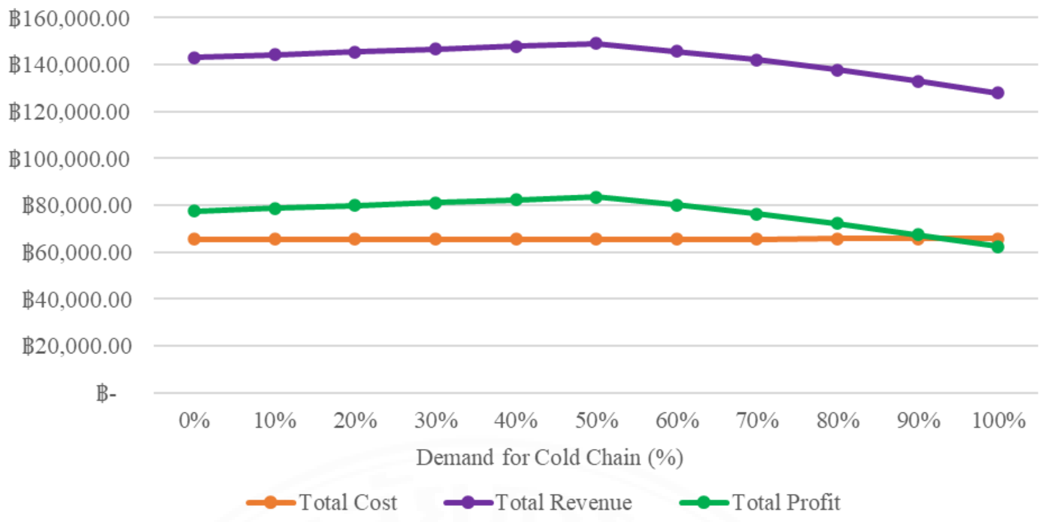

Figure 5.5 Sensitivity analysis for demand and price

After performing the relation between the adjustable percentage of demand that shown in Figure 5.5 and see that from 60 % to 100% of demand for the cold chain that adjusts the price base on the price elasticity the total revenue tend to decrease because sell the product at a lower price than before that cause the total profit also decrease.

Base on the result when adjusting the unit price of the cold product in elasticity, found that the model still suggests the same decision in every scenario that to using both cold storage and cold transport in the supply chain. Although the unit price of cold products is reduced to the same as the unit price in ambient products, the use of cold chain may be slightly reduced because the selling price is not as high as the first but still uses a cold chain that means the cold chain is robustness.

5.3.3 Sensitivity analysis for loss storage

For the sensitivity analysis for loss rate in storage with the ambient mode that is shown in Figure 5.6. 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.

From the graph can state that if the loss rate of the ambient storage is very small the product will store in the ambient mode because the cost of storage in ambient mode is a lower price than the cold mode but if the loss rate of the store in ambient mode is increased, the model will change their decision from the store the product in the ambient mode to use cold mode and from the graph when the loss rate increase to 3.4 % that will change the decision in the mode of storage that changes from using the ambient mode to using the cold storage instead of for keeping the quality or freshness of the product when storing in the storage.

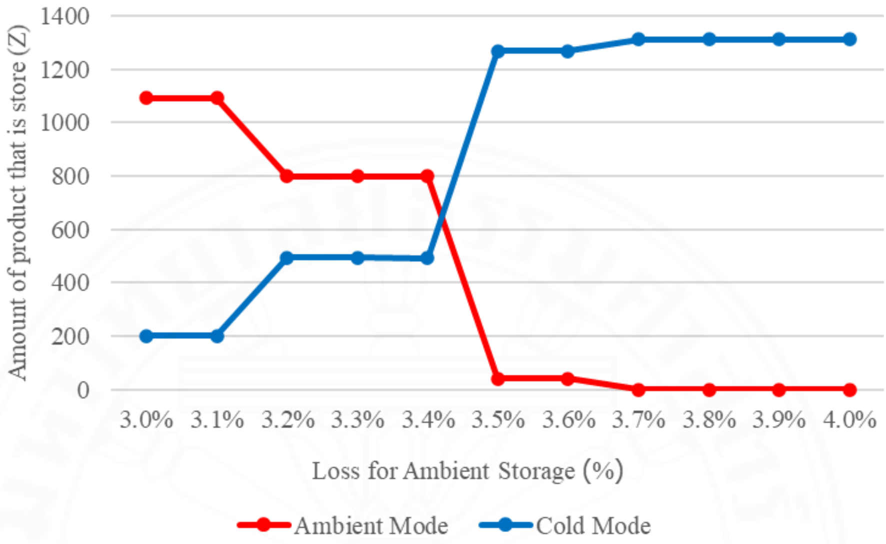

Figure 5.6 Sensitivity analysis for loss storage

5.3.4 Sensitivity analysis for loss transportation

Figure 5.7 shows the sensitivity analysis for loss rate in transportation with ambient mode. this relationship between the amount of product that is transported 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.

