OPTIMIZATION FOR COLD CHAIN MANAGEMENT IN NORTHERN THAILAND: A CASE STUDY IN SWEET CORN SUPPLY CHAIN

BY

MS. PANNITA SUDMEE

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

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

THAMMASAT UNIVERSITY

ACADEMIC YEAR 2020

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INDEPENDENT STUDY

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MS. PANNITA SUDMEE

ENTITLED

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on July 17, 2021

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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Author	Ms. Pannita Sudmee
Degree	Master of Engineering (Logistics and Supply Chain Systems Engineering)
Faculty/University	Sirindhorn International Institute of Technology/ Thammasat University
Advisor	Associate Professor Dr. Jirachai Buddhakulsomsiri, Ph.D.
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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 northern 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.

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

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CHAPTER 1
INTRODUCTION

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 while waiting to be transported to the market or customers and cold transportation is responsible for transporting cold chain products from storage points or various stakeholders to other stakeholders, markets, or customers. The cold chain plays an important role in preserving quality, reducing food spoilage for customers, extending shelf life, and ensuring food safety. This leads to the ability to maintain the quality of products in storage and the ability to transport products across longer distances and increased customer satisfaction.

Thailand is an agricultural country and has many agricultural products, but Thailand is also a tropical country. Heat and humidity can affect these products and increase the chances of the product more easily spoilage or deteriorate that also 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.

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

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 sweet corn, 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.

The scope of this article is conducted for the purpose of finding suitable fruits and processed products in the northern 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 northern region, the suitable fruit is sweet corn and can be processed into sweet corn milk.

Chiang Mai is the largest province in the northern region with agriculture as an important part of the province's economy. Sweet corn is one of the economic crops of the northern region that is the most cultivated in Chiang Mai province. According to the Office of Agricultural Economics (2020), the cultivation area of sweet corn in Chiang Mai province is 33,724 Rai, and the productivity of sweet corn in Chiang Mai province is 82,538 tons per year. Sweet corn is an agricultural product that is extremely perishable. The characteristic is a high respiration rate. At 30°C, 50% to 60% of the sugar in sweet corn can be converted to starch in one day, resulting in rapid loss of sweetness and tenderness (Nunes, et.al, 2013). Therefore, the shelf life of sweet corn in

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ambient temperature is 1-2 days only but in cold temperature can extend the shelf life of sweet corn to around 7 days. The unit price is 6 - 70 baht per kilogram. Sweet corn milk is a beverage packed with nutrients, minerals, and energy, making it a popular beverage for customers. In addition, sweet corn milk is added value to sweet corn by processing. Sweet corn can be processed by boiling, blending, and extracting the sweet corn pulp to obtain nutritious sweet corn milk. The price is 10 – 40 baht per bottle (180-250 ml) or 40-170 baht per kilogram, which varies in different stages in the supply chain. The shelf life of sweet corn milk in cold temperature (3-7°C) is around 15 days. Therefore, sweet corn milk can increase the selling prices and extend the shelf life of sweet corn.

The supply chain structure has four stages before sending to the end customers: supply sources, wholesale markets, small fruit stores, and supermarkets. All four stages 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.

The remainder of this article is organized as follows. Section 2 summarizes the literature that is related to research topics. Section 3 represents the network, sets, parameters, and decision variables followed by mathematical models. Section 4 shows the collected data. Section 5 explains the result and discussion of the optimization model. Section6 analyze the sensitivity analysis of some input parameters. In section 7, the conclusions and recommendations for further research.

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CHAPTER 2
REVIEW OF LITERATURE

The literature review of previous research related to cold chain management 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 refrigerate is necessary for keeping perishable food, and fresh agricultural products. If not kept at the optimal temperature, the spoilage will occur and cause foodborne illness or food wastes and loss of money (Mercier, Vileneuve, Mondor, and Uysal, 2017). 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, and East, 2018). On the other hand, Indian citizens have an understanding of ensuring perishable foods but still lack awareness in cold chain management. In this article, they collected the data by using a questionnaire and evaluated by Microsoft Excel and SPSS program (Joshi, Banwet, and Shankar, 2010). Indian economy is the second-largest agricultural producer (fruits and vegetable products), but also has the biggest waste due to the fruits and vegetable products is perishability. They state the importance of a proper cold chain system in both storage and transportation to reduce the losses and spoiled rate. In the same way, It can make more revenue and develop the economy of Indian citizens (Negi, and Anand, 2015). The integration of the Cold Chain system and Value Chain analysis in China. Value Chain analysis is used to analyze the different scenarios for constructing the direction

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and policy for cold chain companies. This can lead to an increase in the rate of the cold supply chain due to the growth of high-quality food that can raise the customer demand (Wang, and Yip, 2018). The key success factors from the Indian food industry are developed and analyzed by ten sustainable cold chain management (SCCM). They also construct the semi-structured questionnaire for the cold chain companies. Then, they analyzed the answer from the questionnaire to descriptive statistics. So, sustainability has an impact on cold chain performance, but the customer was not aware of the benefits of low carbon emission (Shashi, Singh, and Shabani, 2016). The China economy is also producing agricultural products, which are perishable and short shelf life. The current status of the cold chain system in China is not fully utilized, and also has a lot of wastes and losses. In addition, the refrigerants that are used for the cold chain system produce greatly CFCs and HCFCs (Zhao, Liu, Tian, Yan, and Wang, 2018). In the American Potato Trade Alliance (APTA), they examined the business correlation of cold supply chains used for exploring new food markets in developing countries by using the on-site observation and interview by open-ended questionnaire. So, the problem that they pointed out is the lack of quality of cold storage capacity outside of the capital city and the distribution cost was expensive (Salin, and Nayga, 2002). In order to analyze the cold chain in fresh agricultural products, the temperature is one of the main effects on the deterioration and has an impact on fruit quality. This paper focused on the temperature breaks in case of exporting the product from Western Cape, South Africa to America in the phases of the oranges farm to cold storage and from cold chain to the port. The analysis is measured by using the iButton to record the temperature inside the pulp of fruits and ambient temperature every 30 minutes in both phases. From the result, they conclude that to make the fruit dry after drenching and set the same temperature as in the packaging place (Goedhals-Gerber, and Khumalo, 2020). Similarly, in the study of the temperature profile of an apple in the case of the Ceres district. They also used the iButton device to measure the temperature inside and outside the apples. However, this research suggested harvesting apples from 7 AM to 9 AM and delivered directly to cold storage. According to the temperature in cold storage is not stable at -0.5 °C due to the storage being regularly open and closed. So, they also suggested improving the operation of the cold chain (Valentine, and Goedhals-Gerber, 2017). The quality of agricultural products and food depends on temperature. It should have any device that traces and controls the temperature, to ensure the quality of the product. They state that Radio Frequency Identify (RFID) Tags and Time-Temperature Indicators and Integrators (TTIs) are used to integrate the time and indicate the shelf life. Temperature monitoring is used in the truck warehouse. Computational Fluid Dynamics (CFD) used to solve the industrial solid problem (Asadi, and Hosseini, 2014). The possible problem that makes money lost during the broken fruit cold chain in Africa investigated by analyzing the temperature of export fruits (Apples, pears, and grapes). They focus on two segments which are the time that is taken to transport from cold storage to the port, the average time that the fruits spend in a port, and also measure the temperature in both segments. From the results, they conclude that the main possible problem is from the port, and almost a quarter of the broken cold chain occurred from 12 PM to 3 PM (Freiboth, Goedhals-Gerber, Dyk, and Dodd, 2013).

2.2 Forecasting and data analysis

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

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able to invest in the cold chain system. So, they only store and deliver by room temperature warehouse and cars (Lan, and Tian, 2013). On the other hand, this research used the fundamental data and the data from the survey and predicted by analyzing the excess of cold chain storage facilities. So, the cold chain storage facilities in South Korea are excessive by 7% for the nationwide average (Son, 2012).

