Consolidated Cold Chain Design for Fresh Fruit Supply Chains in Developing Countries: A Simulation Study

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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March 2018

DECLARATION

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Sarunyoo Kanchanasuwan

March 2018

DEDICATION

This thesis is dedicated to:

My beloved parents and brother,

Anan Kanchanasuwan

Potchaman Kanchanasuwan

Worapoj Kanjanasuwan

ACKNOWLEDGEMENTS

Firstly, I would like to express my great gratitude to my first supervisor, Dr. Kwok Hung Lau, for his immeasurable support, invaluable advice and kindest understanding.The achievement of this thesis would not have been possible without his mentoring and tremendous encouragement. I am very lucky to have had the chance to work with him. I learned a lot from him, and I will always consider him my advisor and mentor. My sincere thanks are also expressed to my second supervisor, Dr. France Cheong, for his valuable contribution to the completion of my thesis. His continuous support to the process of my research has been extremely helpful. I would also like to thank Professor Booi Kam for his suggestions and encouragement during my candidature.

Secondly, I am very much grateful to Prince of Songkla University (PSU) in Thailand for providing me with the scholarship to pursue my doctoral studies at RMIT University in Melbourne, Australia. It would have been impossible without their financial support.

My deepest gratitude also goes to my beloved father (Anan Kanchanasuwan), mother (Potchaman Kanchanasuwan), and brother (Worapoj Kanjanasuwan) for their unconditional love, unbounded support, and the belief they always have in me. My heartfelt thanks also go to my loving partner (Siripen Panthuwong), who is always there for me. I also acknowledge the editorial assistance of Dr. Bradley Smith. Moreover, my deepest thanks go to all of my PhD friends, who have offered helpful suggestions and comments during my PhD journey. This journey would not have been completed without your support.

ABSTRACT

Fresh fruit has become a major consumption item for city dwellers and the demand has continuously increased in recent years. A significant proportion of fresh fruit globally is grown by developing countries in tropical regions, especially in Asia, and exported to other countries. This has become an important source of economic income for many developing countries, such as Thailand. Nevertheless, the fresh fruit industry in developing countries is experiencing critical issues, including short shelf life, high wastage, poor quality, and food safety, due to operations in high-temperature environment. Studies reveal that many developed countries have successfully solved these problems by using a cold supply chain with tight temperature control throughout the entire supply chain process. Cold supply chain adoption usually requires heavy investment in infrastructure and technology, as well as technical knowledge training for operational staff to ensure temperature compliance along the supply chain. In developing countries where capital resources are limited, this so-called high-tech high-cost approach has proven to be an obstacle to widespread cold supply chain adoption. As such, the design adopted by developed countries to implement a fresh fruit cold supply chain might not be directly applicable to developing countries, due to the lack of cold chain infrastructure and equipment and the low level of technical know-how.

To address this issue, this study presents a proposal for adopting a low-tech low-cost approach by focusing more on available resources, such as cheap labour, and flexibility in work practices such as work shifts, than on infrastructure and technology in designing cold chain systems for developing countries. It is considered that this option would be more viable for developing countries with limited capital resources and know-how, and would thus enable widespread cold supply chain adoption. It could also play a vital role in the transition of cold supply chain implementation from a nascent stage to a mature development, whereby the high-tech high-cost approach of the developed countries would more readily be adopted. This study incorporates insights from multiple theoretical perspectives, including the theory of constraint (TOC) and network theory (NT), to underpin the low-tech low-cost approach proposed. Two alternative low-tech cold supply chain designs are investigated and developed based upon a comprehensive literature review of the state of the art in the field.

Owing to the fact that fresh fruit cold chain adoption is still relatively rare in developing countries, this study explores different approaches to low-tech cold supply chain design for fresh fruits using simulation as a tool. A traditional fresh mango supply chain in Thailand, which involves five farms, three processors, one transporter and one middleman company, was used as a case study to facilitate the exploration. Discrete-event simulation was employed to evaluate the changes in performance of the typical mango supply chain before and after the adoption of the cold supply chain design. Key performance indicators, such as lead time, total operating cost, shelf life, wastage, and throughput, of the current supply chain and the different cold chain designs were compared. The findings reveal that cold supply chain design using the low-tech low-cost approach performs better in all aspects than the other design relying solely on infrastructure investment. Scenario tests also show that such a design is more robust than the other infrastructure-oriented design when facing fluctuations in demand and increases in labour cost in the long run. By proposing an innovative approach to cold chain design for developing countries and exploring its feasibility using computer simiultaion, this study makes a significant contribution to practice by showing the potential benefits of a low-tech low-cost approach to cold chain adoption in developing countries, thereby expeditng its implementation. It also contributes to knowledge by creating a new scope for research in cold chain design leveraging labour resource, change in work practices, and collaboration instead of merely infrastructure and technology.

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Chapter 1

INTRODUCTION

The study undertaken in this thesis examines a suitable approach to cold supply chain design for fresh fruit supply chains in developing countries to improve performance in throughput, lead time, operating cost, shelf life, and wastage. This chapter provides the context and motivation for the study. The research methodology used as well as the contribution of the study are briefly discussed. Lastly, an outline of the thesis is presented.

1.1 Research context

Fresh fruit is a major food of consumption for city dwellers, due to affluence and changes in lifestyle towards a healthy diet. The amount of global fresh fruit has been on the rise from 2000 to 2013 (Food and Agriculture Organization 2016b), because of the changes of dietary patterns resulting from the expanding global population, increasing income, and consciousness of the health benefits of fruit, including that fruit intake can help prevent major diseases (World Health Organization 2003). The World Health Report (World Health Organization 2003) establishes that adequate daily consumption of fruit lowers the risk of heart disease and cancer. Low intake of fruit leads to approximately 31% of ischemic heart disease and around 11% of strokes worldwide. Research outcomes on fruit and vegetable intake as well as cancer potential, organised by the World Health Organisation's IARC (International Agency for Research on Cancer), have determined that cancer risk, mainly cancers of the gastrointestinal tract, can be reduced by eating fruits and vegetables. IARC evaluates that the percentage of cancer preventable through fruit and vegetable consumption varies from 5-12% for all cancers to more than 20-30% for global upper gastrointestinal tract cancers (World Health Organization 2003).

However, like other agricultural produce, fresh fruit – a high-value perishable product – suffers from issues, such as short shelf life, high wastage, poor quality, and food safety, due to harvesting, transport and storage operations within high-temperature conditions. For example, certain fruits have limited shelf life because of their perishable nature and unfavourable storage conditions. In addition, the quality and safety of fruits can be reduced due to other factors, such as deterioration and spoilage (Van Rooyen 2006). All of these factors are highly reliant on temperature (Kitinoja 2013). As a result, retailers are compelled to sell these fruits to consumers as quickly as possible to ensure safety and quality, and to achieve maximum profit. Therefore, more efficient and effective ways to deliver fresh fruits from farms to supermarkets so as to preserve quality and shorten lead time can significantly increase the value of the fresh fruit supply chain.

The cold chain for the fresh fruit industry is a well-recognised work practice in developed countries, such as Canada, Japan, Germany and the USA (Deng, Wu & Yu 2012; Hodges, Buzby & Bennett 2011; Kitinoja 2013), as it addresses all the above issues. For instance, cold temperature slows down bacterial growth and reduces spoilage of the perishable produce (Coulomb 2008; Ovca & Jevšnik 2009). Kuo and Chen (2010) and Montanari (2008) state that temperature control of fresh produce across the entire supply chain during transportation and storage is critical for preserving product safety and value. Cold chain also helps to preserve the vitamins of fruits and vegetables and protein in meat from the field to the consumer (Salin & Nayga 2003; Zanoni & Zavanella 2012). In addition, Flick *et al.* (2012), Wang and Zhang (2008) and Qi *et al.* (2014) all conclude that cold chain management can lead to an increase in produce shelf life and reduction in waste of produce.

The current approach taken in developed countries to cold supply chain designs, which is considered a high-tech high-cost approach, generally focuses on heavy investment in technology and infrastructure (Hodges, Buzby & Bennett 2011; Kitinoja 2013). It requires technologies such as pre-cooling facilities, vacuum cooling, cold storage, refrigerated warehousing and refrigerated carriers, as well as technical knowledge training for operational staff to ensure temperature compliance along the entire supply chain (Hodges, Buzby & Bennett 2011; Kitinoja 2013; Li 2006). However, technologies and training are normally lacking in developing countries (Sharma & Pai 2015). For instance, the refrigerated storage capacity (m^3/1000 inhabitants) is 200 in developed countries but only 19 in developing countries (Kitinoja 2013).

The high-tech high-cost approach to cold supply chain design for fresh fruit supply chains might not always be applicable to developing countries, due to the issues of technology and training mentioned above. Therefore, an alternative cold supply chain adoption approach utilising other resources readily available in developing countries, such as cheap labour and flexibility in work practices in terms of work shifts, has to be considered, which is termed a low-tech low-cost approach. It is considered that this option would be more viable for developing countries with limited capital resources and know-how, and would enable widespread cold supply chain adoption (Heap 2006; Joshi, Banwet & Shankar 2009; Kitinoja 2013; Salin & Nayga 2003). It could also play a vital role in the transition of cold supply chain implementation from a nascent stage to a mature development, whereby the high-tech high-cost approach of the developed countries could thereafter be more readily adopted.

Owing to the fact that cold supply chain adoption is still not widespread in developing countries (Heap 2006; Joshi, Banwet & Shankar 2009; Kitinoja 2013; Salin & Nayga 2003), and research on the low-tech low-cost approach is, as a result, relatively limited at the moment (Global Cold Chain Alliance 2016; Kitinoja *et al.* 2011; Rijpkema, Rossi & van der Vorst 2014), the present study explores whether this low-tech low-cost approach is feasible for fresh fruit supply chains in developing countries.

1.2 Research motivation

To explore whether a low-tech low-cost cold supply chain approach is feasible for the fresh fruit industry in developing countries, this study attempts to use a simulation approach to evaluate the changes in performance of a typical, traditional fruit supply chain before and after the adoption of the low-tech low-cost cold supply chain design. It is widely considered that simulation is a beneficial technique to study the effects of system modification (Hellström & Nilsson 2006) and impacts of changes in the processes involved (Abed *et al.* 2008). This approach is most suitable for exploration of non-existing systems, such as cold supply chain implementation in this case, when it is impossible to study a real system, on the grounds that it is too costly to build one for investigation (Joshi, Banwet & Shankar 2009).

This study selects the developing country, Thailand, as a case study, because the agricultural sector has played a vital part in the economic development of Thailand (Food and Agriculture Organization 2016a). Thailand's export of various types of farm produce has generated a revenue of more than US$ 215,300 million in 2016 (Ministry of Commerce 2017). The agriculture sector itself contributed 9.78% of the country's gross domestic product (GDP) in 2015 (National Statistical Office 2015), accounting for 33.51% of total employment in 2015 (National Statistical Office 2016). In the fresh fruit business, the volume of fresh fruit produce from Thailand has been on the rise from 2001 to 2016 (Ministry of Commerce 2017). Thailand was listed 6th in production value in 2014 (Food and Agriculture Organization 2015a), and 1st in exporting in 2013 (Food and Agriculture Organization 2015b), for the global tropical fruit business.

A mango supply chain has been chosen in this study for investigation, as mango is one of the major high-value fresh fruits exported from Thailand (Office of Agricultural Economics 2012), and mangoes deteriorate rapidly after harvest and hence have a very short shelf life (Department of Agriculture 2011). In addition, in 2013 Thailand was ranked the world's 3rd largest producer of mangoes, with more than 3.1 million tons (GBD Network 2015). In addition, Thailand was ranked 4th in world mango export in the same year (GBD Network 2015). Therefore, the choice of a typical mango supply chain in Thailand as a representative case study is considered appropriate. Improving the performance of the fresh fruit supply chain in Thailand through cold supply chain adoption can contribute significantly to the value of the industry as well as to the economy of the country.

In Thailand, the fresh fruit supply chain begins with the farmer harvesting fruits from the farms, and sending them to a processing company for grading, consolidating and packaging. Immediately after that, the fruit produce is transported to the middleman company, where they are separated and then delivered to various retailers before sale to consumers in shops or supermarkets. Owing to many obstacles, such as lack of infrastructure, labour-intensive operation, and poor supply chain management, the fruit supply chain in Thailand is currently facing critical issues. One of the major issues is low quality of fruit produce as compared to that of other competing fruit-exporting countries. This is mostly due to lack of knowledge, amongst supply chain members, of fruit supply chain management to reduce wastage and lead time (Somboonsuk *et al.* 2013). The use of delivery trucks without temperature control during transportation of fruit produce from farms to processing centres in the hot climate also expedites the rate of perishability, resulting in lower quality of the product and shortened shelf life (Center for Applied Economics Research 2012). These issues can lead to higher operating costs and significant loss in revenue in both the short and the long term.

In Thailand, a generic fruit supply chain usually involves five parties – farmer, processor, transporter, middleman firm, and retailer – which are diverse in terms of their natures and characteristics (Center for Applied Economics Research 2012; Somboonsuk *et al.* 2013). Farmers, for instance, are mostly individuals who work in farms and know much about growing fruit but little about the supply chain (Somboonsuk *et al.* 2013). Processors are companies which have two levels of employees: operational ground staff, and managers. The operational staff are normally involved in collecting, grading and packing the fruit, whereas the managers work on setting up procedures for the entire operation. Nissen *et al.* (2005) report that processors usually have low- tech methods for preserving fruit quality. Transporters are third party logistics service providers or part of the processor or middleman companies. Many transporters, especially small companies, often face the issue of a lack of temperature-controlled vehicles for delivery of fruit produce (Nissen *et al.* 2005). A middleman company is basically a major buyer and seller that drives and dominates the running of the fruit supply chain. However, the middleman company also faces the issue of lack of temperature control during storage and delivery (Nissen *et al.* 2005; Vellema *et al.* 2005). From the middleman company, the fruits will then either be delivered for export to other countries, or to the local retailers, which can be supermarkets or open air markets. Again, the same issue of lack of temperature control during storage and delivery occurs (Nissen *et al.* 2005). Figure 1.1 shows the various parties in a generic fruit supply chain in Thailand, and the current challenges faced by the industry.