From the graph can state that if the loss rate of the ambient transportation is very small the product will transport in the ambient mode because the cost of transport in ambient mode is a lower price than the cold mode but if the loss rate of transport in ambient mode is increased, the model will change their decision from the ambient mode to use cold mode for transportation mode and when the loss rate increase to 6.6 % that will change the decision in the mode of transport that change from using the ambient mode to using the cold transport instead for help the maintain quality of the product during transportation.

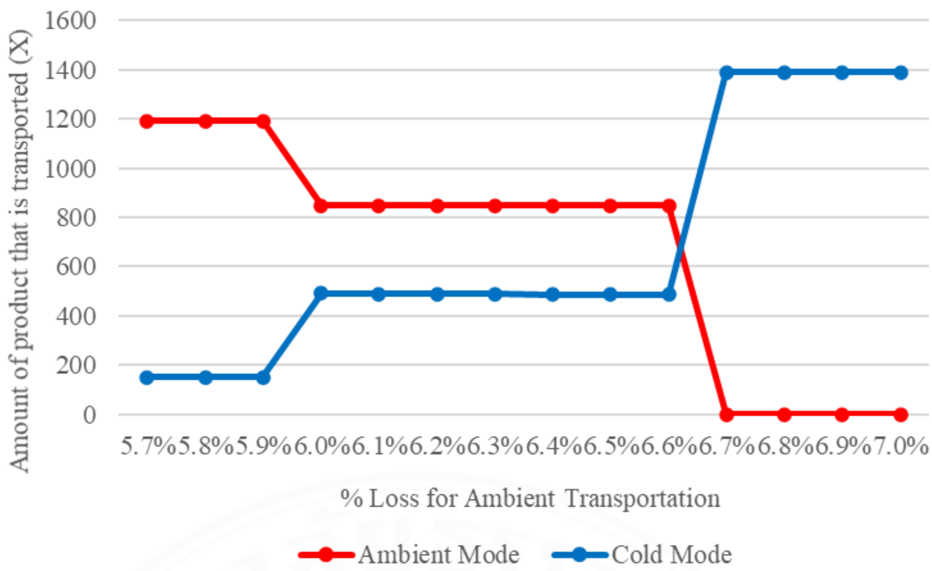

Figure 5.7 Sensitivity analysis for loss transportation

Conclude that in this case of sensitivity analysis for both loss rate of storage and transportation, the suggestion of the model is that when the loss rate in ambient mode has increased the model will change the decision from using in ambient mode to use cold mode instead.