2.3 Optimization model

There is a lot of research about optimization in the cold chain. The perishable food supply chain proposed the research to consider the optimal temperature of a storage and transportation and also consider the cost of energy consumption to optimal price and make a decision by using non-linear optimization to maximize the profit (Yang, et al., 2017). Besides, there is also some research on perishable product optimization, using a mix-integer linear programming model(MILP)to formulate the production-distribution planning with indicating an influence of the weather conditions to minimize overall cost (Riccardo, et al., 2017) another research that focus on the distribution planning to formulate the mathematical model to generate a distribution plan for fulfilling the customer requirement for various foods with quality concern by adapted biogeography-based optimization (BBO) to solve the problem and also applied the genetic algorithm (GA) to be a benchmarking method to minimize the overall cost which consist of a vehicle and product related viewpoint (Hsiao, et al., 2017). In the operation of fresh food supply chains, cold chain plays important role to reducing food spoilage and guarantee food safety then has a research focus to find the optimization model to maximize the manufacturer's profit and the retailer's profit and then optimize decision about investment levels of cold chain construction and advertisement , and pricing decisions (Wang, M., Zhao, L., 2021) likewise the research using MILP to optimize the overall energy consumption throughout all stages of perishable supply chain and find the routes and transportation modes to save energy on the Silk Road Belt (Gallo, et al., 2017). About transportation and vehicles, cold chain logistics has grown rapidly since high consumption. Meanwhile, the grow-up of the cold chain logistics can generate more carbon emission. The company should be focus to reduce carbon emissions while maintain customer satisfaction so, in this paper use the vehicle routing optimization model to minimize the cost of a unit satisfied customer (Qin et al.,

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2019).There has another research related to transportation and vehicle in cold chain by using the vehicle routing problem (VRP) to design the appropriate routes for a different group of customers for vehicles to travel in an acceptable and controllable way and meet the constraints, under the condition like quantity, time limit, vehicle limit, etc. To achieve a certain objective like the least cost, the least time (Liu et al., 2018). For emergency cold chain to optimize distribution route for minimizing the loss cost and also consider the change of driving speed in different time periods by constructed the mathematical model that including loss of vehicle, refrigeration consumption and damage of goods over time (Qi, C.M., Hu, L.S., 2020) moreover to the extension of the VRP model by combining inventory allocation problem, vehicle routing problem, and cold supply chain (CSC) is formulated, denoted as IVRPCSC Model or inventory allocation with vehicle routing problem in the Cold Supply Chain system and almost all constraints, like sub-tour elimination, vehicle availability, and feasibility constraints to identify the routes, are categorized by these variables into six key categories: variables of pickup, distribution, use, inventory, deviation, and binary routing, for minimize transportation, penalty, and inventory costs.(Al Theeb, et al., 2020). The last about the environmental issue there has a research that want to minimize transportation cost and also environment cost by using mathematical model and using Generalized Reduced Gradient method for solving two main problems are location of distribution center and flow of product from supplier to consumers (Matskul V, et al., 2021).

2.4 Multi-criteria decision making (MCDM)

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

2.5 Simulation

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

Based on all the literature reviews, an issue related to this work is the optimization in the cold chain that is distribution planning for fulfilling the customer requirement and vehicle routing problem. However, the previous 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. 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.

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

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CHAPTER 3
METHODOLOGY

This chapter describes the methodology of the research. First, the cold chain network for fresh agricultural and processed fruit will be explained. Then, applying the sweet corn case study and cold chain network for fresh and processed sweet corn in the northern region will be also explained.

The mathematical model both generic and specific are described also the sets, parameters and decision variables are declared to use in the model.

3.1 Generic cold chain network

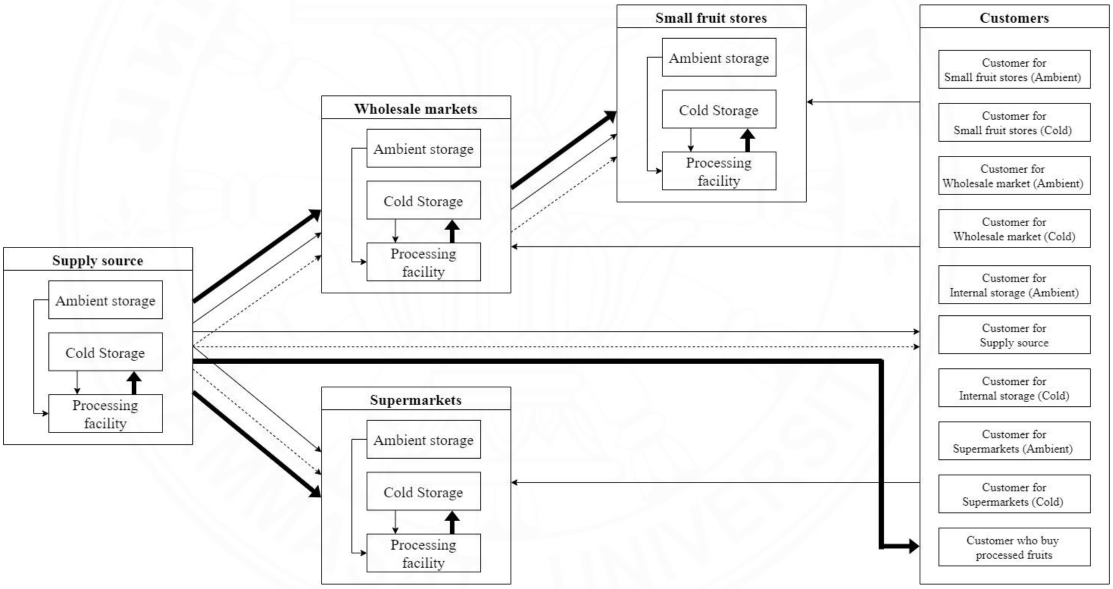

Figure 3.1 Generic cold chain network for fresh and processed fruit.

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

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3.2 Generic mathematical model

3.2.1 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 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.

3.2.2 Notation

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,
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 processed fruit in each stage : $E = \{e_o, e_w, e_r, e_k\}$

A = Set of transportation arcs:

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

B = Set of transportation arcs (Transportation loss):

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

N = Set of transportation arcs (Transportation cost):

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

V = Set of transportation arcs for processed stage:

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

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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.

3.2.3 Objective function and Constraint

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)

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

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

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

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

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

$$l_{s_2} \times Z_{p_g,s_2} = \sum_{w=1}^{2}\sum_{m=1}^{2} X_{p_g,s_2,w,m} +$$

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

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

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

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

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

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

$$Y_{p_g,w_2,e_w} \quad (22)$$

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

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

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

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

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

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

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

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

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

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

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

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

$$Z_{p_h,k_2} = X_{p_h,k_2,c_{p_h},m_0} \quad (35)$$

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

Constraint 2: Requirements must be fulfilled.

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

$$X_{p_g,r_2,c_{r,2},m_0} \leq D_{p_g,c_{r,2}} \quad (38)$$

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

Ref. code: 25636222040690VMS

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

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

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

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

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

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

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

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.

Ref. code: 25636222040690VMS

3.3 Specific cold chain network

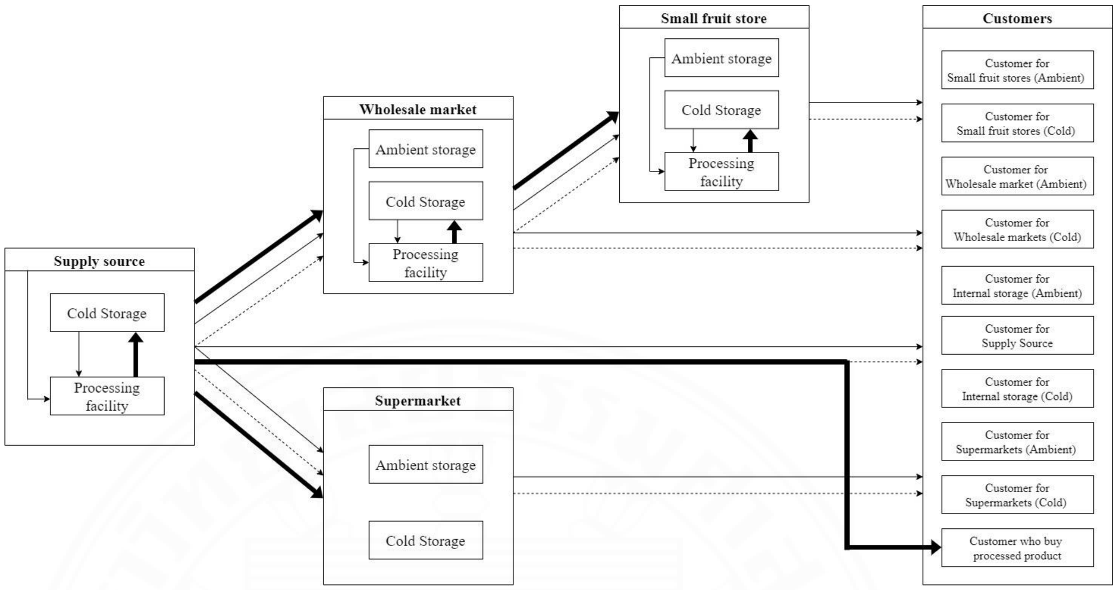

Figure 3.2 Cold chain network for fresh and processed sweet corn in the northern region.