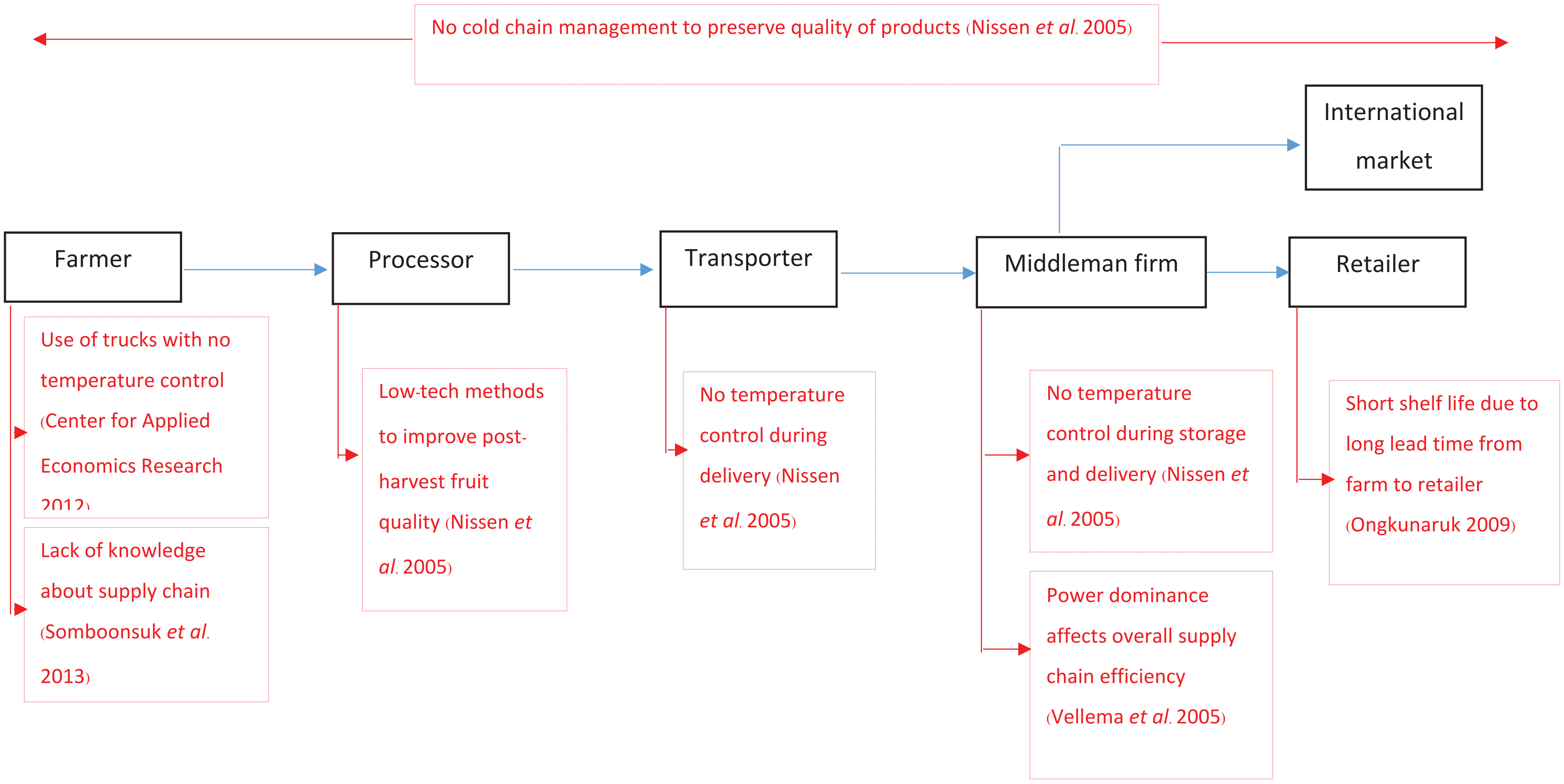


Figure 1.1 – **A typical fruit supply chain in Thailand, with related issues (Somboonsuk *et al.* 2013)**

Thailand is one of the developing countries that has not ventured into cold supply chain practice due to an absence of awareness of quality control at the farms and limited cold chain infrastructure in the country (Buurma & Saranark 2006; Nissen *et al.* 2005; Salin & Nayga 2003). Cold chain implementation requires an enormous amount of money to develop infrastructure, transfer knowledge, and change management and operational practices of the entire supply chain to ensure success (Kitinoja 2013). These are mostly lacking in the agricultural industry of Thailand and other developing countries at the moment.

1.3 Research questions

In view of the above-mentioned challenges faced by developing countries, such as Thailand, in cold chain adoption, this study aims to answer the following primary research question:

What is an appropriate approach to cold chain design for fresh fruit supply chain in developing countries?

To answer the primary research question, a typical fresh fruit supply chain in a developing country, Thailand, is used as a case study for exploration utilising simulation as a tool for investigation. The following subsidiary research questions are raised:

a. What is the performance in terms of throughput, lead time, operating cost, shelf life and wastage, of a fresh fruit supply chain in a developing country, with different cold chain designs, in the short run?

b. What is the performance of the fresh fruit supply chain in a developing country with different cold chain designs, when subject to fluctuations in demand and other uncertainties, over the long term?

1.4 Research objectives

To answer the subsidiary research questions, the following research objectives are set:

a. To investigate, through discrete event simulation (DES) with a model built on data collected from site observations and interviews with various supply chain partners, how cold chain adoption can impact on the performance of fresh fruit supply chains in developing countries such as Thailand.

b. To explore, using the simulation model developed in (a) above with scenarios created based on business trends and other national statistics, how cold chain adoption can impact on long-term supply chain surplus of fruit supply chains in developing countries such as Thailand.

1.5 Scope of the study

This study will use DES to model the operation of an existing, typical fresh fruit supply chain in Thailand, and compare its performance before and after cold chain adoption. This will be done by comparing major supply chain key performance indicators (KPIs), such as total operating cost, throughput, lead time, shelf life, and wastage, for the current real system and for the simulated cold chain design. Comparison of performance in both the short term and the long term will also be conducted. To investigate the impacts of cold chain adoption in the long term, different scenarios, such as changes in demand for exported fruits, increased uncertainty in supply, and increase in operating cost, will be simulated using the model. This study will focus on the supply chain of mangoes because it is one of the most consumed fruits in Thailand. The fruit is also chosen for investigation because of its high demand for export (hence, its significant contribution to the economy) and short shelf life (hence, demanding short lead time to ensure product quality). The stages of the supply chain to be investigated comprise farms, processors, transporters and middleman firm. How the fresh fruits are handled when they reach the retailers locally or overseas falls outside the scope of the study. Detailed operational data and patterns of practices will be collected and observed to help construct the simulation model for investigation.

1.6 Contributions

This thesis makes key contributions as follows:

1.6.1 Academic contributions

1. Extant literature on cold chain approaches for perishable produce mainly focuses on the technological aspect. In this study, the feasibility of alternative cold chain designs in developing countries is explored by focusing more on available

resources, such as cheap labour and flexible work practices. Findings of this study can contribute to knowledge by expanding the literature in this area with an alternative and agruably more appropriate and feasible approach to cold chain design for the fresh fruit industry in developing countries.

2. Findings of this study can also point to new directions for research on cold chain adoption for fresh fruit supply chains in developing countries, by leveraging technology, collaboration and changes in work practices.

1.6.2 Managerial contributions

1. The study provides knowledge of the benefits of using a low-tech low-cost approach to cold chain adoption in developing countries, in contrast to the heavy reliance on technology in developed countries.
2. The findings of this research can help supply chain members by providing a reference for cold chain design for fresh fruit supply chains, and can serve as a guide for developing future best practices in developing countries.
3. The research findings may also assist firms in formulating appropriate strategies for cold chain adoption in the fresh fruit supply chain, addressing issues of short shelf life, high wastage, and low quality of fruit produce in developing countries.

1.7 Thesis outline

The thesis consists of seven chapters. In Chapter 2, previous studies will be reviewed and critiqued in terms of four aspects. The first part covers the need to adopt cold chain in the fresh fruit industry in developing countries, and the issues in cold chain adoption in these countries. The second part elaborates on the theories used to underpin this study, and the roles they play in the development of the cold chain design proposed in this study. The third part reviews the cold chain management for different designs. The final part addresses the tool for investigating cold chain design.

Chapter 3 describes the methodology used in this research, and provides a general explanation of the steps involved in DES modelling.

Chapter 4 explains how the base model is created through a detailed explanation of the system under study. It then discusses the verification and validation procedures that have been followed to validate the model. Outputs of the base model are also presented, and are compared against the actual performance of the investigated fresh fruit supply chain.

Chapter 5 explains how the alternative models are created. It begins by describing the alternative model development, which includes an individual cold chain design and a consolidated cold chain design. In addition, this chapter describes how the different scenarios, such as change in total demand, increase in supply uncertainty, and change in operating cost, are represented in the simulation to test the robustness of the model under various circumstances. Outputs of the alternative model with the two alternative designs under three different scenarios are presented and compared, so as to determine the appropriate approach to cold chain design for the fresh fruit industry in developing countries.

Chapter 6 presents a discussion of the findings, including the implications for knowledge and practice, with a view to promoting cold chain adoption for fresh fruit supply chains in developing countries.

Chapter 7 presents the conclusion to the research and its findings, including a discussion on the contributions to the field. Moreover, this chapter presents the limitations of this study and offers recommendations for future research.

Chapter 2

LITERATURE REVIEW

This chapter firstly presents an overview of cold chain adoption for the fresh fruit industry and reports on previous research in this field. Secondly, it elaborates on the theories used to underpin this study and the roles they play in the development of the cold chain designs investigated. Thirdly, it reviews the literature on commonly used cold chain designs and the pros and cons of different designs. Moreover, the tool for investigating cold chain designs is also discussed. Finally, a theoretical framework of cold chain design for the fresh fruit industry in developing countries is proposed.

2.1 Cold chain adoption for the fresh fruit industry

As the standard of living for people continues to increase, the development of cold chains for preserving food has rapidly increased and received widespread attention in the academic literature and in industry (Luo *et al*. 2016). Food quality and safety are priorities for the livelihood of people worldwide (Wang *et al*. 2015). The core concerns for a cold chain are to decrease food loss and health hazards at every stage of the cold chain (Stahl *et al*. 2015). According to Bogataj, Bogataj and Vodopivec (2005), cold chain management is the procedure of planning, implementing and controlling the effective and efficient flow and storage of perishable produce. Wang and Luo (2012) further elaborate that cold chain logistics includes the processes and equipment to preserve fresh foods under restricted cold conditions, during assembly, processing, warehousing, and shipping. Typical cold chain processes include post-harvest handling, refrigerated storage and transport, chilled or cold processing, and retail and home refrigeration (Bledsoe 2009; Montanari 2008). The flow of produce in a typical cold chain is shown in Figure 2.1.

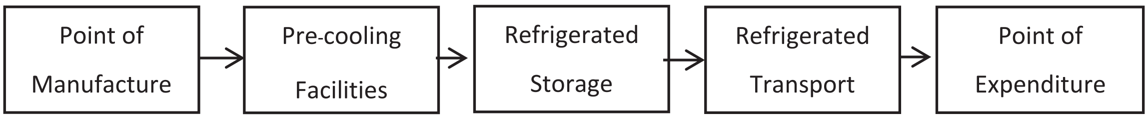


Figure 2.1 – Flow of produce in a cold chain (Sharma & Pai 2015)

It is crucial that consistency throughout the cold chain is preserved, from the production point, through processing and every step of the transportation as well as warehousing, to point of sale (Salin & Nayga 2003). In the perishable produce business, deterioration begins right after harvest because of the perishability and short shelf life of the produce. Unlike other products, fresh produce requires strict temperature control throughout the entire supply chain process (Aung & Chang 2014). Even a short-term exposure of a few minutes to extreme cold or hot temperature can lead to a loss of quality and a decline in shelf life. Accurate and cautious temperature control throughout the supply chain is, therefore, important to quality control of the product (Helal *et al*. 2007).

According to Aung, Chang and Kim (2012), Luo *et al*. (2016) and Smith (2005), cold chain can be applied to several industries, such as pharmaceuticals, chemicals, flowers, and food. Lately, the development of cold chain in the food industry is becoming more important, especially in developing countries (Luo *et al*. 2016). Most studies suggest that cold chain is needed for reducing post-harvest loss in agricultural produce; but there is much less research on how to implement a cold chain (Kitinoja 2013; Serrano 2005; Sharma & Pai 2015). It is essential to study the cold chain design for agricultural produce, such as fresh fruits, because of their unique characteristics, such as being readily prone to rapid deterioration.These characteristics make greater demands on cold chain logistics technology, such as temperature-controlled storage and transportation (Zheng 2015), due to the most important factor affecting fresh fruit products being temperature (Defraeye *et al*. 2015). In addition, the deterioration issue arises mainly for fresh products such as fresh fruit, among the food industries, because of their perishability and short shelf life (Aung, Chang & Kim 2012). According to Gustavsson *et al*. (2011) and Minten *et al*. (2016), the highest level of food waste and loss is for fruits and vegetables, which is approximately 44% of the total food loss globally. Table 2.1 summarises the findings of a number of studies that discuss how the common problems of fruit produce can be solved using a cold chain.

Researchers such as Joshi, Banwet and Shankar (2010) and Viswanadham (2006) argue that weaknesses in infrastructure between connecting partners, such as farmers, wholesalers and retailers, and the lack of coordination of freight distribution (Wang & Zhang 2008) have resulted in the waste of fruit products. Others (Blanco *et al.* 2005; Cagnon *et al.* 2013) consider that the quality of fruit can be affected by materials used for packaging that are unable to protect the fruit products from water vapour during transfer throughout the supply chain. In addition, lack of temperature control decreases fruit quality (Bogataj, Bogataj & Vodopivec 2005). Furthermore, the safety of the fruit products is affected by bacterial contamination of the fresh harvest produce (Jacxsens *et al.* 2010; Johnston *et al.* 2006). Lastly, fruit products can have limited shelf life due to inappropriate inventory policy (Duan & Liao 2013) and improper supply chain structure (Thron, Nagy & Wassan 2007). Not surprisingly, these common issues in fresh fruits occur more frequently in developing countries (Kuo & Chen 2010; Stephen 2009).

Table 2.1 – Benefits of cold chain for fruit produce

Fruit issues	Cause of the issues	Studies	Solution provided by cold chain adoption	Studies
Waste	Waste is generated due to weaknesses of the supply chain structure in connecting, deterioration in freight distribution, and inappropriateness in quality control.	Ahumada and Villalobos (2009); Gustavsson *et al.* (2011); Joshi, Banwet and Shankar (2010); van der Vorst, Tromp and van der Zee (2009); Viswanadham (2006); Wang and Li (2012); Wang & Zhang (2008)	Maintaining consistent temperature during operation can reduce deterioration rate and hence food waste.	Defraeye *et al.* (2014); Joshi, Banwet and Shankar (2011); Xu, Lan and Ruijiang (2010); Wang & Zhang (2008)
Quality	Quality is reduced due to lack of temperature control, inappropriate materials used for packaging, and poor storage conditions.	Blanco *et al.* (2005); Bogataj, Bogataj and Vodopivec (2005); Cagnon *et al.* (2013); Lambert *et al.* (2014); Perdana and Kusnandar (2012)	Temperature control throughout the entire cold chain is vital to preserving the quality of produce, such as colour, taste and freshness.	Jol *et al.* (2007); Kang *et al.* (2012); Salin and Nayga (2003); Zanoni and Zavanella (2012); Zwierzycki *et al.* (2011)
Safety	Safety of fruits is affected by microbiological contamination and lack of coordination among supply chain members.	Jacxsens *et al.* (2010); Rossi, Rijpkema and van der Vorst (2012)	Cold chain with proper handling can reduce possibility of contamination of produce by microorganisms and bacteria, thus enhancing food safety.	Coulomb (2008); Kang *et al.* (2012); Kuo and Chen (2010); Laguerre, Hoang and Flick (2013); Ovca and Jevšnik (2009)
Shelf life	Shelf life is reduced due to poor inventory management and non-optimised supply chain structure.	Duan and Liao (2013); Thron, Nagy and Wassan (2007)	Refrigeration slows down natural deterioration of produce, hence extending its shelf life	Flick *et al.* (2012); James and James (2010); Qi *et al.* (2014); Tsironi *et al.* (2009)

The use of a cold chain can have significant positive impacts on shelf life, quality, waste, and safety of perishable produce, impacts that cannot be obtained using traditional supply chain management methods only (Aung & Chang 2014). For example, cold temperature slows down bacterial growth and reduces spoilage of perishable produce (Coulomb 2008; Ovca & Jevšnik 2009). Kuo and Chen (2010) and Montanari (2008) state that temperature control of fresh produce across the entire supply chain during transportation and storage is critical for preserving product safety and value. The cold chain also helps to preserve the vitamin content of fruits and vegetables and protein content of meat, from the field to the consumer (Salin & Nayga 2003; Zanoni & Zavanella 2012). In addition, Flick *et al.* (2012), Qi *et al.* (2014) and Wang and Zhang (2008) all conclude that cold chain management can lead to increases in produce shelf life and reduction in produce waste.