5.3.5 Sensitivity analysis for the price of processed fruit product

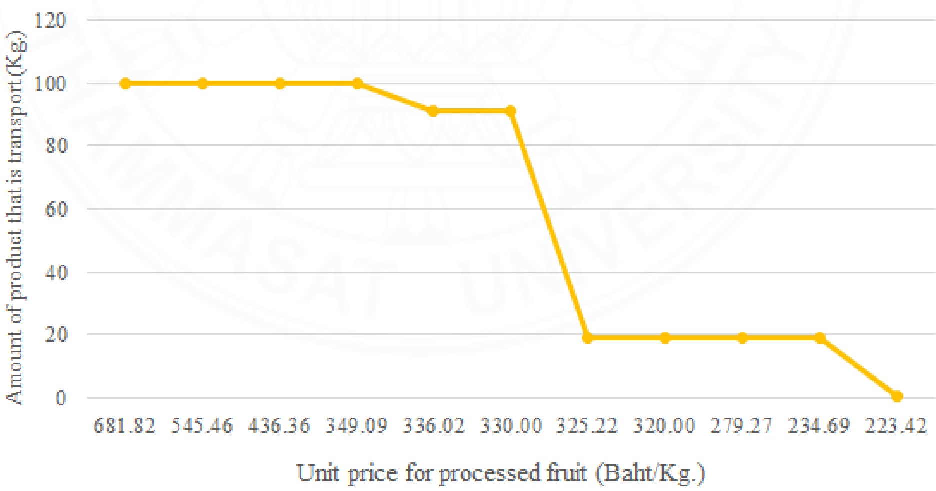

Figure 5.8 Sensitivity analysis for the price of processed mangosteen

For the sensitivity analysis for the price of processed fruit, mangosteen cold-pressed juice is shown in Figure 5.8. Considering the unit price of processed fruit to find out how much the price has dropped to what price it is not worth making processed fruit. The current unit price for processing fruit is 681.82 baht per kilogram and the amount of processed fruit that can be sold is 100 kilogram that is, the amount that can satisfy all the customer demand. However, if the value of the processed fruit does not increase much or the unit price for the processed fruit decreases until the price of 336.02 baht per kilogram, the processed fruit can be sold at 91 kilograms which can satisfy the customers demand up to 91%, a slight decrease from the current one then, can indicate that it is still worth to processing the product. But if the unit price of the processed fruit is reduced to 325.22 baht per kilogram it can show that the sales volume of processed fruit has greatly decreased came in at 19 kilograms it can satisfy customer demand only 19%, which may show that if the unit price for processed fruit is at this price, it will be less profitable from selling the product, or it may not be worth to processed the product for sale but when the unit price for processed fruit decreases until it reaches 223.42 baht per kilogram or less. The sales volume of processed fruit is 0 which shows it is not worth processing the product.

CHAPTER 6
CONCLUSION AND RECOMMENDATION

This chapter consists of the conclusion and recommendations in the way to manage the supply chain for the benefit of individual members in the supply chain, also the customer base on the result and the recommendation for future research.

6.1 Conclusion

For the food and agricultural products supply chains, cold chains play an important role in preserving quality, reducing food spoilage, extending shelf life, and ensuring food safety. Despite these advantages, the implementation of cold chains will make more benefits to supply chain members and increase the value-added to the agricultural products.

In this research, a mixed-integer linear programming model has been formulated to suggest the plan for using cold chain management in the fruit supply chain. The model can estimate the flow of fresh and processed fruit in the supply chain and provide a finding result of revenue, cost, and profit of each stage in the supply chain and also provide the maximum total profit of the whole supply chain of fruit products. Based on the result, the model does not consider only the routing, storage mode, and transportation mode but also concerns customer satisfaction. After getting the optimized model for fresh fruit products, then extend the model by optimizing the that have a potential to use cold chain and aim to make fruit products to be more marketable and attractive to potential customers, and use cold chains to extend their shelf life and maintain the quality of the processed fruit product.

In order to gain the maximum profit and maintain the quality of the product, the results suggest to should use the cold chain management in the supply chain network and also this research can help convince supply chain members to use the proper cold chain systems to maintain the product quality, reduce perishable and increase the value to the fruit products.

6.2 Recommendation

Recommendation for managing the supply chain for the benefit verbally to the user or the supply chain member based on the result. Convincing all members in the whole supply chain to believe in the result or to follow the result of the model by making trust in collaboration planning to collaborate and share the information otherwise there is no supply chain management and then explain the benefit to each of them.

If investing more in the cold chain, the higher quality products are available to customers. The supply source should use more cold chains because it will get less loss during storage and transportation, more of the remaining products to be sold, and when the product is high quality, it will make the product sell at a more expensive price then resulting in more income.

In the wholesale markets, small fruit stores and supermarkets get the benefit because if products arrive in cold, there will be a lot of products left for sale and no need to sort out the waste again. In terms of cold storage service providers will also get the benefit because the supply chain recognizes the importance of using a cold chain. It will make the cold storage that is underutilized will be used by more supply chain members and the service provider should set an attractive price. The cold transport market is likely to expand with the promotion. In addition, the model can also identify which area or which stage there should be used for cold storage and cold transport, but if there is no service, the model will suggest where service providers should increase the capacity for a particular product.

If cold storage or cold transportation is not available enough, many products will deteriorate quality during transportation and storage and then the amount of good quality product will be reduced and make it more expensive but if quality products are more, customers can able purchase the high-quality product at a slightly lower price that is the benefit to the customer and the benefit to the entire fresh food industry as well.

For further research direction, extending the scope of the problem by adding the time window condition such as the time for product deterioration or adding the quality level of product based on the shelf life. The mathematical model from this research can be improved by adding more factors or information that are related to the product or supply chain problem to make the model more realistic such as cost, consider the cost to cover all aspects realistically, and study various products with a high potential to use a cold chain in the whole country starting from economic crops of the country to involve cold chain management in their system.

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BIOGRAPHY

Name	Ms. Chatsuda Jiaranaicharoen
Date of Birth	December 2, 1997
Education	2019: Bachelor of Science (Management Mathematics) Thammasat University