The sweet corn and sweet corn milk supply chain network is almost similar to the generic supply chain network as Figure 3.2. According to sweet corn characteristics that can lose sugar rapidly, vehicles are often prepared before harvesting. When the harvest is complete, it will be transported as soon as possible. Therefore, the internal ambient storage is not available in the sweet corn and sweet corn milk supply chain.

Sweet corn milk is a popular beverage that can be easily purchased from the supply sources, wholesale market, small fruit store, and supermarket. Each stage can use both their sweet corn for processing into sweet corn milk or purchase sweet corn milk from other stages to resell. Sweet corn milk processing is available at all stages in the sweet corn and sweet corn supply chain except the supermarket who only purchases sweet corn milk from the supply source.

3.4 Specific mathematical model

3.4.1 Additional model assumptions for sweet corn in the northern region

1. The processed sweet corn (Sweet corn milk) is processing and stored in cold storage at the supply source, wholesale market, small fruit store.

3.4.2 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,
1 denotes ambient and
2 denotes cold.

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

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

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 processed fruit in each stage : $E = \{e_o, e_w, e_r\}$

A = Set of transportation arcs:

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

B = Set of transportation arcs (Transportation loss):

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

N = Set of transportation arcs (Transportation cost):

$$N = \begin{Bmatrix} (o, w_1), (o, w_2), (o, k_1), (o, k_2), \\ (s_2, w_1), (s_2, w_2), (s_2, k_1), (s_2, k_2), \\ (w_1, r_1), (w_1, r_2), (w_2, r_1), (w_2, r_2) \end{Bmatrix}$$

V = Set of transportation arcs for processed stage:

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

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.

$T_{i,j,m}$ = 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.

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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.

3.4.3 Objective function and Constraint

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

e) Supply Source

iii) No storage

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

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

iv) Internal storage

Revenue = $\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s_2,w,m} \times U_{p_g,s_2,w} \times X_{p_g,s_2,w,m}) + \sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s_2,k,m} \times U_{p_g,s_2,k} \times X_{p_g,s_2,k,m}) + \sum_{m=1}^{2}(L_{s_2,c_{s,1},m} \times U_{p_g,s_2,c_{s,1}} \times X_{p_g,s_2,c_{s,1},m}) + \sum_{m=1}^{2}(L_{s_2,c_{s,2},m} \times U_{p_g,s_2,c_{s,2}} \times X_{p_g,s_2,c_{s,2},m}) + \left(U_{p_h,s_2,w_2} \times X_{p_h,s_2,w_2,m_2}\right) + \left(U_{p_h,s_2,k_2} \times X_{p_h,s_2,k_2,m_2}\right) + \left(U_{p_h,s_2,c_{p_h}} \times X_{p_h,s_2,c_{p_h},m_2}\right)$ (51)

Cost = $\sum_{w=1}^{2}\sum_{m=1}^{2}(T_{s_2,w,m} \times X_{p_g,s_2,w,m}) + \sum_{k=1}^{2}\sum_{m=1}^{2}\left(T_{s_2,k,m} \times X_{p_g,s_2,k,m}\right) + \left((f_{s_2} + u_o) \times Z_{p_g,s_2}\right) + (f_{s_2} \times Z_{p_h,s_2}) + \left(T_{s_2,w_2,m_2} \times X_{p_h,s_2,w_2,m_2}\right) + \left(T_{s_2,k_2,m_2} \times X_{p_h,s_2,k_2,m_2}\right)$ (52)

f) Wholesale markets

Revenue = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}(U_{p_g,w,r} \times X_{p_g,w,r,m}) + \sum_{w=1}^{2}(U_{p_g,w,c_{w,1}} \times X_{p_g,w,c_{w,1},m_0}) + (U_{p_g,w_2,c_{w,2}} \times X_{p_g,w_2,c_{w,2},m_0}) + \left(U_{p_h,w_2,r_2} \times X_{p_h,w_2,r_2,m_2}\right) + \left(U_{p_h,w_2,c_{p_h}} \times X_{p_h,w_2,c_{p_h},m_2}\right)$ (53)

Cost = $\sum_{w=1}^{2}\sum_{m=1}^{2}(L_{o,w,m} \times U_{p_g,o,w} \times X_{p_g,o,w,m}) + \sum_{w=1}^{2}\sum_{m=1}^{2}(L_{s_2,w,m} \times U_{p_g,s_2,w} \times X_{p_g,s_2,w,m}) + \sum_{w=1}^{2}(f_w \times Z_{p_g,w}) + \left(f_{w_2} \times Z_{p_h,w_2}\right) + \left(U_{p_h,s_2,w_2} \times X_{p_h,s_2,w_2,m_2}\right) + \sum_{w=1}^{2}(Y_{p_g,w,e_w} \times v)$ (54)

g) 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 = $\sum_{w=1}^{2}\sum_{r=1}^{2}\sum_{m=1}^{2}((T_{w,r,m} + U_{p_g,w,r}) \times X_{p_g,w,r,m}) + \sum_{r=1}^{2}(f_r \times Z_{p_g,r}) + \left(f_{r_2} \times Z_{p_h,r_2}\right) + ((T_{w_2,r_2,m_2} + U_{p_h,w_2,r_2}) \times X_{p_h,w_2,r_2,m_2}) + \sum_{r=1}^{2}(Y_{p_g,r,e_r} \times v)$ (56)

h) 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 = $\sum_{k=1}^{2}\sum_{m=1}^{2}\left(L_{o,k,m} \times U_{p_g,o,k} \times X_{p_g,o,k,m}\right) + \sum_{k=1}^{2}\sum_{m=1}^{2}(L_{s_2,k,m} \times U_{p_g,s_2,k} \times X_{p_g,s_2,k,m}) + \sum_{k=1}^{2}\left(f_k \times Z_{p_g,k}\right) + \left(f_{k_2} \times Z_{p_h,k_2}\right) + \left(U_{p_h,s_2,k_2} \times X_{p_h,s_2,k_2,m_2}\right)$ (58)

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

$Y_{p_g,o,s_2} + \sum_{w=1}^{2}\sum_{m=1}^{2}X_{p_g,o,w,m} + \sum_{m=1}^{2}X_{p_g,o,c_{o,1},m} + \sum_{k=1}^{2}\sum_{m=1}^{2}X_{p_g,o,k,m} + Y_{p_g,o,e_o} = CAP_o$ (59)

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

$Y_{p_g,o,s_2} = Z_{p_g,s_2}$ (61)

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

$l_{s_2} \times Z_{p_g,s_2} = \sum_{w=1}^{2}\sum_{m=1}^{2}X_{p_g,s_2,w,m} + \sum_{m=1}^{2}X_{p_g,s_2,c_{s,1},m} + \sum_{m=1}^{2}X_{p_g,s_2,c_{s,2},m} + \sum_{k=1}^{2}\sum_{m=1}^{2}X_{p_g,s_2,k,m}$ (63)