Cold chain in developed countries, such as the USA and EU countries, has been adopted and implemented for many decades (Kitinoja 2013). In these countries, the cold supply chain of agricultural goods forms a complete system. All products use advanced cold chain technology along the entire supply chain with advanced management (Li 2006; Pan, Yu & Li 2017). However, cold chain adoption in developing countries is primarily at a nascent stage, and can encounter many difficulties. For example, it is usually only implemented in some parts of the country and not sufficiently maintained (Yahia 2009). It also requires major investment which is very challenging for the food industry. Less developed countries generally need infrastructure as well as human and organisational resources to develop effective cold chain capabilities (Bharti 2014).

2.1.1 Issues faced by developing countries in cold chain adoption

The main reasons for food loss in less developed countries include improper harvesting practices, lack of cold chain, insufficient infrastructure, and government policies (Winkworth-Smith, Foster & Morgan 2015). Previous studies have identified issues in the adoption of cold chain in developing countries, as summarised in Table 2.2.

Table 2.2 – Problems of cold chain adoption in developing countries

Problems	Primary perspective	Countries	Studies
High cost	High costs in terms of equipment and infrastructure	China, Ghana, India, Iraq	Billiard (2003); Joshi, Banwet and Shankar (2009); Li (2006); Maxwell Agyapong (2013); Negi and Anand (2015); Stephen (2009); Subin (2011); Zeng and Yu (2011)
Lack of equipment	Cold chain primary structure is limited by the nature of infrastructure as a community product and cost	China, Sub-Saharan Africa, India, Azerbaijan, Egypt, Iraq, Kenya, Pakistan, the Philippines, Thailand	Joshi, Banwet and Shankar (2009); Maheshwar and Chanakwa (2006); Zeng and Yu (2011); Kumar (2008); Bharti (2014); Bishop (2013); Drame and Meignien (2016); Global Cold Chain Alliance (2016); Jing and Jian (2015); Joshi, Banwet and Shankar (2009); Li (2006); Navita (2015); Promethean Spenta Technologies Limited (2014); Runzhou (2014); Salin and Nayga (2003); Shane (2016); Stephen (2009); Viswanadham (2005); Winkworth-Smith, Foster and Morgan (2015); Xiaosheng (2011); Yahia (2009); Yahia (1999)
Lack of knowledge and training	Lack of education and training, and operators are not familiar with the equipment	China, Azerbaijan, Ghana, India, Iraq, Kenya, Pakistan	Billiard (2003); Bishop (2013); Bledsoe (2009); Global Cold Chain Alliance (2016); Li (2006); Maxwell Agyapong (2013); Shane (2016); Stephen (2009); Zeng and Yu (2011); Yahia (2009)
Lack of awareness	Lack of awareness of cold chain system and the use of information technology	India, Iraq	Bharti (2014); Joshi, Banwet and Shankar (2009); Negi and Anand (2015); Stephen (2009)
Lack of collaboration	Lack of continuous control and monitoring of temperature across the entire cold chain	China, India, Pakistan	Bharti (2014); Bishop (2013); Ji and Guo (2009); Jing and Jian (2015); Joshi, Banwet and Shankar (2009); Kochi (2009); Negi and Anand (2015); Salin and Nayga (2003); Shane (2016); Subin (2011); Viswanadham (2005); Wang & Zhang (2008)
Lack of government support	Lack of integrated cold chain infrastructure Regulations and laws	China, India	Joshi, Banwet and Shankar (2009); Li (2006); Shane (2016); Yachao (2013)

2.1.1.1 High cost

Modern cold chain technologies have been developed over the last few decades. However, various tropical countries have not been able to use these advanced cold chain technologies because of their high cost (Maxwell Agyapong 2013), particularly developing countries (Yahia 2009). In India, there are some factors that make the usage of cold storage in industries difficult. The high capital expenditure costs are a major discouragement. Installation cost is also high, because of the costs of cold chain equipment imports, including high import duties, and excise duty (Joshi, Banwet & Shankar 2009). The installation and operating costs for cold storage units in India are double the costs of these in the West (Joshi, Banwet & Shankar 2009), leading to the high cost of logistics in India, which is approximately 15-25% of the end cost, as compared with 7-9% in the UK and the USA (Joshi, Banwet & Shankar 2009).

2.1.1.2 Lack of equipment

Investment in infrastructure for cold chain adoption, such as temperature- controlled warehouses and vehicles, is vital to the success of cold chain implementation (Salin & Nayga 2003). The cold chain in developed countries is well-developed, but in developing countries there remains a lack of refrigeration, which is a cause of the huge post-harvest loss that occurs in these countries (Maxwell Agyapong 2013). Yahia (2009) asserts that transportation of perishable produce in developing countries is generally without temperature control and is in bulk, which leads to an enormous loss of food. Table 2.3 shows the cold chain capacities of a range of developed and developing countries. It can be seen that there is a big difference in cold chain capacity between developed and developing countries.

Unlike developed countries, such as the USA and Japan, which are sustained by strong infrastructure (Joshi *et al.* 2012), many developing countries, such as India and China, do not have sufficient cold chain infrastructure (Greis 2011). China still lacks elements of cold chain infrastructure, such as refrigerated trucks, cold storage facilities, and retail refrigeration; and existing cold storage facilities in China are often out of date; both of which issues lead to wastage and spoilage (Shane 2016). There are also a lack of cold chain facilities and insufficient capacity of cold chain operations in India, which result in approximately 40% loss of agricultural produce (Bharti 2014; Negi & Anand 2015). In both these countries, major development in building cold chain facilities is required.

Table 2.3 – Cold chain capacity in developed and developing countries

Nation	2004		2006		2008	
	Cubic meters (Million)	Cubic feet (Million)	Cubic meters (Million)	Cubic feet (Million)	Cubic meters (Million)	Cubic feet (Million)
USA	66.8	2,357.1	69.0	2,435.8	70.7	2,498.2
Japan	27.5	969.7	27.7	977.9	27.7	977.9
Germany	6.5	229.6	8.7	307.2	13.4	473.2
France	5.4	190.7	5.4	190.7	8.5	300.2
Canada	6.3	223.9	6.8	239.8	6.9	243.3
Australia	5.3	187.1	6.0	211.9	6.0	211.9
Netherlands	1.2	42.4	9	317.8	12.6	445.0
Austria	0.7	23.0	0.8	28.3	0.8	28.3
Denmark	1.8	63.6	1.8	63.6	1.9	67.1
Italy	3.0	105.9	3.0	105.9	3.5	123.6
India	-	-	-	-	18.6	656.2
Russia	-	-	-	-	16.0	565.0
China	-	-	-	-	15.0	529.7
Argentina	-	-	-	-	0.5	17.7
Chile	-	-	-	-	0.2	6.0
Columbia	-	-	-	-	0.1	4.2
Malaysia	-	-	-	-	0.0	0.5
Mexico	-	-	-	-	1.4	47.7
Peru	-	-	-	-	0.0	1.4
Namibia	-	-	-	-	0.0	1.4

Source: Yahia (2009)

2.1.1.3 Lack of knowledge and training

Cold chain management requires professional operators that have the skills to operate across the various aspects of the entire supply chain (Joshi, Banwet & Shankar 2009). Otherwise, there will be breakdowns in the cold chain, which can significantly reduce its effectiveness. Cold chain breakdown can happen when farmers lack education and training in cold chain practice (Joshi, Banwet & Shankar 2009). In developing countries, knowledge of accurate cold supply chain practices is very weak (Yahia 2009), and there are very limited numbers of sufficiently trained technicians (Bledsoe 2009). There are several developing countries that face a lack of knowledge and training in cold chain issues, such as China (Li 2006) and India (Joshi, Banwet & Shankar 2009). China is a country with abundant labour, and there is ample available labour in the cold chain industry, but these workers are still in an early phase of learning and have little experience of cold chain logistics (Bledsoe 2009). In India, even though there is a growing number of cold chain infrastructure projects, there is a deficiency of manpower with proper skill sets to handle the new technology (Joshi, Banwet & Shankar 2009). There are very limited training centres for farmers to adopt innovation and production methods regarding proper handling and harvesting systems (Bharti 2014); and also processing divisions across India require greater information on new techniques of handling and packing technology as well as on the cold storage and distribution system (Subin 2011).

2.1.1.4 Lack of awareness

A lack of awareness of cold chain systems and the use information technology is one of the main obstacles to cold chain adoption in developing countries. To take Iraq as an example, the growers are conscious of the positive effect of field heat removal as well as getting fresh harvest quickly into cooling, but there is a lack of consciousness of the use of cold storage to increase product shelf life at the wholesale market level (Stephen 2009). Furthermore, the awareness of Internet usage is very low in developing countries, such as India, which leads to a significant negative impact on cold chain reliability (Joshi, Banwet & Shankar 2009).

2.1.1.5 Lack of collaboration

The cold chain often lacks collaboration amongst its members. Tamimi, Sundarakani and Vel (2010) claim that it is vital to maintain the correct and consistent temperature throughout the whole supply chain during transportation and storage. This requires efficient teamwork amongst participant players in the supply chain, from farmers to retailers (Khan 2005). Inappropriate cooperation planning amongst these players may cause inconsistencies at various stages, such as forecast sharing, inventory management, labour scheduling, or optimising transport (Joshi, Banwet & Shankar 2009). Ji and Guo (2009) and Salin and Nayga (2003) mention that some countries, such as China (Wang & Zhang 2008) and India (Joshi, Banwet & Shankar 2009), have not been successful in developing cold chain logistics because they have been unable to control the temperature throughout the entire cold chain process. Moreover, there is a lack of integrated cold chain facilities in India (Negi & Anand 2015). The cold chain infrastructure design is not flexible enough to permit full use of the system, given various goods containers as well as flexible workforce (Kochi 2009). In China, the whole coordination of the supply chain is insufficient, which leads to serious impacts on the composition of resources for fresh produce cold chain transport, as well as obstructing the establishment of cold chain systems (Jing & Jian 2015; Xie & Zhao 2016).

2.1.1.6 Lack of government support

Many governments have taken various actions regarding regulations and laws for cold chain in their countries (Li 2006). These government regulations vary across different countries and regions regarding safety in transportation and storage (Shane 2016). Some countries face issues in cold chain adoption because regulations are not standardised and there is a lack of international laws and regulations (Jing & Jian 2015; Shane 2016). For example, some regulations in China have stipulated standard requirements for food cold chain logistics. However, some government departments neglect their duty of control and engage in ineligible or illegal processes (Jing & Jian 2015). For another example, India suffers from a lack of cold chain because of government regulations on taxes. India has among the highest taxes in the world for processed food, which can increase the final product cost by approximately 20-40% (Joshi, Banwet & Shankar 2009).

To summarise, previous studies reveal that the cold chain design commonly adopted in developed countries cannot be directly implemented in developing countries. These studies claim that cold chain adoption in developing countries is very challenging due to a lack of collaboration among supply chain members, lack of cold chain equipment, lack of training, and the requirement of large amounts of money for investment. These barriers cannot be overcome in a short period of time. Meanwhile, developing countries cannot wait until all these issues are resolved to introduce cold chains. Therefore, the present study proposes an alternative approach to designing cold chain systems which attempts to lessen or evade the direct impacts of these issues. For example, low-cost technology that requires a lesser amount of monetary investment than high-cost technology does can be used. In addition, technology that is not difficult to implement (Kitinoja 2013), and approaches to the design of cold chains that focus on collaboration, such as sharing information among supply chain members, can be leveraged to increase supply chain performance (Runzhou 2014).

2.1.2 Related studies on perishable food cold chain

In this section, the existing literature on perishable food cold chains is reviewed as a basis to set up the research topic of the present study. To begin with, a discussion is presented on cold chains for perishable foods in developed countries, focusing on major perspectives, such as cold chain monitoring, the effect of poor temperature control, and effects of cold chain on the environment. After that, a discussion on cold chains in developing countries is presented, focusing on the cold chain situation and cold chain development. Studies on perishable food cold chains are summarised in Table 2.4.

Table 2.4 – List of selected papers categorised by cold chain issues and countries by level of economic development

Research category	Primary perspective	Countries	Studies
Cold chain monitoring	To apply information technology for monitoring the temperature such as RFID	Developed countries	Abad *et al.* (2009); Carullo *et al.* (2009); De-La-Fuente and Ros (2010); Derens, Palagos and Guilpart (2006); García-Herrero *et al.* (2010); Gogou *et al.* (2013); Kacimi, Dhaou and Beylot (2009); Kang *et al.* (2012); Ko *et al.* (2015); Le Grandois *et al.* (2013); Richardson (2005); Riem-Vis (2004); Ruiz-Garcia and Lunadei (2010); Thakur and Forås (2015); Zubeldia *et al.* (2016)
		Developing countries	Asadi and Hosseini (2014); Draganić *et al.* (2017); Emenike, Van Eyk and Hoffman (2016); Lu *et al.* (2013); Qi *et al.* (2014); Shih and Wang (2016)
Temperature abuse	To study the effect of temperature abuse regarding product quality and safety	Developed countries	Bruckner *et al.* (2012); Cruz, Vieira and Silva (2009); Dermesonluoglu *et al.* (2015); Raab *et al.* (2008); Rediers *et al.* (2009)
		Developing countries	Cruz, Vieira and Silva (2013)
Effect to environment	To study the effect of cold chain on environment regarding global warming	Developed countries	Coulomb (2008); James and James (2010); James and James (2011)
Cold chain situation	To demonstrate the cold chain situation, issues and countermeasures at the moment in various countries.	Developed countries	Arduino and Parola (2010)
		Developing countries	Chen and Lan (2016); Deng, Wu and Yu (2012); Freiboth et al. (2013); Haasbroek (2013); Jemrić and Ilić (2012); Ji and Guo (2009); Jie (2010); Joshi, Banwet and Shankar (2009); Joshi, Banwet and Shankar (2011); Li and Zheng (2014); Prentice and McLachlin (2010); Rathore (2013); Ren (2011); Tian *et al.* (2015); Yang *et al.* (2012); Zeng and Yu (2011); Zhang *et al.* (2016); Bledsoe (2009); Stephen (2009)
Cold chain development strategies	To suggest some strategies for cold chain management	Developed countries	Jol *et al.* (2007)
		Developing countries	Lan, Liu and Wang (2010); Lan, Xue and Tian (2013); Lan *et al.* (2014); Qiu *et al.* (2009); Ren, Hu and Huang (2011); Tang, Liu and Chen (2013); Wang, Xuebing (2016); Xu, Lan and Ruijiang (2010); Yifeng and Ruhe (2013); Ying and Xi (2010)
Alternative cold chain adoption	To suggest some alternative cold chain technologies	Developing countries	Global Cold Chain Alliance (2016); Kitinoja (2013)

Cold supply chains in developed countries are advanced because they have enough money for training professionals and purchasing equipment (Li 2006). This high-tech high-cost approach to cold chain adoption ensures that there will be little or no technical issues during implementation. Therefore, much of the focus in previous studies about perishable food cold chains in developed countries have been placed on cold chain monitoring, effect of cold chain on the environment, and effect of temperature abuse. The objective of cold chain monitoring in the perishable food cold chain is to control and monitor temperature along the whole supply chain, by using technologies such as radio frequency identification (RFID) (Abad *et al*. 2009; Kang *et al*. 2012), bar codes (Thakur & Forås 2015), and wireless sensor network (Carullo *et al*. 2009; Riem-Vis 2004). Real-time temperature checking is vital, for reducing losses in a cold supply chain arising from decay of goods affected by temperature fluctuation, and for preserving food safety (Le Grandois *et al*. 2013; Thakur & Forås 2015). The second group of previous studies focus on the effect of temperature abuse in the cold chain, for example incorrect refrigeration. Some studies have investigated the outcome of temperature abuse on product quality and microbial safety (Bruckner *et al*. 2012; Cruz, Vieira & Silva 2009; Raab *et al*. 2008; Rediers *et al*. 2009). For example, Raab *et al*. (2008) develop a generic model based on laboratory investigations for the calculation of remaining shelf life of fresh pork in various cold chains. Lastly, previous studies on perishable food cold chains in developed countries has focussed on the effects of cold chain on the environment, which lead to global warming and ozone depletion (Coulomb 2008; James & James 2010).

Table 2.4 shows that the majority of previous studies on cold chain in developing countries report on the cold chain situation, suggest some strategies, and provide alternative cold chain technologies to develop cold supply chains. This is because cold chains in developing countries are still not widespread at the moment (Heap 2006; Joshi, Banwet & Shankar 2009; Kitinoja 2013; Salin & Nayga 2003). The first category for developing countries is the cold chain situation, issues, and countermeasures. For example, to demonstrate the current situation and issues, Joshi, Banwet and Shankar (2009) and Rathore (2013) conducted their researches in the context of India, Jemrić and Ilić (2012) in Serbia, Prentice and McLachlin (2010) in Mexico, and Deng, Wu and Yu (2012), Ren (2011) and Tian *et al*. (2015) in China. In the second category, there are previous studies proposing strategies to improve the efficiency of the cold chain. For example, Qiu *et al*. (2009) propose a new model of cross-docking logistics policy in the food cold supply chain. Xu, Lan and Ruijiang (2010) identify the critical points of the cold supply chain process by using quantitative analysis. Lastly, Global Cold Chain Alliance (2016) and Kitinoja (2013) have suggested some low-cost cold chain technologies to implement cold chains in developing countries, such as CoolBot^{TM} and walk-in cold rooms (see Appendix A).

2.1.2.1 Research gap

Overall, it was found that for a majority of studies on cold chains in developing countries, in particular those which investigate the situation and problems of cold chain adoption, suggestions have been made for developing alternative strategies to cold chain design or leveraging alternative cold chain technology. Despite the call, there is little research on alternative cold chain designs that deviate from the high-tech high-cost approach commonly adopted in developed countries. Although the use of available less expensive cold chain technologies can be an option, the full potential of using less expensive technologies, together with other abundant resources in developing countries that can be leveraged for implementing cold chain, has not yet been intensively investigated. To fill this research gap, the present study explores in depth whether a low-tech low-cost approach to cold chain adoption is practical and beneficial for developing countries.

2.2 Theories on cold chain design

According to Halldorsson *et al*. (2007), a unified theory of supply chain management is currently not available. Furthermore, it is also nearly impossible to give a thorough explanation for any supply chain phenomenon with a single theory, due to the complexity of supply chain interactions (Chen, Daugherty & Landry 2009). Therefore, the present study employs a combination of theories to underpin an appropriate approach to cold chain design in developing countries. Two key underpinning theories used in this study are the theory of constraints (TOC) and the network theory (NT). TOC helps to account for the need to invest in cold chain technology, while NT explains why collaboration plays a significant role in cold chain adoption in developing countries.

2.2.1 Theory of constraints

The theory of constraints (TOC) is a management philosophy which was developed by Goldratt (1990). The objective of the TOC is to recognise and focus on constraints that preclude a system from reaching an upper level of performance. The TOC philosophy basically claims that there is at least one constraint in every firm (Simatupang, Wright & Sridharan 2004). The TOC involves three interested areas: logistics, logical thinking, and performance measurement (Cox III & Spencer 1997; Simatupang, Hurley & Evans 1997). Logistics is based on the drum-buffer-rope scheduling method and buffer management (Simatupang, Wright & Sridharan 2004). Logical thinking is based on a continuous development cycle comprising five steps: (1) recognise the bottleneck; (2) make a decision on how to exploit the bottleneck; (3) make all other things in the system subsidiary to the previous step; (4) upgrade the bottleneck; and (5) evaluate whether the bottleneck has been broken, and go back to the beginning (Costas *et al.* 2015). Performance measurement is needed to determine whether the system is accomplishing its operational measures or not, which can be based on throughput or net profit. Pegels and Watrous (2005) state that a simplified version of TOC is to recognise the bottleneck and, after that, take whatever action is necessary to reduce that bottleneck.

The TOC was firstly used to resolve issues in production systems by using several techniques, such as constraint-focused performance and drum-buffer-rope scheduling (Goldratt & Cox 1992). Further extension of the TOC has incorporated resolutions for businesses regarding supply chain management, marketing, and project management (Costas *et al.* 2015; Goldratt 1994; Simatupang, Wright & Sridharan 2004). Recently, increasing numbers of supply chain management scholars apply the TOC to suggest improvements to productivity in the supply chain (Costas *et al.* 2015; Dos Santos *et al.* 2010; Pegels & Watrous 2005). Pegels and Watrous (2005) apply TOC to show how to increase the performance of the manufacturing capability. Dos Santos *et al.* (2010) discuss a TOC application regarding how vendor managed inventory (VMI) adoption can increase the global supply chain performance. Costas *et al.* (2015) apply TOC to reduce the bullwhip effect in a supply chain using agent-based modelling. Umble (2001) defines the use of TOC in the application of an enterprise resource planning (ERP) system to operate a supply chain. It can be seen that TOC has been used to gradually inform various supply chain management issues. As a cold chain requires equipment to maintain consistency in temperature, the TOC is also considered appropriate for explaining the investment of resources in cold chain adoption.

2.2.2 Network theory

Network theory (NT) defines and clarifies relationships amongst linked entities (Thorelli 1986). NT contributes greatly to an acceptance of inter-organisational dynamics by highlighting the significance of personal chemistry among the parties, the construct of belief for positive long-term supportive relations, and the shared adoption of practices and systems for exchange procedure (Halldorsson *et al.* 2007). NT suggests that, by working together, companies can enhance the competitiveness of the entire supply chain and achieve more than they could by operating independently (Axelsson & Easton 1992). Powell (1990) defines a network as a way of resource allotment where transactions happen through a network of individuals engaged in mutual, advantageous and commonly supportive actions.

NT is expressive in nature, and has principally been applied in supply chain management to chart activities, actors and assets in a supply chain. The emphasis has been on improvement in the long term, and on belief-based relations among the supply chain participants (Halldorsson *et al.* 2007). Some previous studies on supply chains have used NT to underpin the research. For instance, Wilson (1996) uses the NT approach to suggest improvement for the competitive advantage of an agri-food supply chain. Nair and Lau (2013) use the NT approach to develop a design for cold chain collaboration for fruits and vegetables. Jarosz (2000) applies NT to provide directions for research on regional agri-food networks. Skjoett-Larsen (2000) discusses numerous meanings of third-party logistics and the related theories, including network theory and transaction cost, for developing third-party activities. Again, NT is considered applicable to the study of cold chain adoption using the low-tech low-cost approach in particular, as it leverages the close collaboration of supply chain members during implementation.

In the present study, the TOC explains why cold chain adoption should be considered, as it is a measure to overcome current constraints in the system and further enhance its performance. The TOC can also guide the design of the cold chain by identifying bottlenecks and overcoming them through investment of resources or alteration of practices. NT accounts for the need for collaboration among supply chain members, as it permits firms to leverage one another's resources and expertise to perform better together than any individual party alone could. By working as a network, collaboration helps to reduce the total amount of resources required for improvement, and removes the weaker links in the supply chain, thereby making it more robust and competitive. The theory also serves as a guide to develop collaboration practices in the cold chain design investigated in this study, so as to maximise the overall benefit. The reasons for using these theories in this study are summarised in Table 2.5.

Table 2.5 – Summary of underpinning theories for this study

Research question	Underpinning theory	Reason for using the theory	Application
What is an appropriate approach to cold chain design for fresh fruit supply chains in developing countries?	Theory of constraints (TOC)	This theory explains why cold chain adoption is investigated, as it is a measure to overcome existing constraints in the fruit supply chain and help enhance performance.	To improve KPIs of fruit supply chain in Thailand through removal of system constraints, and reduction of non-value-added activities.
	Network theory (NT)	This theory accounts for the need to collaborate among all supply chain members within the cold chain, so as to leverage resources and expertise, share information and knowledge, and standardise practices.	To improve KPIs of fruit supply chain in Thailand, through development of a better relationship among fruit supply chain members, so as to better compete against neighbouring fruit-exporting countries.

2.3 Cold chain categorised

Extant studies on cold chain design have been reviewed for the present study, the findings of which are summarised in Table 2.6. Focuses of these studies can be categorised into two groups: (1) individual cold chain design; and (2) consolidated cold chain design. Individual cold chain design is based on the TOC to use the cold chain technology in the proper way to overcome these constraints. Individual cold chain design also leverages the NT to account for the need for information sharing among supply chain members, such as on temperature control parameters. It refers to the adoption of the various cold chain technologies, which can be high-cost or low-cost (see Appendix A). They include pre-cooling facilities, temperature-controlled trucks, and temperature-controlled warehouses invested in by each member of the supply chain individually to maximise flexibility of operations (see, for example, Global Cold Chain Alliance 2016). Consolidated cold chain design is also based on the ideas of the TOC and NT. It needs technologies to overcome the constraints, and requires collaboration among supply chain members. Consolidated cold chain design refers to the sharing of cold chain technologies, infrastructure, knowledge and information among the supply chain members, so as to reduce total investment cost and maximise usage of resources (see, for example, De-La-Fuente and Ros 2010).

Table 2.6 – Studies on cold chain management with different designs

Category	Primary perspective	Design Approach	Studies
Individual cold chain designs	**Technology**	**Use low-cost technology** ▪ Portable forced air cooling systems ▪ CoolBot ▪ USDA Porta-cooler	CDH Energy Corp (2009); Dubey (2011); Global Cold Chain Alliance (2016); Kitinoja (2013); Robert, Andrew and John (2016)
		Use high-cost technology ▪ Vacuum cooling ▪ Mechanical refrigeration	Bishop (2013); Bledsoe (2009); Brecht *et al.* (2010); California Strawberry Commission (2011); Picha (2006); Shane (2016); Wang & Luo (2012)
Consolidated cold chain design	**Management**	**Develop a collaborative network** ▪ Share information ▪ Integrate logistics capabilities ▪ Alliance	Bishara (2006); D&B Tangram Advisory Services (2016); De-La-Fuente and Ros (2010); Drame and Meignien (2016); Hou, Xie and Wang (2015); Kitinoja (2014); Li (2006); AT Kearney Limited (2005); D&B Tangram Advisory Services (2016); Hou, Xie and Wang (2015); Jing and Jian (2015); Kitinoja (2014); Lan *et al.* (2014); Lan, Liu and Wang (2010)
		Reduce processing time ▪ Use a hub and spoke design ▪ Leverage cross docking ▪ Set up a cold chain logistics centre	Ma and Wu (2015); Zhu *et al.* (2014); Qiu *et al.* (2009); Yachao (2013); Pawanexh (2010); Anjum Asim Shahid Rahman Limited (2009); Pakistan Horticulture Development & Export Board (2007); Yu and Yan (2010)

For individual cold chain design, the high-cost or low-cost facilities and technologies of the cold chain are used to operate a cold chain adoption (Quaye 2011). The design usually involves the use of pre-cooling technologies, cold storage, and refrigerated carriage, in order to control the temperature of products at the various stages along the entire supply chain. To take the strawberry cold chain as an example, forced-air cooling is set up at farms to remove field heat from the fruit. After the pre-cooling process, the fruits will be held in a cold room to maintain the same temperature before the pick-up by the truck comes for transportation. The trucks also have to be temperature-controlled, because the fruits need to be kept at a constant temperature to reduce the rate of natural degradation until they reach the consumers. This is necessary to preserve the freshness or quality of the fruit and ensure food safety (California Strawberry Commission 2011). Similarly, seafood, milk, meat and other perishable products (Bledsoe 2009) need to undergo pre-cooling after harvest to a specific temperature. Refrigerated transport is also needed to ship the products to a packing house that is also temperature-controlled. After that, the products can be moved to cold storage, either in the packing house or a distribution centre, again by temperature-controlled trucks. Later, the products are transferred to the retailers, which also need refrigeration facilities to maintain the temperature of the goods. With the use of advanced cooling technologies and specialised equipment, cold chain design in developed countries is generally robust and reliable. However, this may not be suitable for developing countries because of the high cost involved.

Generally speaking, the advanced infrastructure and technology for cold chain is mostly lacking in developing countries (Kitinoja 2013). However, previous studies suggest that there are various low-cost cold chain technologies for preserving temperature along the cold chain (Global Cold Chain Alliance 2016; Kitinoja 2013). For example, instead of using forced-air cooling, which requires investment in equipment, pre-cooling at farms or small-scale businesses can be done using low-cost approaches such as ice or portable forced-air cooling. For cold storage, instead of building large, fully temperature-controlled storerooms, there is less expensive equipment available, such as walk-in cold rooms, which can be CoolBot^{TM}-equipped. For refrigerated transportation, again, low-cost cooling can be achieved by passive cooling technologies, such as ice or the use of USDA Porta coolers for short-distance delivery, instead of using specialised temperature-controlled vehicles which are quite expensive. In Kenya as an example, the locals use a low-cost approach for pre-cooling called portable forced-air cooling, which is suitable for low humidity areas. Economic temperature-controlled storage devices, such as the CoolBot^{TM} systems, are often used, which cost less than half the cost of the standard commercial cold room. This approach has also been proven to be effective in Bangladesh and India (Global Cold Chain Alliance 2016). Low-cost cold chain technologies might also be suitable for other developing countries, such as Thailand, which has a large number of farmers with limited resources or knowledge of the use of advanced cold chain technologies (Buurma & Saranark 2006; Nissen *et al*. 2005; Salin & Nayga 2003).