$Z_{p_h,s_2} = X_{p_h,s_2,w_2,m_2} + X_{p_h,s_2,k_2,m_2} + X_{p_h,s_2,c_{p_h},m_2}$ (64)

$\sum_{m=1}^{2}(L_{o,w,m} \times X_{p_g,o,w,m}) + \sum_{m=1}^{2}(L_{s_2,w,m} \times X_{p_g,s_2,w,m}) = Z_{p_g,w}\ , \forall_w$ (65)

$X_{p_h,s_2,w_2,m_2} + Y_{p_h,e_w,w_2} = Z_{p_h,w_2}$ (66)

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

$$l_{w_2} \times Z_{p_g,w_2} = \sum_{r=1}^{2} \sum_{m=1}^{2} X_{p_g,w_2,r,m} + X_{p_g,w_2,c_{w,1},m_0} + X_{p_g,w_2,c_{w,2},m_0} + Y_{p_g,w_2,e_w} \quad (68)$$

$$Z_{p_h,w_2} = X_{p_h,w_2,r_2,m_2} + X_{p_h,w_2,c_{p_h},m_0} \quad (69)$$

$$q_w \times \sum_{w=1}^{2} Y_{p_g,w,e_w} = Y_{p_h,e_w,w_2} \quad (70)$$

$$\sum_{w=1}^{2} \sum_{m=1}^{2} (L_{w,r,m} \times X_{p_g,w,r,m}) = Z_{p_g,r} \text{ , } \forall_r \quad (71)$$

$$X_{p_h,w_2,r_2,m_2} + Y_{p_h,e_r,r_2} = Z_{p_h,r_2} \quad (72)$$

$$l_{r_1} \times Z_{p_g,r_1} = X_{p_g,r_1,c_{r,1},m_0} + Y_{p_g,r_1,e_r} \quad (73)$$

$$l_{r_2} \times Z_{p_g,r_2} = X_{p_g,r_2,c_{r,1},m_0} + X_{p_g,r_2,c_{r,2},m_0} + Y_{p_g,r_2,e_r} \quad (74)$$

$$Z_{p_h,r_2} = X_{p_h,r_2,c_{p_h},m_0} \quad (75)$$

$$q_r \times \sum_{r=1}^{2} Y_{p_g,r,e_r} = Y_{p_h,e_r,r_2} \quad (76)$$

$$\sum_{m=1}^{2} (L_{o,k,m} \times X_{p_g,o,k,m}) + \sum_{m=1}^{2} (L_{s_2,k,m} \times X_{p_g,s_2,k,m}) = Z_{p_g,k} \text{ , } \forall_k \quad (77)$$

$$X_{p_h,s_2,k_2 m_2} = Z_{p_h,k_2} \quad (78)$$

$$l_{k_1} \times Z_{p_g,k_1} = X_{p_g,k_1,c_{k,1},m_0} \quad (79)$$

$$l_{k_2} \times Z_{p_g,k_2} = X_{p_g,k_2,c_{k,1},m_0} + X_{p_g,k_2,c_{k,2},m_0} + Y_{p_g,k_2,e_k} \quad (80)$$

$$Z_{p_h,k_2} = X_{p_h,k_2,c_{p_h},m_0} \quad (81)$$

Constraint 2: Requirements must be fulfilled.

$$X_{p_g,r_1,c_{r,1},m_0} + X_{p_g,r_2,c_{r,1},m_0} \leq D_{p_g,c_{r,1}} \quad (82)$$

$$X_{p_g,r_2,c_{r,2},m_0} \leq D_{p_g,c_{r,2}} \quad (83)$$

$$X_{p_g,w_1,c_{w,1},m_0} + X_{p_g,w_2,c_{w,1},m_0} \leq D_{p_g,c_{w,1}} \quad (84)$$

$$X_{p_g,w_2,c_{w,2},m_0} \leq D_{p_g,c_{w,2}} \quad (85)$$

$$\sum_{m=1}^{2} (L_{o,c_{o,1},m} \times X_{p_g,o,c_{o,1},m}) \leq D_{p_g,c_{o,1}} \quad (86)$$

$$\sum_{m=1}^{2} (L_{s_2,c_{s,1},m} \times X_{p_g,s_2,c_{s,1},m}) \leq D_{p_g,c_{s,1}} \quad (87)$$

$$\sum_{m=1}^{2} (L_{s_2,c_{s,2},m} \times X_{p_g,s_2,c_{s,2},m}) \leq D_{p_g,c_{s,2}} \quad (88)$$

$$X_{p_g,k_1,c_{k,1},m_0} + X_{p_g,k_2,c_{k,1},m_0} \leq D_{p_g,c_{k,1}} \quad (89)$$

$$X_{p_g,k_2,c_{k,2},m_0} \leq D_{p_g,c_{k,2}} \quad (90)$$

$$X_{p_h,s_2,c_{p_h},m_2} + X_{p_h,w_2,c_{p_h},m_0} + X_{p_h,r_2,c_{p_h},m_0} + X_{p_h,k_2,c_{p_h},m_0} \leq D_{p_h,c_{p_h}} \quad (91)$$

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Constraint 3: Non-negativity constraints

All decision variables ≥ 0 (92)

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) - (81) 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 (82) - (91) 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 (92) are non-negativity constraints.

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CHAPTER 4
DATA COLLECTION

This research collected data from both online and onsite information. For the reliable sources data, the agricultural fruits information from the Official of Agricultural Economics. The Department of Industrial Works provides lists of cold chain companies in Thailand. The financial statement data comes from the Department of Business Development. The Food and Agriculture Organization of the United Nations provides information on the loss rate of agricultural products. This research shows the loss rate of ambient storage is 9%, and transportation is 10%. It is 1% and 0.001% for cold storage and transportation, respectively [36].

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

Based on the current situation, the demands are set as 80% for ambient sweet corn, 20% for cold sweet corn. The demand proportion of each market channel for sweet corn is assumed as 40% for small fruit stores, 15% for wholesale markets, 10% for directly from the supply source, 5% for internal ambient storage, 15% for internal cold storage, and 30% for supermarkets. After extending the scope of the model by considering sweet corn together with sweet corn milk, the demands are reset as 70% for ambient sweet corn, 20% for cold sweet corn, and 10% for sweet corn milk.

The parameters are used in the optimization model for sweet corn and sweet corn milk. The price that origin sells to the destination, which differs in each stage is given in Table 4.1. The capacity at the supply source is set to 1000 kilograms and other stages are unlimited capacity. The sweet corn cultivation cost is 2.58 bath per kilogram. The cost for sweet corn milk that will consist of material cost, packaging cost, and labor cost is 10.80 baht per kilogram. The storage costs at the origin node are obtained from SCG Logistic and Inter Express Logistic. The transportation cost, which is the average

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price based on multiple inquiries consist of the transportation cost from the supply source and internal storages to wholesale markets and supermarkets are 3.00 baht per kilogram for ambient mode and 5.00 baht per kilogram for cold mode and from wholesale markets to small fruit stores are 0.97 baht per kilogram for ambient mode and 2.11 baht per kilogram for cold mode. For the processed product, the conversion factor is needed to refer to the proportion of fresh agricultural products to be transferred to processed products and for sweet corn milk, the conversion factor is 64.52%.

Table 4.1 Parameters in the optimization model for sweet corn in the northern region.