With proper collaboration among supply chain partners and consolidation of activities, low-cost cold chain design might still lead to significant improvement in performance (AT Kearney Limited 2005). A number of previous studies (Bishara 2006; Hou, Xie & Wang 2015; Ma & Wu 2015; Pakistan Horticulture Development & Export Board 2007; Pawanexh 2010; Qiu *et al*. 2009) have developed some cold supply chain strategies to improve the efficiency of food logistics and reduce the total cost. One of these strategies is to set up a collaborative network involving all cold supply chain members. For example, Rodríguez, Amorrortu and Álvarez (2011) and Lan *et al*. (2014) argue that a successful cold chain logistics system can be achieved through collaboration, integrated planning, information and resource sharing during the cold chain process for the food entity from providers to consumers. Another strategy is to design the chain is such a way that processing time from farm to end customers can be reduced. The argument is that the cold chain is basically about speed. The shorter the lead time in transportation is, the longer is the shelf life of the product (Zhu *et al*. 2014). For example, Billiard (2003) suggests that the time interval between harvesting, processing and cooling should be reduced to decrease water loss from the produce and minimise the effects of fungi (Wardlaw 1939). Similarly, cold chain distribution centres should be located near the ports or farms to minimise transfer time (Yu & Yan 2010).

Individual cold chain design (which can be seen as a high-tech high-cost approach) commonly applied in developed countries requires an enormous amount of capital investment in refrigeration technologies and equipment for each member. This might not be suitable for developing countries, such as Thailand, which are limited in resources and less advanced in cold chain technologies (Serrano 2005). For basic cold chain adoption to keep harvested fruits at low temperature across the entire supply chain, low-cost technologies may suffice which require less resources and expertise than do the conventional cold chain technologies. Using a consolidated cold chain design (which can be seen as a low-tech low-cost approach), infrastructure and capital investment requirements may be further reduced, while utilisation of assets and efficiency can be enhanced.

2.3.1 Pros and cons of different cold chain designs

The literature reveals that there are various advantages and limitations of cold chain designs. Table 2.7 summarises the findings of a number of studies on the pros and cons of various cold chain designs, which, as mentioned earlier, can be categorised into two groups: (1) individual cold chain design; and (2) consolidated cold chain design.

Table 2.7 – Studies on the advantages and limitations of cold chain management in different designs

Type of cold chain design	Advantages		Limitations	
	Category	References	Category	References
Individual cold chain	The stable operation of the whole cold chain	Hou, Xie and Wang (2015)	▪ Lack of financial resources to invest ▪ High cost ▪ Waste of resources in the off-season	Drame and Meignien (2016); Global Cold Chain Alliance (2016); Hou, Xie and Wang (2015); Kitinoja (2013) Hou, Xie and Wang (2015)
Consolidated cold chain	Minimise cost	Hou, Xie and Wang (2015); Kitinoja (2013); Shane (2016); Stephen (2009)	▪ Difficult to find members who have the ability to apply it	Global Cold Chain Alliance (2016)

Generally speaking, individual cold chain design can guarantee the possibility of the longest shelf life, thereby sustaining the flavour and quality of the product (Global Cold Chain Alliance 2016), because it supports a steady operation across the entire cold chain (Hou, Xie & Wang 2015). This design can be valuable as even minor errors in handling temperature-sensitive goods may cause serious consequences such as decreasing shelf life (Shane 2016) . Nevertheless, such design requires an enormous amount of money to invest in cold chain infrastructure and technologies (Drame & Meignien 2016; Global Cold Chain Alliance 2016; Hou, Xie & Wang 2015; Kitinoja 2013). Moreover, during the off-peak season, part of the invested cold chain infrastructure and technologies are often left in an idle state (Hou, Xie & Wang 2015).

Consolidated cold chain design, on the other hand, can help to reduce the cost of infrastructure and technologies to invest in (Kitinoja 2013), because supply chain members can share the infrastructure used, such as pre-cooling and cold rooms. It can also improve the level of technology used for cropping, delivery process, and storage, and enhance the efficiency and responsiveness of all cold chain members (Winkworth-Smith, Foster & Morgan 2015). Unfortunately, it is often difficult to find supply members to participate in the collaboration (Global Cold Chain Alliance 2016), because some of the members, for example farmers, are not well-educated, trained or prepared to apply the consolidated cold chain design.

In sum, individual cold chain design has benefits in terms of productivity improvement. In addition, it enables maximum cold chain coverage during operation. However, it requires an enormous amount of money to invest in infrastructure, which is a major obstacle for developing countries (Kitinoja 2013). In contrast, consolidated cold chain is considered a more feasible approach for developing countries, because it requires a relatively low cost of investment and can also improve the efficiency of the entire cold chain through collaboration among cold chain members.

2.4 Tool for investigating cold chain designs

There are very limited existing fresh fruit cold chains in developing countries, such as Thailand, for investigation (Buurma & Saranark 2006; Nissen *et al.* 2005; Salin & Nayga 2003). Furthermore, the testing of alternative designs cannot be implemented without significantly impacting on the current operation of a cold chain. As such, a simulation approach can be adopted, as it is free of the above-mentioned issues (Hellström & Nilsson 2006).

2.4.1 Simulation approach

The simulation approach is commonly used in the supply chain field to show the actual situation that occurs in a logistics system or to test scenarios that are created on the basis of different input assumptions (Sumari *et al.* 2013; Tako & Robinson 2012). In general, discrete event simulation (DES), system dynamic simulation (SDS), and agent-based simulation (ABS) are the most commonly used simulation methods, because they can deal with the different variabilities and uncertainties of the system (Sumari *et al.* 2013).

A number of studies on supply chain simulation are summarised in Table 2.8. The focus of these studies can be categorised into four groups: (1) process design, (2) supply chain network, (3) supply chain policy, and (4) supply chain performance. Process design refers to the examination and rationalisation of physical processes to assist in decision-making and to control waste. Supply chain structure refers to the optimisation of supply chain configuration and the sequence or links between activities. Supply chain policy refers to the identification of the most appropriate strategies to deal with changes in circumstances. Supply chain performance looks at the output of a supply chain using certain indicators, such as cost and lead time.

Table 2.8 – List of selected papers categorised by logistics and supply chain issues and simulation approach

Research category	Primary perspective	Simulation method	Studies
Process design	To design process with uncertainties and address transport issues in order to be an efficient process	Discrete event simulation (DES)	Iannoni and Morabito (2006); Jung *et al.* (2004); Kumar and Rahman (2014); van der Vorst, Beulens and van Beek (2000); van der Vorst *et al.* (1998); van der Vorst, Tromp and van der Zee (2005, 2009)
Supply chain structure	To configure the supply chain structure and network in order to be an efficient network and structure	Discrete event simulation (DES)	Carvalho *et al.* (2012); Katsaliaki, Mustafee and Kumar (2014); Kristianto *et al.* (2012); Persson (2011); Persson and Olhager (2002); Reiner and Trcka (2004)
		System dynamic simulation (SDS)	Özbayrak, Papadopoulou and Akgun (2007)
		Agent-based simulation (ABS)	Zhang *et al.* (2006)
Supply chain policy	To implement policy into the supply chain for solving supply chain issues, and developing produce quality	Discrete event simulation (DES)	Cigolini *et al.* (2014); Jacxsens *et al.* (2010); Lyu, Ding and Chen (2010); Meng *et al.* (2014); Rickard and Sumner (2011); Saad and Kadirkamanathan (2006); Thron, Nagy and Wassan (2007); Wang and Li (2012)
		System dynamic simulation (SDS)	Cedillo-Campos *et al.* (2014); Georgiadis, Vlachos and Iakovou (2005); Low (2013); Martínez-Olvera (2009); Pierreval, Bruniaux and Caux (2007); Ramanathan (2014); Teimoury *et al.* (2013); Lee and Chung (2012);
		Agent-based simulation (ABS)	Dominguez, Cannella and Framinan (2014); Zhang *et al.* (2006); Chan and Chan (2010)
Systems performance	To assess the operation performance by using certain criteria such as cost	Discrete event simulation (DES)	Fleisch and Tellkamp (2005); Jacxsens *et al.* (2010); Jansen *et al.* (2001); Kang *et al.* (2012); Mohan, Gopalakrishnan and Mizzi (2013)
		System dynamic simulation (SDS)	Bueno-Solano and Cedillo-Campos (2014); Kumar, Sameer and Nigmatullin (2011); Low (2013); Martínez-Olvera (2009); Kumar and Nigmatullin (2011)

Among the three major simulation approaches, DES is widely used in all the supply chain research categories. For instance, it is used for redesign processes in order to solve supply chain uncertainty problems, such as order cancellation and machine breakdowns (van der Vorst, Beulens & van Beek 2000; van der Vorst *et al.* 1998). In addition, DES is also used to address supply chain network issues in terms of designing an efficient supply chain network or structure (Kristianto *et al.* 2012; Persson & Olhager 2002). Some researchers have used DES to explore the use of a certain policy for solving supply chain problems, such as the replenishment problem (Lyu, Ding & Chen 2010). Lastly, DES is used to evaluate system performance with different inventory levels (Fleisch & Tellkamp 2005) or supply chain configurations (Cigolini *et al.* 2014).

Compared to DES, SDS is less often used as a simulation technique to investigate or explore process design, supply chain structure, and system performance. There is a general belief that SDS is most suitable for modelling problems at a policy level (Tako & Robinson 2012). For example, there are studies which have used SDS to investigate the effect of logistics and supply chain policies, such as inventory policy (Georgiadis, Vlachos & Iakovou 2005), "leagile" (a hybrid between lean and agile) strategy (Zhang, Wang & Wu 2012), collaboration policy (Pierreval, Bruniaux & Caux 2007; Ramanathan 2014), and export-import policy (Cedillo-Campos *et al.* 2014; Teimoury *et al.* 2013).

Some researchers have used the ABS technique to examine the impacts of supply chain network and supply chain policy. For instance, ABS has been used to study the bullwhip-limiting effect in a supply chain (Dominguez, Cannella & Framinan 2014). Nevertheless, compared to DES and SDS, ABS is not as popular as a simulation technique, based on the number of studies that have used the different approaches.

As revealed in the literature, DES is a widely used simulation approach for studies in all of the four research focus categories. In studies using simulation to design a more effective fruit supply chain, such as cold chain adoption, DES appears to be an appropriate tool for the purpose. However, both SDS and ABS are appropriate candidates mainly when long-term policies or complex interactions between supply chain members are involved (Lau &

Kanchanasuwan 2015). Therefore, this approach has been used to develop the fresh fruit supply chain model for analysis in the present study.

2.5 Key performance indicators for the simulation study

To employ a simulation methodology, it is necessary to use some key performance indicators (KPIs) to compare the results of the simulation model. A review of previous studies identifies some commonly used KPIs in supply chain simulation. For example, van der Zee and van der Vorst (2005) use cost, such as holding costs and transportation costs, as a KPI to evaluate the result of an alternative approach of vendor managed inventory (VMI) through supply chain simulation. Similarly, Persson and Olhager (2002) use lead time and cost to assess the impact of quality level for the alternative supply chain designs in the mobile communications business. In addition, Umeda and Zhang (2006) offer a simulation model to investigate collaboration between business partners using throughput, order lead-time, and shortage rate as KPIs. There have been efforts to systematically collect measures for appraising supply chain performance. For example, Chan (2003) has identified seven core performances: cost (operating cost), resource usage (machine, labour, capacity and energy), quality (lead time), flexibility (volume of output), visibility (accuracy), belief (consistency), and innovation (new use of technology).

There are certain KPIs that are normally used in studies of the fruit and vegetable supply chain, as presented in Table 2.9. The KPIs used for these studies can be categorised into six groups: (1) shelf life, (2) safety, (3) wastage, (4) cost, (5) lead time, and (6) production.

Table 2.9 – List of KPIs that are normally used for fruit and vegetable research

KPIs group	KPIs	Central perspective	Studies
Quality	Shelf life	To improve shelf life by using several strategies	Aung and Chang (2014); Cagnon *et al.* (2013); Jacxsens *et al.* (2010); Rijpkema, Rossi and van der Vorst (2014); van der Vorst, Tromp and van der Zee (2009)
	Safety	To improve fruit safety by using several strategies	Jacxsens *et al.* (2010); Joshi, Banwet and Shankar (2010); Narrod *et al.* (2009)
	Wastage	To reduce fruit wastage by using several strategies	Hsieh, Wang and Su (2011); Rossi, Rijpkema and van der Vorst (2012); Wang and Li (2012)
Normal supply chain	Cost	To use as a performance for comparison	Bogataj, Bogataj and Vodopivec (2005); Rijpkema, Rossi and van der Vorst (2014)
	Lead time	To use as a performance for comparison	Bogataj, Bogataj and Vodopivec (2005); Cadilhon *et al.* (2006)
	Production	To use as a performance for comparison	Bogataj, Bogataj and Vodopivec (2005); Rickard and Sumner (2011)

Several literature reviews have been conducted focusing on the improvement of fruit quality (Cagnon *et al*. 2013; Jacxsens *et al.* 2010; Joshi, Banwet & Shankar 2010; Rijpkema, Rossi & van der Vorst 2014). Cagnon *et al.* (2013) apply the requirement-driven approach (RDA) to strawberry packaging to extend shelf life and reduce risk of damage to the strawberries. Rijpkema, Rossi and van der Vorst (2014) evaluate a sourcing policy which can improve supply chain performance regarding wastage, cost and shelf life of fresh fruit. Jacxsens *et al.* (2010) study policy development in order to ensure the long run of fresh produce safety. Narrod *et al.* (2009) explore the practices between Indian customers in order to investigate the relationship between preservation of food using cold chain and food safety. Moreover, Hsieh, Wang and Su (2011) study the implementation of green supply chain management policies to the hotel industry in order to reduce fruit and vegetable wastage. Rossi, Rijpkema and van der Vorst (2012) examine the effect of dual sourcing policies on the fresh strawberry industry, in terms of quality and wastage.

Moreover, there are several previous studies on fresh fruit supply chains using KPIs, such as cost, lead time, and production (Bogataj, Bogataj & Vodopivec 2005; Rijpkema, Rossi & van der Vorst 2014). Rickard and Sumner (2011) examine the effect of policies on the evolution of the European Union (EU) domestic market for fruits and vegetables, by using production as a comparison. Cadilhon *et al.* (2006) study improvements in the Vietnamese vegetable industry by using lead time as a performance measure to compare between modern and traditional chains. Lastly, some studies have used cost as a performance measure for the fresh fruit supply chain (Bogataj, Bogataj & Vodopivec 2005; Rijpkema, Rossi & van der Vorst 2014). Rijpkema, Rossi and van der Vorst (2014) use cost to evaluate the effectiveness of an existing sourcing policy for the fresh fruit supply chain.

Shelf life and wastage of perishable produce are significantly influenced by temperature control (Aung & Chang 2014). Joshi, Banwet and Shankar (2011) suggest that the suitable performance factors for cold chain study are throughput, timeliness, quality, and cost. To evaluate the results of cold chain design, the present study uses five KPIs to examine the impacts of cold chain adoption: total operating cost of the entire supply chain, shelf life, wastage, throughput, and lead time.