Origin	Destination	Unit price (baht/kg.)
Small fruit store	Customer for Small fruit store (Ambient)	22.50
	Customer for Small fruit store (Cold)	33.87
Small fruit store with cold storage	Customer who buys processed product	95.00
Wholesale market	Small fruit store	10.77
	Customer for wholesale market (Ambient)	15.00
	Customer for wholesale market (Cold)	22.58
Wholesale market with cold storage	Small fruit store (Processed product)	56.00
	Customer who buys processed product	80.00
Supply source	Wholesale market	6.67
	Supermarket	6.67
	Customer for supply source (No storage)	25.56

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Origin	Destination	Unit price (baht/kg.)
Internal storage	Wholesale market	6.67
Internal cold storage	Supermarket	6.67
	Customer for internal storage (Ambient)	25.56
	Customer for internal storage (Cold)	38.84
	Wholesale market (Processed product)	40.00
Supermarket	Supermarket (Processed product)	40.00
	Customer who buys processed product	129.31
	Customer for supermarket (Ambient)	44.38
Supermarket with cold storage	Customer for supermarket (Cold)	66.80
	Customer who buys processed product	170.56

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CHAPTER 5
RESULT AND DISCUSSION

This chapter shows the suggest plan for using cold chain management in the supply chain, and 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

5.1 Result for fresh sweet corn in the northern region

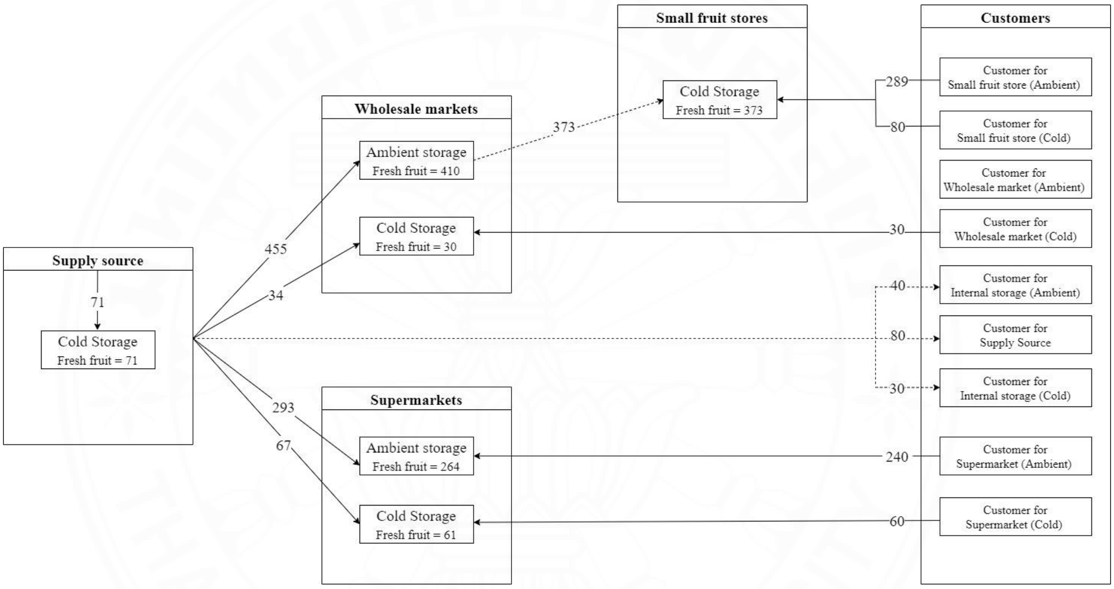

Figure 5.1 Network of fresh sweet corn in the supply chain.

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

Stages in supply chain	Total revenue	Total cost	Total profit
Supply source	9,319.67	5,255.15	4,064.52
Wholesale market	4,692.84	3,109.94	1,582.91
Small fruit stores	9,214.31	5,473.32	3,740.99
Supermarkets	14,659.20	2,349.99	12,309.21
Total	37,886.03	16,188.40	21,697.63

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Table 5.2 Satisfied demand of fresh sweet corn in each market channel.

Origin	Destination	Actual demand (kg.)	Satisfied demand (kg.)	Satisfied demand (%)
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)	0	120	0%
	Customer for wholesale market (Cold)	30	30	100%
Small fruit stores	Customer for small fruit store (Ambient)	289	320	90.35%
	Customer for small fruit store (Cold)	80	80	100%
Supermarkets	Customer for supermarket (Ambient)	240	240	100%
	Customer for supermarket (Cold)	60	60	100%

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Discussion

After applying all data of the sweet corn case study to the mathematical model and using Excel Open Solver to find an optimal solution. The maximum profit cold chain management plan for the sweet corn supply chain consisting of appropriate routes, storage capacity, storage modes, and transport modes is shown in Figure 5.1 starting from 1000 kilograms of sweet corn at the supply source transported to different stages. Ambient transportation is used to transport sweet corn from the supply source to wholesale markets with both ambient and cold storage 455 kilograms and 34 kilograms and also to supermarkets with both ambient and cold storage 293 kilograms and 67 kilograms. Cold transportation is used to transport sweet corn from the supply source to customer for supply source 80 kilograms, internal cold storage to the customer for internal ambient storage 40 kilograms, internal cold storage to the customer for internal cold storage 30 kilograms, and wholesale market with ambient storage to small fruit store with cold storage 373 kilograms.

All stages in the sweet corn and sweet corn milk supply chain use cold storage. Cold storage capacity is used at supply source 71 kilograms, wholesale market 30 kilograms, small fruit store 373 kilograms and supermarket 61 kilograms. Ambient storage capacity is used at wholesale market 410 kilograms and supermarket 264 kilograms.

The total profit of the sweet corn supply chain is 21,697.63 baht and revenue, cost, and profit at each stage of the sweet corn supply chain are shown in Table 5.1. It can be seen that most of the profits and revenues come from supermarkets as they have the highest selling prices.

The cold sweet corn demand is completely satisfied because of the high selling prices, while the ambient sweet corn demand at customer for supply source and supermarket also are completely satisfied. But the ambient sweet corn demand at customer for small fruit store can be satisfied only 90.35% and the ambient sweet corn demand at customer for wholesale market is not satisfied at all because the ambient sweet corn prices sold to the customer for small fruit store and wholesale market are lower than supply source and supermarket, thus satisfying the demand with the remaining sweet corn after supply source and supermarkets satisfaction to small fruit stores and wholesale markets respectively.

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5.2 Result for fresh and processed sweet corn in the northern region

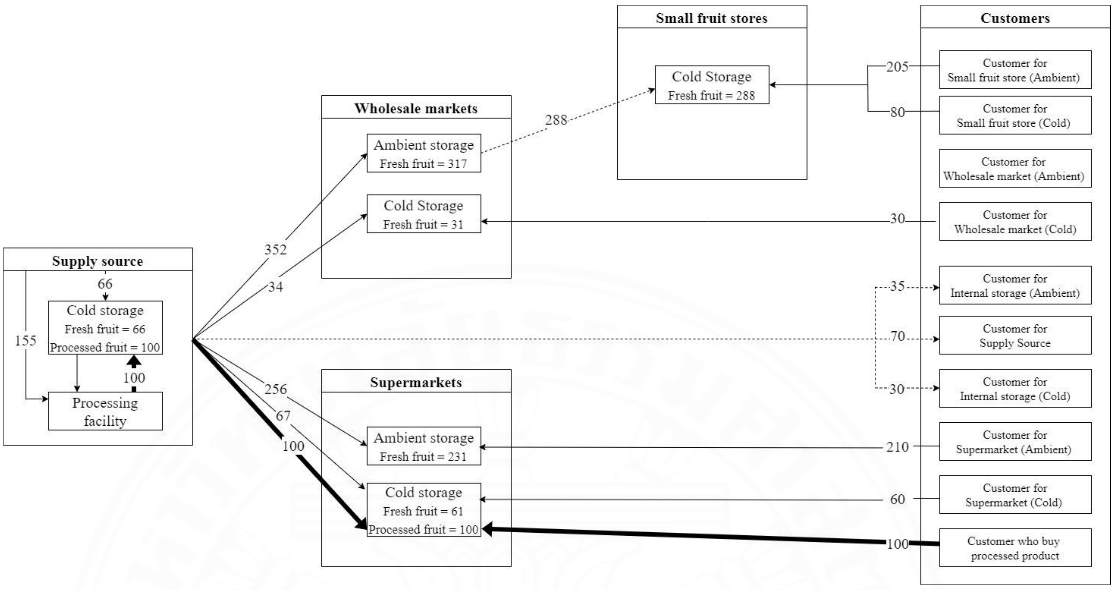

Figure 5.2. Network of fresh and processed sweet corn in the supply chain.

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

Stages in supply chain	Total revenue	Total cost	Total profit
Supply source	12,096.15	7,180.21	4,915.95
Wholesale market	3,781.50	2,462.37	1,319.13
Small fruit stores	7,329.45	4,231.12	3,098.33
Supermarkets	30,383.36	6,300.41	24,082.95
Total	53,590.46	20,174.11	33,416.35

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

Origin	Destination	Actual demand (kg.)	Satisfied demand	
			(kg.)	(%)
Supply source	Customer for supply source (No storage)	70	70	100%
Internal storages	Customer for internal storage (Ambient)	35	35	100%
	Customer for internal storage (Cold)	30	30	100%
Wholesale markets	Customer for wholesale market (Ambient)	0	105	0%
	Customer for wholesale market (Cold)	30	30	100%
Small fruit stores	Customer for small fruit store (Ambient)	205	280	73.34%
	Customer for small fruit store (Cold)	80	80	100%
Supermarkets	Customer for supermarket (Ambient)	210	210	100%
	Customer for supermarket (Cold)	60	60	100%
	Customer who buys processed fruit	100	100	100%

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Discussion

After extending the scope of the model by considering sweet corn together with sweet corn milk, applying all data of the sweet corn and sweet corn milk case study to the mathematical model and using Excel Open Solver to find an optimal solution. The maximum profit cold chain management plan for the sweet corn and sweet corn milk supply chain consisting of appropriate routes, processing stages, storage capacity, storage modes, and transport modes is shown in Figure 5.2 starting from 1,000 kilograms of sweet corn at the supply source, then transported or processed into sweet corn milk to different stages.

Ambient transportation is used to transport sweet corn from the supply source to wholesale markets with both ambient and cold storage 352 kilograms and 34 kilograms and also to supermarkets with both ambient and cold storage 256 kilograms and 67 kilograms. Cold transportation is used to transport sweet corn from the supply source to customers for supply source 70 kilograms, internal cold storage to customers for internal ambient storage 35 kilograms, internal cold storage to customers for internal cold storage 30 kilograms, and wholesale market with ambient storage to small fruit store with cold storage 288 kilograms. Cold transportation is also used to transport sweet corn milk from supply source to supermarket with cold storage 100 kilograms.

All stages in the sweet corn and sweet corn milk supply chain use cold storage. Cold storage capacity is used to store sweet corn at supply source 66 kilograms, wholesale market 31 kilograms, small fruit store 288 kilograms, and supermarket 61 kilograms. And cold storage capacity is also used to store sweet corn milk at supply source 100 kilograms and supermarket 100 kilograms. Ambient storage capacity is used at wholesale market 317 kilograms and supermarket 231 kilograms.

The total profit of the sweet corn and sweet corn milk supply chain is 33,416.35 baht and revenue, cost, and profit at each stage of the sweet corn and sweet corn milk supply chain are shown in Table 5.2. When adding value to sweet corn through processing, it increases the profit at each stage and the total profit of this supply chain as compared to the non-processing supply chain and the most of the profits and revenues come from supermarkets as they have the highest selling prices of both sweet corn and sweet corn milk.

The cold sweet corn demand and sweet corn milk are completely satisfied because of the high selling prices, while the ambient sweet corn demand at customer for supply source and supermarket also are completely satisfied. But the ambient sweet corn demand at customer for small fruit store can be satisfied only 73.34% and the ambient sweet corn demand at customer for wholesale market is not satisfied at all again.

In summary, the model suggests that cold storage and cold transportation should be used together with ambient storage and ambient transportation in the sweet corn and sweet corn milk supply chain. The model suggests choosing ambient storage and ambient transportation because it wants to reduce cost and transport sweet corn more than the demand instead and choosing cold storage and cold transportation because it wants to avoid the loss of sweet corn and satisfy the demand. Therefore, cold chain management is necessary for the sweet corn and sweet corn milk supply chain to maintain the quality and extend the shelf life, increase the value-added opportunity of the sweet corn by producing processed products such as sweet corn milk, and achieve the maximum total profit.

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CHAPTER 6
SENSITIVITY ANALYSIS

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

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

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 Figure 6.1. 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 the graph, the highest profit is on the supermarket nodes for sweet corn supply chain.

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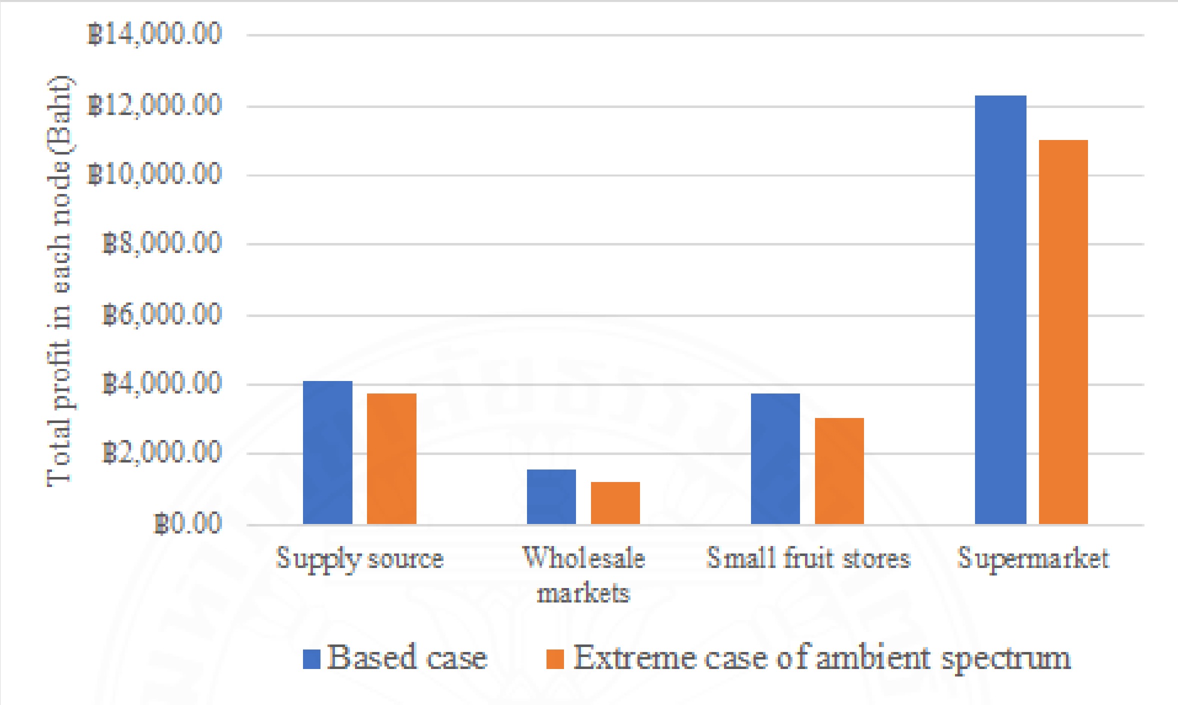

Figure 6.1 Comparison of the total profit between base case and extreme case of ambient spectrum in each node of the supply chain.

6.2 Sensitivity analysis of demand and price

According to the Figure 6.2 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 cost seems to be gradually increasing from the demand of 0% to 100% for cold chains, which means if the demand for sweet corn that uses the cold chain system is increased, the total cost will increase. Meanwhile, the unit price of selling cold products is higher than ambient products, which means the overall revenue and profit will also be increased. The model suggested sweet corn to use the storage and transport in both ambient and cold modes.

Then, considering the sensitivity analysis of demand and price, if there is more demand in the cold chain, the supply of fresh products should increase, but the unit price will be decreased at the end of the supply chain toward the customer. Next, trying to adjust the data to be more reasonable in the case of sensitivity analysis of demand and price by assuming that if demand for cold chain rises to 60%, cold product prices will fall linearly until cold demand for cold chain reaches 100%. Unit prices for the

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cold product will be equal to the unit price for the ambient product at all stages. After that total revenue and total profit tend to decrease as shown in Figure 6.3 because of selling the product at the lower unit price.