2.6 Theoretical framework

For the traditional fruit supply chain in developing countries, lack of supply chain management knowledge, no temperature control during storage and distribution, and low technology to improve post-harvest fruit quality, are some of the causes that lead to issues, as depicted in Figure 2.2. These issues include high wastage, limited shelf life, low quality, reduced safety, and low efficiency. Previous studies have suggested some solutions to address these issues. For example, several studies recommend packaging development (Blanco *et al.* 2005; Sandhya 2010), demand analysis (Mergenthaler, Weinberger & Qaim 2009; Verdouw *et al.* 2010), and cold chain adoption (Chen, Hong & Lin 2000; Freiboth *et al.* 2013). Cold chain is a commonly used solution to address fresh fruit issues in developed countries. However, cold chain adoption is still uncommon in developing countries, due to limitations in infrastructure and knowledge. Thailand is one of those developing countries that is very limited in cold chain practice, for the foregoing reasons. To promote cold chain adoption in developing countries, the present study uses simulation as a methodology to explore the appropriate approach to cold chain design for fresh fruit supply chains in developing countries, based on the ideas of the TOC and the NT. The TOC is used to identify bottlenecks and improve on them through the allocation of resources. The NT is employed to account for collaboration among supply chain members. The study expects to identify suitable cold chain designs for the fresh fruit industry in developing countries, so as to help improve supply chain performance in terms of lower operating cost, increased throughput, reduced lead time, extended shelf life, reduced wastage, and improved efficiency.

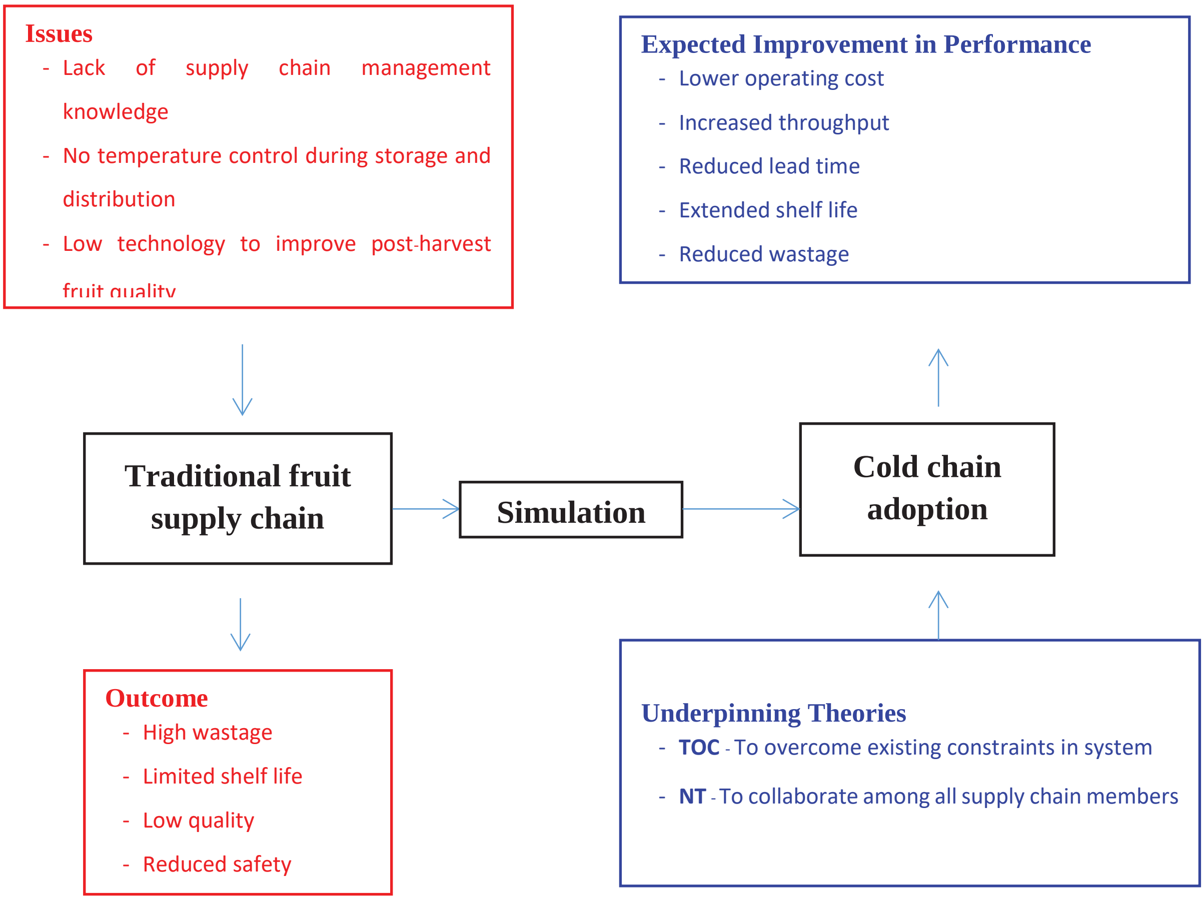


Figure 2.2 – Proposed framework of this study

2.7 Chapter summary

This chapter discussed the need to adopt cold chain in developing countries, especially in the fresh fruit industry, and reviewed the issues faced by developing countries in cold chain adoption to understand why cold chains in developing countries have not succeeded. The two theories used to underpin this study – the theory of constraints, and the network theory – have been discussed. They provide guidance for developing the cold chain designs investigated in this research. Furthermore, in this chapter commonly used cold chain designs were reviewed. In addition, tools for investigating cold chain designs were discussed in detail. Finally, a theoretical framework for cold chain design for the fresh fruit industry in developing countries, such as Thailand, was proposed. The next chapter will discuss the methodology used in this study.

Chapter 3

METHODOLOGY

The primary objective of this study is to examine an alternative approach to cold chain design for fresh fruit supply chains in developing countries. As cold chain implementation for fresh fruit products in developing countries is still uncommon, simulation is considered the most appropriate technique to compare the performance of a fruit supply chain before and after cold chain implementation. This chapter explains in general the approach used in this study.

3.1 Modelling and simulation approach

A simulation is a representational computer model of the real world or a system over time. Simulation is utilised to define and analyse a system's behaviour, to ask what-if queries about the actual system, and to assist in the design of actual system (Banks 1998; Rossetti 2015). A simulation approach can assist in: (i) discovering a system through the alteration of procedures, operations, strategies and approaches, with a relative lack of interference in the actual system and low cost; and (ii) slowing down or speeding up a phenomenon of attention so that it can be explored completely (Iannoni & Morabito 2006; Kelton, Sadowski & Sturrock 2004). The simulation method is appropriate for this study because, to date, cold chain adoption is very limited in developing countries due to limited cold chain infrastructure, high cost, and the lack of awareness and training (Buurma & Saranark 2006; Nissen *et al.* 2005; Salin & Nayga 2003).

There are numerous categories of computer-based simulation, such as system dynamics, discrete event simulation, and agent-based simulation. For the present study, discrete event simulation (DES) is used to develop the fresh fruit supply chain model for analysis, because it is generally used in the area of tactical or operational level, focusing more on the process in the business, and is typically used in decision making (Sumari *et al.* 2013). As revealed in the literature, DES is the most commonly used simulation approach for studies in supply chain performance analysis (Fleisch & Tellkamp 2005), supply chain design (Carvalho *et al.* 2012), and supply chain policy formulation (Rickard & Sumner 2011).

There are many software packages for discrete event simulation. Commercial DES packages, such as Promodel and ARENA, are commonly used by modellers to run simulations (Schriber & Brunner 2007; Sumari *et al.* 2013). The present study used ARENA to create the simulation models required for scenario testing and analysis. Developed by the software company Rockwell, ARENA (Rockwell Automation 2018) is designed to model logistics and supply chain systems, among others. It is a relatively popular DES tool commonly used by the manufacturing and the production industries (Setyaningsih & Basri 2013; Thomassey 2014). In the following sections, details of each step of the simulation methodology will be presented.

3.2 Modelling and simulation process

According to the literature, there are alternative explanations of the simulation methodology, which are frequently outlined as a flowchart (Figure 3.1) with a series of phases. Despite the different explanations, the main idea is the same and the variances are confined to the operation details (Steins 2010). This section presents a brief description of the typical phases in a discrete event simulation. The explanation is based primarily on the simulation study stages recommended by Rossetti (2015), Banks *et al.* (2010), Altiok and Melamed (2007), and Kelton, Sadowski and Sturrock (2004).

3.2.1 Expressing the purposes of the study

Simulation is frequently realised as a problem-solving technique. The initial step in construction of a simulation model is to indicate the problem to be solved, even though, occasionally, the actual issue itself comes to be clear after or during the simulation process. The problem statement sets up purposes for the entire simulation study. This comprises what queries the simulation model should address. If the simulation model intends to appraise some alternatives, these options are outlined (Altiok & Melamed 2007; Steins 2010).

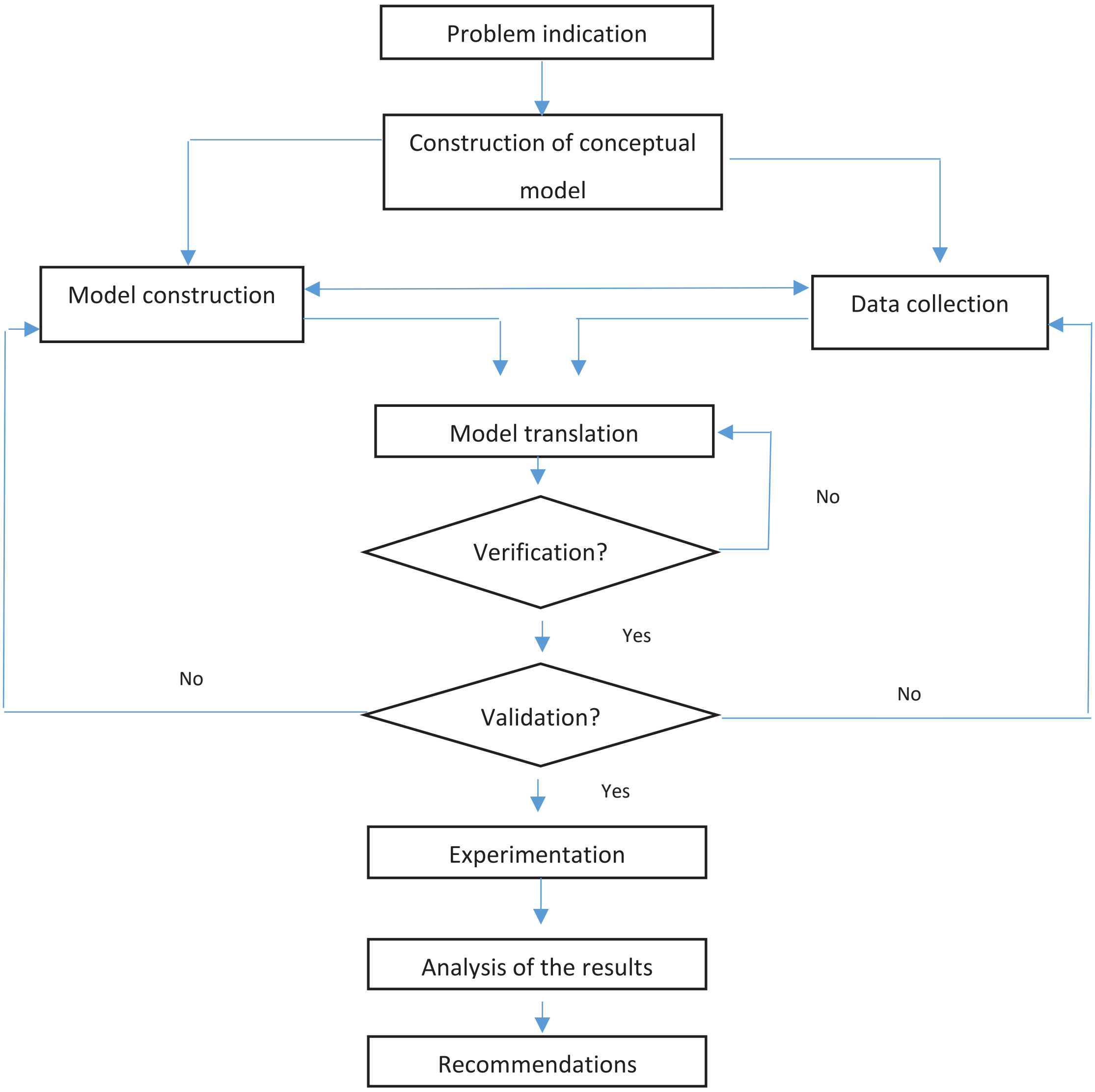


Figure 3.1 – Simulation methodology in general (Rossetti 2015)

3.2.2 Conceptual model design

The modeller usually makes a conceptual modelling tool, such as a flow chart and/or conceptual diagrams, to obtain a clear understanding of the system under study (Rossetti 2015). The tasks for conceptual modelling are to decide on how to clarify the reality, what to include in the simulation model, and how to select the correct level of model detail (Steins 2010). The process of modelling starts with a basic model, and after that, further detail can be included if needed (Banks *et al.* 2010).

3.2.3 Data collection and analysis

The data collection and analysis steps are usually run in parallel with the conceptual model design. All parameters in the model are recognised through this stage, and appropriate data regarding the system under investigation are gathered consistently within the scope of the model. Data are generally collected by direct observation, conducting interviews, querying database, and investigation of the remaining documentation (Steins 2010). According to Altiok and Melamed (2007), data gathering is required for model validation, as will be explained in the verification and validation step.

3.2.4 Model translation

After the problem is wholly formulated and the necessary data gathered, a working simulation model is constructed using computer language, which can be a special-purpose simulation language (*e.g.*, Promodel, ARENA, and GPSS) or a general-purpose simulation language (*e.g.*, Visual Basic, C++, and FORTRAN) (Altiok & Melamed 2007; Steins 2010).

3.2.5 Verification and validation

To develop an accurate simulation model, verification and validation is an important procedure. Model verification, by definition, is a process to substantiate that the model is transformed from one form into another as proposed with adequate exactness (Balci 1998). It relates to the exactness in transforming the formulation of a problem into a model determination, or the correctness in transforming a model representation from a micro flowchart method into an executable computer program, as is appraised in model verification (Alzahrani 2011; Balci 1998). In other words, it deals with building the model correctly. It can be performed by using debugging tools (Steins 2010). However, model validation is confirming that, within its area, the model performs with satisfactory exactness consistent with the research objectives (Balci 1998). It deals with building the correct model. Validation can be achieved by comparing the historical data with the output of a simulation model and by sensitivity analysis (Sargent 2005).

3.2.6 Experimentation

Designing and conducting simulation experiments to achieve the purposes of the study follows the verification and validation step. The design of experiments includes choosing the alternatives to be simulated. Experimental design involves making decisions on the number of replications and length of simulation run (Steins 2010).

3.2.7 Analysis of the results

The majority of discrete-event simulation models include stochastic elements (Kelton, Sadowski & Sturrock 2004). Therefore, the output is analysed by using statistical techniques. Average values over several replications are computed for necessary output measures at a confidence level of 99%. Simulation regularly involves more than assessing a single alternative. Analysis of output from a simulation also includes comparing the outputs from several experiments and choosing the best alternative from the results (Steins 2010).

3.2.8 Recommendations

The last phase in a simulation study is using the results to make recommendations for the fundamental system. This is normally part of a written report (Altiok & Melamed 2007).