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

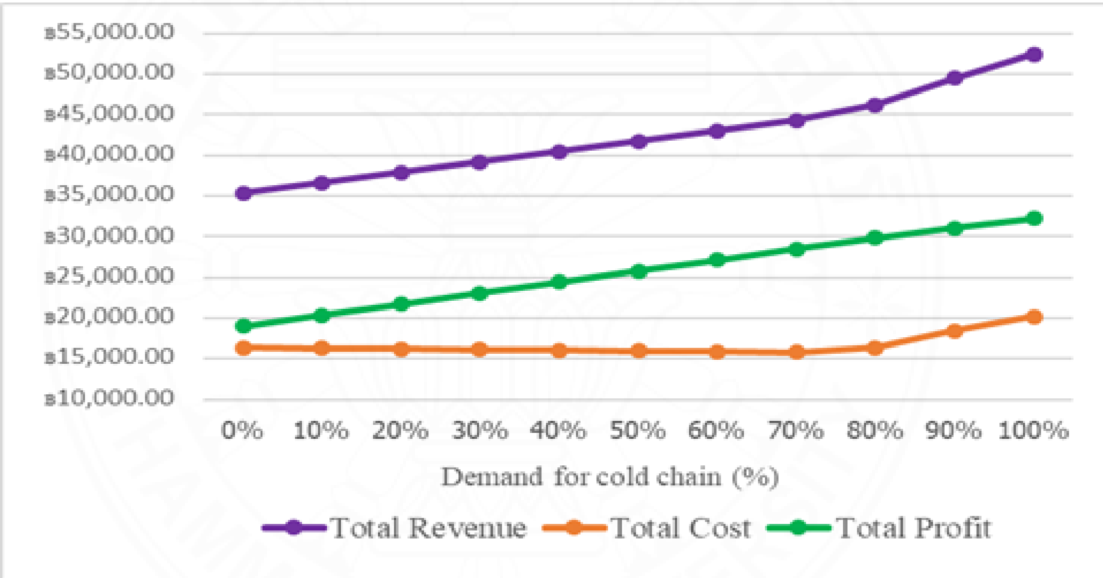

Figure 6.2 Sensitivity analysis of demand.

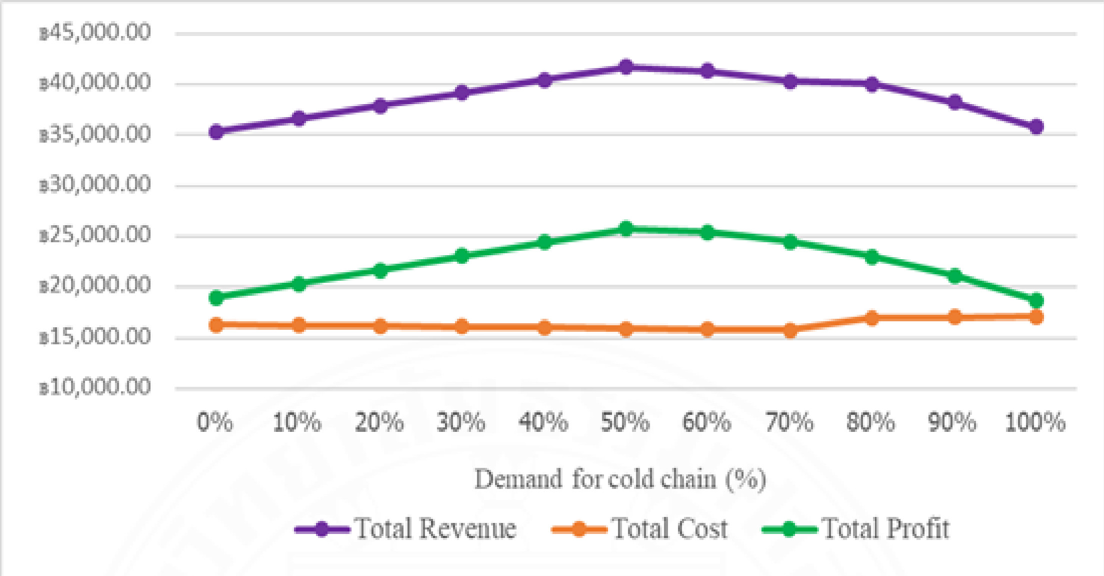

Figure 6.3 Sensitivity analysis of demand and price.

6.3 Sensitivity analysis for loss storage

For the sensitivity analysis for loss rate in storage with ambient mode are shown in Figure 6.4. This relationship between ambient storage loss compared with amounts that are stored in both cold and ambient modes can state that when the loss rate increases, the model will change the decision from the ambient mode to use the cold mode instead, because when stored in the ambient mode, the cost of storage is lower than in the cold mode. If the ambient storage loss is 9.3%, sweet corn will be stored in the cold storage rather than the ambient storage, and if the ambient storage loss is 11.1% or greater, all sweet corn will be stored in the cold storage. The current situation of sweet corn ambient storage loss is 9%, which is less than the sweet corn ambient storage loss rate that causes sweet corn will be stored in cold storage rather than ambient storage and all sweet corn will be stored in cold storage. Therefore, in current situation, both ambient and cold storage are used to store sweet corn and ambient storage is used rather than cold storage.

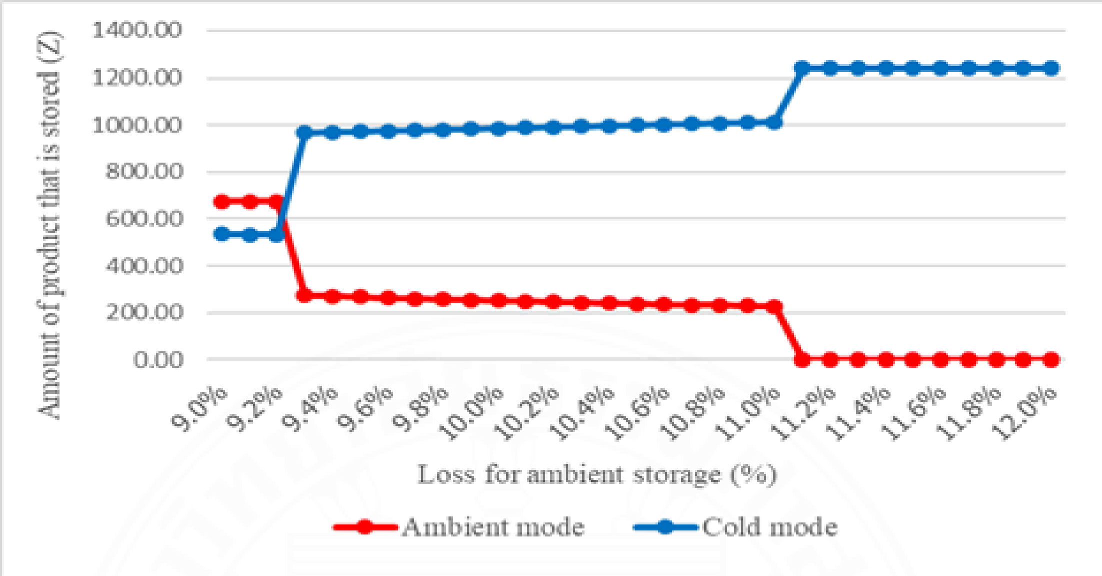

Figure 6.4 Sensitivity analysis for loss storage.

6.4 Sensitivity analysis for loss transportation

From Figure 6.5, 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. , if the ambient transportation loss rate is 12.2%, the sweet corn will be transported by cold transportation rather than ambient transportation, and if the ambient transportation loss rate is 15% or greater, all the sweet corn will be transported by cold transportation. The current situation of sweet corn ambient transportation loss is 10%, which is less than the sweet corn ambient transportation loss percentage that causes sweet corn will be transported by the cold transportation rather than the ambient transportation and all sweet corn will be transported by the cold transportation. Therefore, in current situation, both ambient and cold transportation are used to transport sweet corn and ambient transportation is used rather than cold transportation.

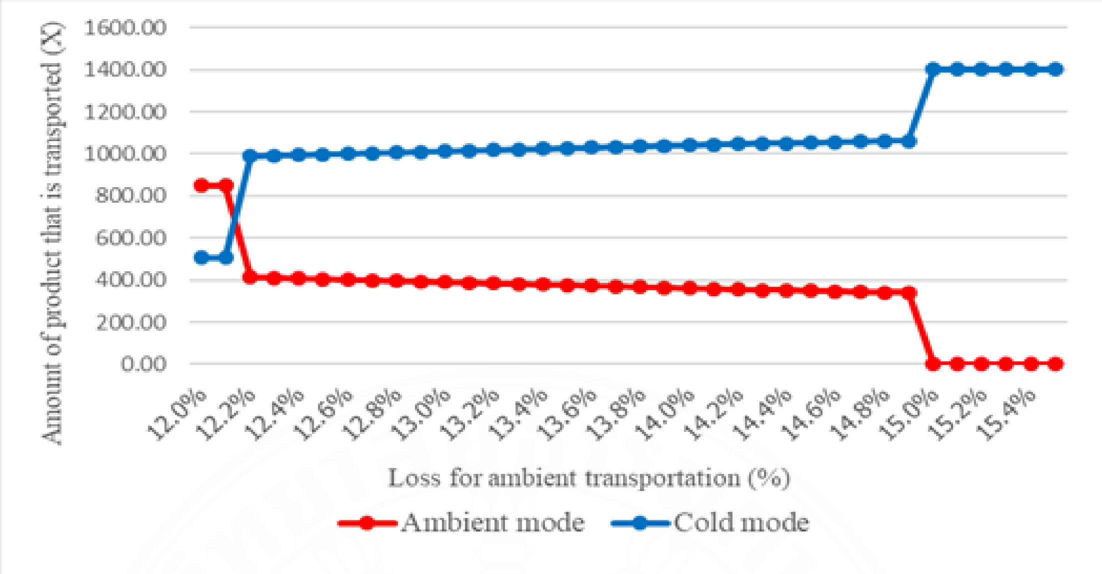

Figure 6.5 Sensitivity analysis for loss transportation.

6.5 Sensitivity analysis for storage cost

The relationship between storage costs and the number of sweet corns stored is shown in the Figure 6.6 That is, the lower cold storage costs will increase the trend of sweet corn cold storage. If the cold storage cost is 1.6 baht per kilogram, sweet corn will be stored in cold storage rather than in ambient storage, and if the cold storage cost is 1.4 baht per kilogram or lower, all sweet corn will be stored in the cold. The current situation with cold storage costs is 1.8 baht per kilogram. Therefore, both ambient and cold modes are used for storage. However, the ambient mode is used rather than the cold mode. To encourage the supply chain members to store more sweet corn in cold storage, a promotion should be conducted by reducing the price of the cold storage to below 1.8 baht to 1.4 baht per kilogram.

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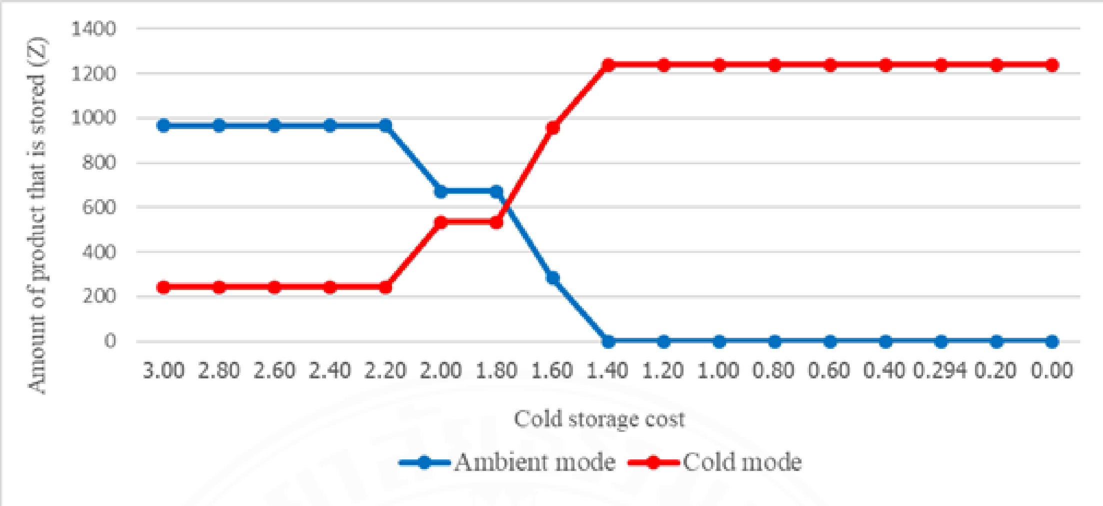

Figure 6.6 Sensitivity analysis for storage cost.

6.6 Sensitivity analysis of price for processed sweet corn

Figure 6.7 demonstrates the relationship between the discount percentage of sweet corn milk from 0% to 100 % compared with the amount of sweet corn milk that is transported to the customer who buys sweet corn milk. The current price of sweet corn milk is the price that is discounted 0% every stage. If the sweet corn milk price is the current price until the 70% discount price, the sweet corn milk will sell for 100 kilograms. But if the corn milk price is discounted 80% or more, that is, the price is almost equal to or lower than the unprocessed product, the sweet corn milk will sell for 0 kilograms. This means the model is not suggested to processed sweet corn because it has the cost for processing sweet corn and conversion factor makes it not worth for processing.

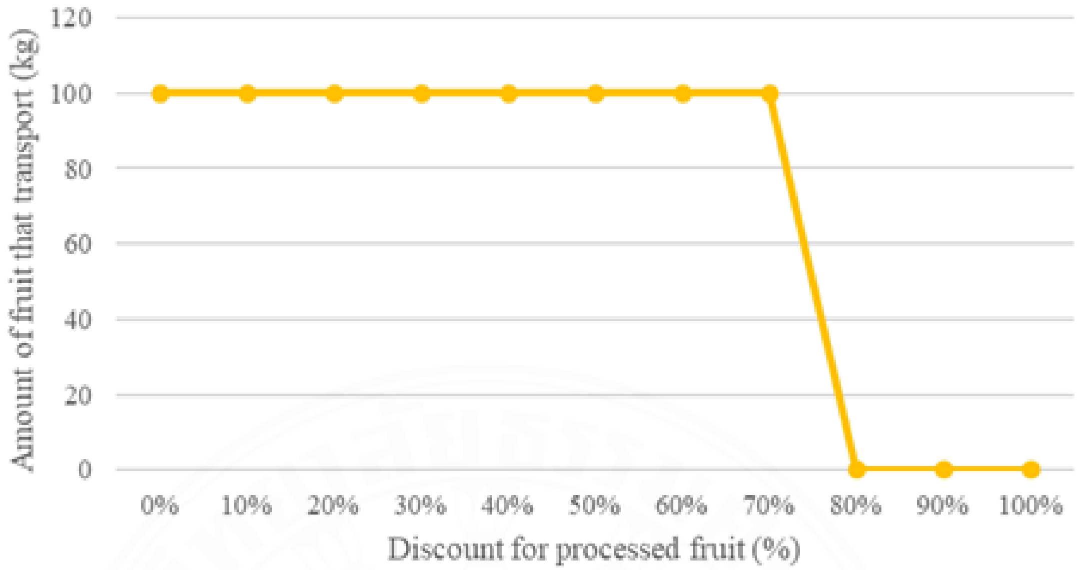

Figure 6.7 Sensitivity analysis of price for processed sweet corn.

CHAPTER 7
CONCLUSION

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.

7.1 Conclusion

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

In order to gain the maximum total profit and maintain the quality of the product, the results of sweet corn suggest that the supply chain should use cold chain management in some proper stages.

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

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7.2 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 and follow the model's results can be achieved by making trust in collaboration planning to collaborate and share the information and then explain the benefit to each of them.

If there is more investment 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 will 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 and study various products with

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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. Pannita Sudmee
Date of Birth	April 7, 1998
Education	2019: Bachelor of Science (Management Mathematics) Faculty of Science and Technology and Sirindhorn International Institute of Technology Thammasat University
	2021: Master of Engineering (Logistics and Supply Chain Systems Engineering) Thammasat University

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