3.3 Overview of the modelling and simulation process in this study

3.3.1 Problem identification

In this study, DES is employed to explore the performance of a fresh fruit supply chain in a developing country before and after cold chain adoption, using both the high-tech high-cost and the low-tech low-cost designs. A typical fresh mango supply chain in Thailand is chosen as a case study to develop the base system. The commercial DES package ARENA is used as the tool for the building and testing of the models for the current situation and the future scenarios. At present, cold chain adoption in the fresh fruit industry in Thailand is very limited. Owing to the high ambient temperature of the tropical country, fresh fruits harvested from farms deteriorate quickly during processing and transportation, thereby shortening their shelf life and leading to high wastage. The major problem in the system under investigation is the lack of temperature control in storage and transit. It is believed that cold chain adoption can provide a solution to this problem. The question is, which design is most suitable for developing countries, taking into consideration requirements and availability of resources, knowledge and skills, as well as flexibility of work practices.

3.3.2 Conceptual model development

This research used the conceptual modelling tools, flowcharts and conceptual diagrams, in Microsoft Visio 2013 software, to translate the identified actual fresh mango supply chain into a logical representation of the concerned activities and processes. The conceptual models help the modeller to understand the current system better. Simulation model building began after creating a solid conceptual model of the fresh mango supply chain as a case study.

3.3.3 Data collection

This study collected data and information about the sampled fresh mango supply chain by visiting all the parties involved, conducting semi-structured interviews, and making site observations. The semi-structured interviews were used to gather data and information about the cost, capacity of the machines, and exceptions, such as the operation during peak and off-peak seasons, that might occur outside the period of investigation. Site observations were used to collect the actual flow rates and operation time. These observations also enabled cross-checking of the information provided by the interviewees, and recording of the characteristics of the operations, which could help to refine the simulation model to reflect accurately the actual situation.

3.3.4 Model translation

The conceptual model and the data collected about the mango supply chain were then used to create a DES model using ARENA, a commercial DES software package widely used for supply chain redesign (Sumari *et al*. 2013).

3.3.5 Model verification and validation

This research used several verification and validation techniques to test the validity of the simulation model. Process maps, 2D animation, and the ARENA debugger were used to confirm that the simulation model was correctly created. Comparison of output from the simulation model against that of the real system was made through statistical analysis. Several sensitivity analysis tests were also conducted to investigate the validity of the model logic.

3.3.6 Experimentation

Upon model verification and validation, the validated model was modified to create alternative models to examine various cold chain designs, with a view to identifying the most appropriate one for developing countries. Previous studies reveal two types of cold chain design, individual cold chain design (which can be seen as a high-tech high-cost approach) and consolidated cold chain design (which can be seen as a low-tech low-cost approach). These two designs were translated into two alternative models for exploration. The operation length of the system in each simulation run was 72 hours (1 cycle), and 100 replications were made for each design. In addition, three scenarios regarding change in total demand, increase in supply uncertainty, and change in operating cost were created to test the robustness of the alternative cold chain designs in the long run.

3.3.7 Analysis of the results

This research used the *t*-test for independent samples to compare the performance of the actual system with the base model, and well as between the alternative models. 100 runs were used to obtain the sample means for comparison. This statistical technique was consistently applied to compare the simulation outcomes between the base model and the actual system during the model validation stage, as well as for the comparison of alternative cold chain designs within different scenarios.

3.4 Chapter summary

This chapter has described the methodology used for this study. It has described the process and the steps of the discrete-event simulation to be undertaken through the several phases of the research. It also gives an overview of how the methodology is applied in this study, using a fresh mango supply chain in Thailand as a case study. The next chapter will present the base model development (*i.e.*, the actual situation).

Chapter 4

DEVELOPMENT OF THE BASE MODEL

This chapter describes the approach used in this study to create the base model, following the procedures recommended by Altiok & Melamed (2007), Banks *et al.* (2010), Kelton, Sadowski & Sturrock (2004) and Rossetti (2015). These procedures include system definition, model building, and model verification and validation. In addition, this chapter presents the outputs of the base model and the validation results to verify that the base model is representative of the real system. Outputs of the base model in throughput, processing time, operating cost, shelf life and wastage, using the mean values of 100 replications, are compared against the actual values of the real system. Student's *t*-test for independent samples will be used to determine whether there are significant differences between both means – simulated outcome versus actual performance – for each indicator.

4.1 Modelling and simulation process

Modelling and simulation is a complex process usually divided into distinctive phases. This section describes the four phases of the simulation methodology that were followed in building the simulation model (Altiok & Melamed 2007; Banks *et al.* 2010; Kelton, Sadowski & Sturrock 2004; Rossetti 2015) for the fresh fruit supply chain under investigation. As shown in Figure 4.1, these phases constitute a guiding framework for constructing, running, validating and modifying the simulation model for scenario testing. The entire process from an operational perspective is represented in Figure 4.2.

1. Phase 1: System definition

2. Phase 2: Model building

3. Phase 3: Model validation

4. Phase 4: Alternative model development and scenario testing

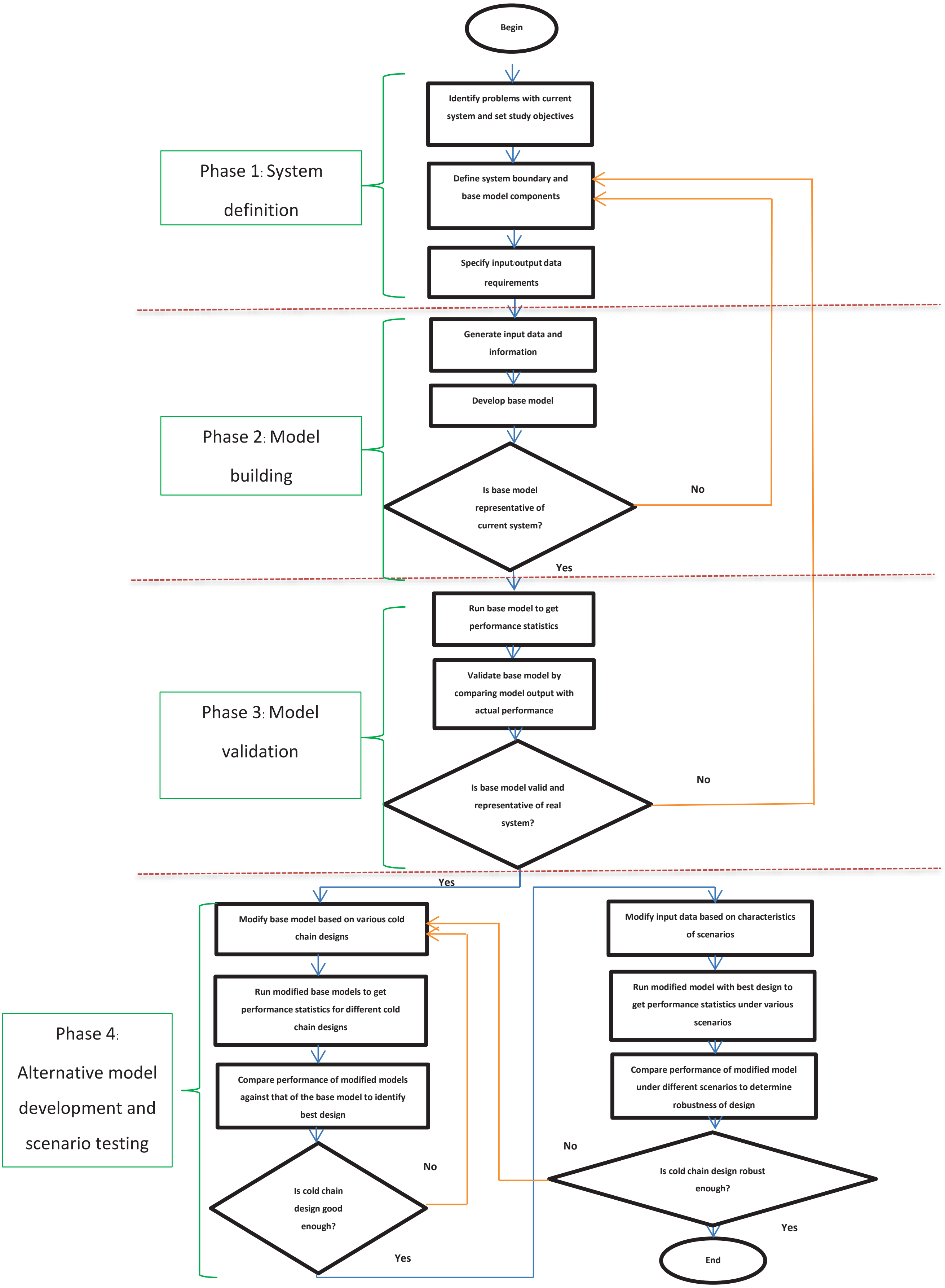


Figure 4.1 – Flow chart for the simulation process of this study (Rossetti 2015)

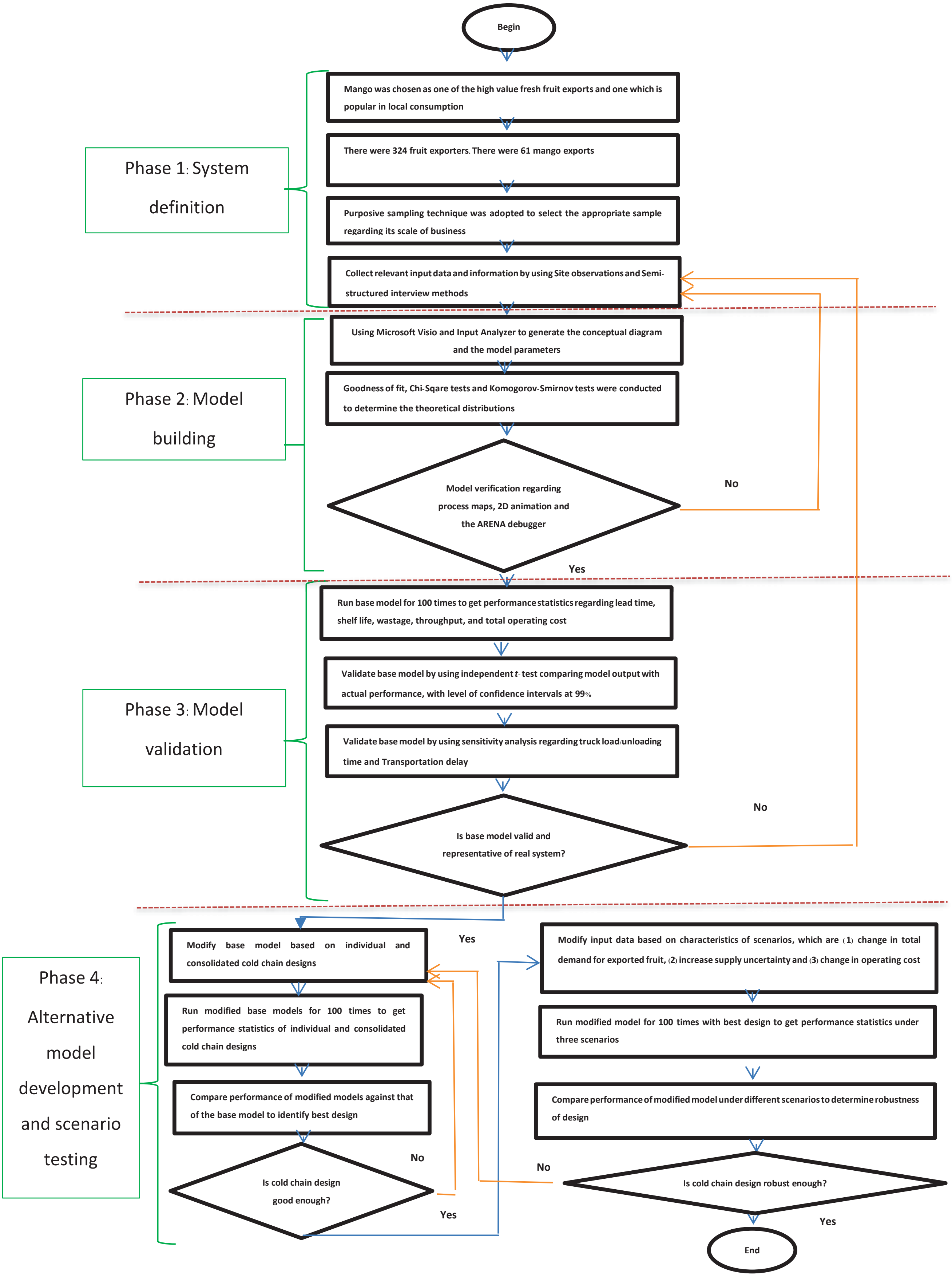


Figure 4.2 – **Flow chart for the simulation process of this study from an operational perspective**

4.2 Phase 1: system definition

This stage covers the selection of study sample, identification of problem, and description of the system.

4.2.1 Study sample

In developing the simulation model, a single fresh fruit supply chain was selected for detailed analysis so that the current operation could be replicated. Mango was chosen as the fruit for investigation as it is one of the major high-value fresh fruit exports in Thailand (Panichsakpatana 2013; Wangsinthaweekhun 2007). It is also a very popular fruit for local consumption in the country (Department of Agriculture Extension 2010; Department of International Economic Affairs 2015). Furthermore, the fruit deteriorates easily in hot weather, and therefore needs to be processed quickly upon harvest (Yahia 1999). These characteristics render a mango supply chain an appropriate candidate for cold chain adoption.

As this study aims at developing a simulation model to investigate whether the performance of fresh fruit supply chains in developing countries such as Thailand can be improved through the adoption of cold chain design, a single representative fruit supply chain was selected and used as the base system for modelling. The objective was to understand in detail the structure and the processes of the selected fruit supply chain, and the parties and the activities involved, and to collect the operational data and performance statistics at different stages. For this reason, purposive sampling technique was adopted (Etikan, Musa & Alkassim 2016; Ritchie *et al*. 2013; Tongco 2007). The selection criteria included size and value of export.

To select the appropriate sample, data published by the Ministry of Commerce of Thailand were used. According to the data, there were 324 fruit exporters, *i.e.*, middleman companies, in Thailand (Department of International Trade Promotion 2011). They formed the population of this study. Among the 324 companies, there were 61 fruit exporters that exported mangoes. They formed the sampling frame of the research (Department of International Trade Promotion 2011). This study chose one of the top mango exporting companies, *i.e.*, the middleman firm that was the focal company of the mango supply chain, on the assumption that the firm was representative in the fruit supply chain operation and management in

Thailand because of its scale of business. The chosen firm – a middleman company – was reported by the media (Focus 2008; Rattana 2011) and the Thailand Research Fund (Somboonsuk *et al.* 2013) as being one of the major players in the mango exporting industry in Thailand. Its supply chain operation was a typical example of the industry. The owner of the middleman firm was contacted on 6 May 2015 to explain the purpose of the research and seek agreement to participate. When the firm agreed to take part in the study, requests were made to invite its supply chain partners, such as farms, processors, and transporters who worked directly with the firm, to participate. The data and information collected from the members of the supply chain enabled the development of a simulation model of the mango supply chain under study, to investigate how its performance could be improved through cold chain adoption.

4.2.2 Problem identification

During the data collection process, it was observed that there was basically no temperature control in the entire mango supply chain, although occasionally temperature-controlled trucks were used to deliver the harvested mangoes. To incorporate these real-world problems of the mango supply chain into the simulation model, the effect of temperature on spoilage of fresh fruit was incorporated in the model through the use of a spoilage formula (see Figures B21-B23 in Appendix B). This would enable the investigation of the impacts of cold chain adoption on the reduction of wastage and shelf life of mangoes in the supply chain.

4.2.3 System description

In this study, the system under investigation is a mango supply chain that consists of five farms, three processors, one transporter, and one middleman firm. They are labelled as farm A, farm B, farm C, farm D, farm E, processor A, processor B, processor C, transporter, and middleman company. The size, capacities, and resources, including workforce, forklifts, hand lifts and trucks, were recorded during the site visits and interviews with the managers. The system runs seven days a week from 8 AM to 5 PM.

Farms A, B and C

Farms A, B and C were small groups of mango growers from the central part of Thailand. The logistics and supply chain activities at the farms started from harvesting the mangoes, removing protective covers, surface grading based on the appearance of the fruit, and wrapping to protect the mangoes from damage during transportation.

Activities at the farms were largely manual. Farmers (A, B, and C) harvested the mangoes and brought them to the group leader (Processor A).

Processor A

The leader of the mango growers (Processor A) played an important role in collecting products from group members. Staff at processor A initially graded the mangoes to estimate the quantity of saleable products. Processor A cooperated with its own group members (the farmers) and the exporter (middleman firm) on time and product yield.

The purpose of the grading process is to select qualified mangoes for export to the international market. The process takes into consideration the condition of the peel, size, weight, and maturity of the fruit. Moreover, packing according to the grade of the fruit is also a primary responsibility of processor A.

Farms D and E and processors B and C

The activities at farms D and E were slightly different from those at farms A, B, and C, because of the different business characteristics. For the mango supply chain under investigation, farm D and processor B were owned by the same owner. Similarly, farm E and processor C were owned by another owner. As a result, activities conducted at the farms, although similar, are not identical. Certain activities that were carried out at the farms in one group were conducted at the processor site instead in the other group. For example, surface grading was conducted at the farm in one group but at the processor site in the other. Nonetheless, the primary responsibilities of processors B and C were similar to those of processor A, which included grading and packing.

Transporter

The transporter was a third-party firm which had been working together with the middleman firm for a long time. The main responsibility of the transporter was to transport the mangoes to the middleman firm for export.

Middleman firm

This middleman firm was the focal company of the mango supply chain comprising other members including farms, processors and transporter. The middleman firm's operational activities involved receiving customers' orders, sorting, labelling, and exporting the mangoes to various countries. Figure 4.3 gives an overview of the mango supply chain under investigation and the activities involved at different segments.

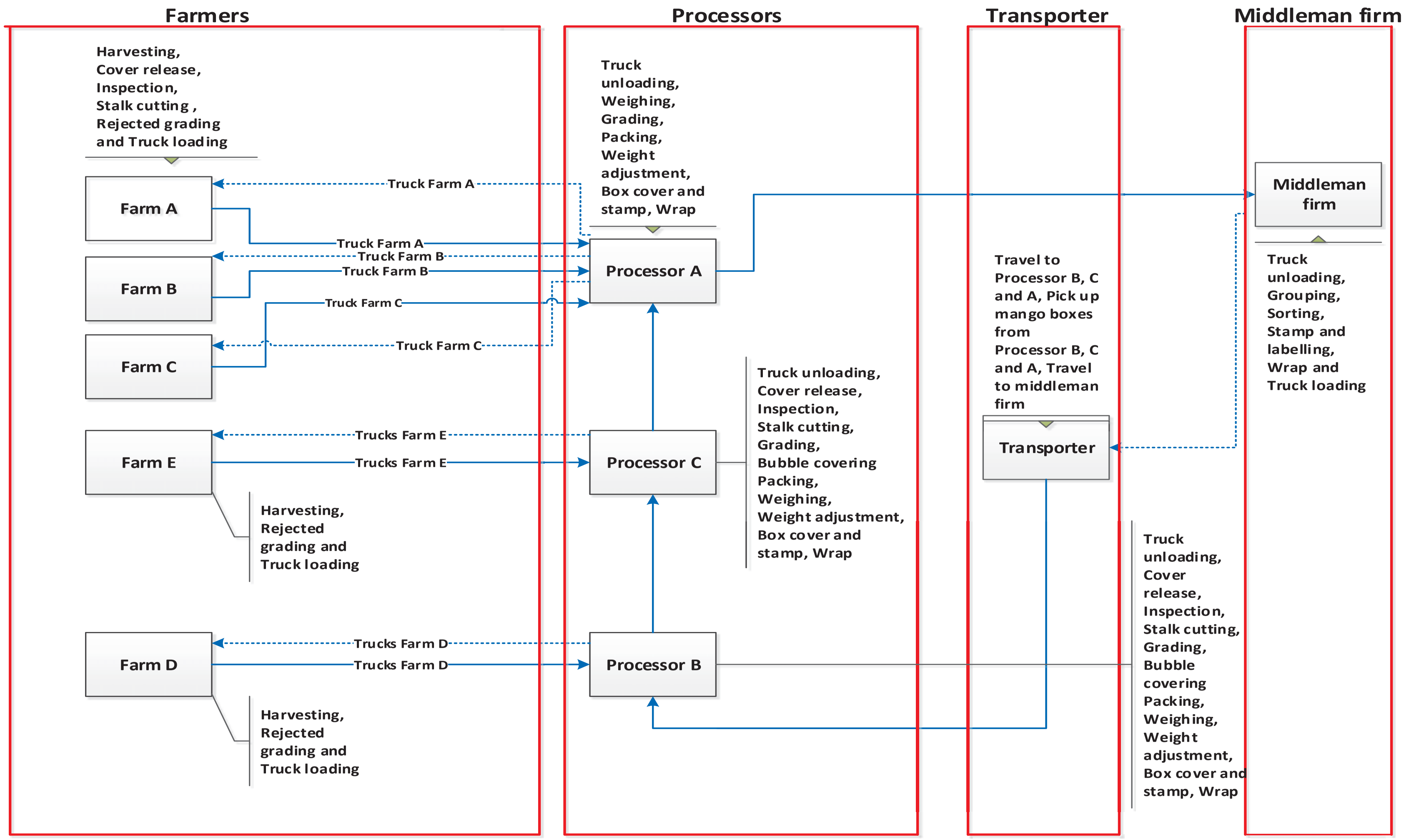


Figure 4.3 – The mango supply chain under investigation

4.2.4 Data collection procedure

This study gathered data and information from the respective four parties – farms, processors, transporter, and middleman firm – involved in the running of the selected mango supply chain, to help develop a simulation model. Thirteen and a half days were spent in collecting the data, starting from 8 May 2015 to 26 May 2015. Data collected from site observations and semi-structured interviews were used as input parameters for the simulation model. In order to collect the required amount of information (process logic and resource process time) for the development of the simulation model, some members of the mango supply chain were interviewed. Six members at the managerial level from farm A, farm D, processor A, processor B, transporter and the middleman firm were interviewed during the site visits, which started from 8.00 AM till 5.00 PM on the interview day. Most of the data collection time was spent at the middleman firm, followed by at the processors, the farms, and lastly the transporter. A total of 250 minutes were spent with the interviewees to understand the logic of each operation system and the details of the operation, which could change across different times of the day, week, and month, as well as year. During the site visits, a number of informal interviews or casual conversations were conducted with the operational staff to understand their activities. Table 4.1 shows the duration of the data collection process.

Table 4.1 – Summary of data collection process for the mango supply chain under study

Mango supply chain member	Farm		Processor		Transporter	Middleman firm
	A	D	A	B		
Number of interviewees (Managerial level)	1	1	1	1	1	1
Duration of interview (Managerial level) (Mins)	30	30	30	30	15	60
Number of interviewees (Operational level)	1	1	1	1	1	1
Duration of interview (Operational level) (Mins)	10	10	10	10	5	10
Site observation (Days)	2	2	2.5	2.5	0.5	4

Owing to the substantial workload of the staff during the harvesting season, most of the interviews and casual conversations were of relatively short duration. The purpose was mainly to find out the actual rates of operation and the common issues encountered in the supply chain which could not be observed in a few site visits. As the research did not employ a case study approach to explore in depth a particular phenomenon, long interviews were not required. The brief interviews enabled the capture of the necessary information for model building, and at the same time did not disrupt the busy work of the supply chain members on the site.

Site observations

This study conducted several on-site observations of each member in the mango supply chain. Data collected include, among others, the actual number of workers and machines used, and actual flow rate and time required in each process. During the observations, behaviours and activities of individual members were noted. The site observations provide snapshots of the various operational processes in the mango supply chain under study, for the modeller to develop a simulation model that is realistic and representative of the real system.

Semi-structured Interviews

Semi-structured interviews were conducted face-to-face with various members of the mango supply chain at the managerial and operational levels. The interviews took place at the worksites of the farmers and the offices of the processors, the transporter, and the middleman firm. The interviewees, being the key representatives of the current system structure, provided information and data about the cost (including labour cost and vehicle and machine operating cost), the number of workers, the number of machines used, capacity of the trucks, and the probability data (which were collected by asking the respondents for probability estimates together with onsite observations). The interviewees also explained the situations that were not readily available for observation during the site visits, such as changes in resources utilisation during peak and off- peak seasons. This information was used to develop the simulation model to give a more realistic view of the operation of the fruit supply chain process.

The following input data were required in order to build the base model:

- Number of workers
- Number of trucks
- Number of mangoes harvested

- Truck capacity in containers
- Probability that a mango is accepted or rejected
- Number of mangoes in a basket
- Scheduled time of the operation in minutes
- Operating cost in Thai Baht
- Operation breakdown time in minutes
- Probability that a mango is grade AA, grade A, grade B, grade C
- Probability that a mango is exported to country A, country B
- Probability a mango box fails for 10kg of weight
- Speed of the forklift in kilometres per hour
- Temperature degrees Celsius
- Number of mango boxes exported
- Processing time of each activity in seconds
- Shelf life of mango in days
- Transportation time in hours
- Number of mangoes per box in different grades of mango
- Number of mango boxes per pallet
- Distance for forklift operation in feet

4.3 Phase 2: model building

Data collected from semi-structured interviews and onsite observations were used as input to create a simulation model representative of the actual mango supply chain under study. For example, the data collected during site observations were used to model practices that are close to reality. These include the number of operators deployed in each process and the frequencies of operation delays due to machine breakdowns (*e.g.*, box wrap machine) and other causes. Lastly, information that was collected from semi-structured interviews was used to help the modeller understand in greater depth the operation process under different situations at different times, and for giving some details about the operating cost. The model outputs are compared with actual performance as a part of the model validation process. Once the simulation model is created and validated, the model can be used to simulate long-run operation of the mango supply chain with different cold chain designs under various scenarios.

4.3.1 Conceptual diagram

In this step, the real-world system was translated into a logical representation of the processes and activities involved. The conceptual model represents the basic concepts of the real system - a mango supply chain with five farms, three processors, one transporter, and one middleman firm. Figure 4.4 shows the swim lane diagram representing the logical representation of the simulation model and the description of the high-level business-mapping diagram for the mango supply chain activities, which are presented in Table 4.2.

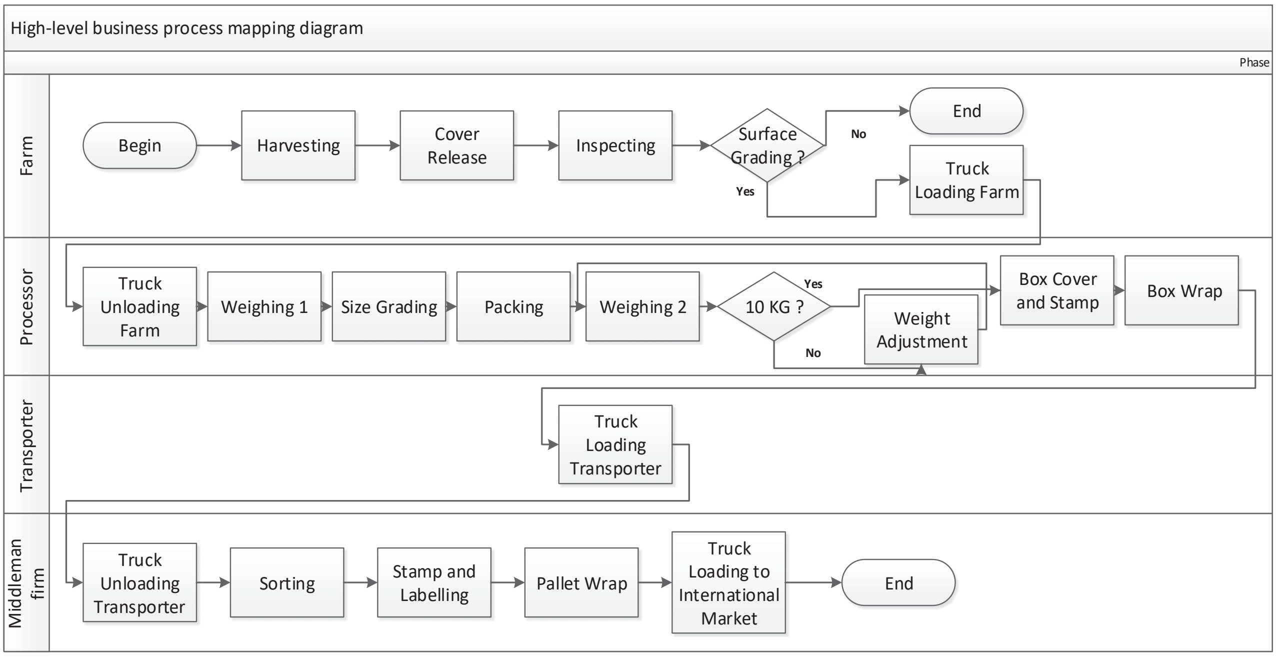


Figure 4.4 – High-level business process-mapping diagram

Table 4.2 – Explanation of mango supply chain activities

Activity	Explanation
Harvesting	To cut the mangoes from the mango tree
Cover release	To release the cover enclosing the mango that was placed to protect the fruit from insects and rain during the growing process
Inspecting	To select the good mangoes to export by looking at the appearance such as the colour of the peel of the mangoes
Truck loading farm	To load baskets of mangoes onto the truck
Truck unloading farm	To unload baskets of mangoes from the truck
Weighing 1	To check the weight of the baskets for paying to the farmer the value of the mangoes
Size grading	To grade the mangoes based on their size
Packing	To pack mangoes into boxes for transportation
Weighing 2	To check the weight of the mango boxes to ensure 10 kg/box
Weight adjustment	To adjust the number of mangoes in each box to ensure 10 kg/box
Box cover and stamp	To put a box cover and stamp the name of the processor and the grade of the mangoes
Box wrap	To wrap the boxes
Truck loading transporter	To load the mango boxes onto the truck for delivery to the middleman firm
Truck unloading transporter	To unload the mango boxes from the truck
Sorting	To sort the mango boxes by country for export
Stamp and labelling	To stamp and label the name of middleman firm on the boxes
Pallet wrap	To wrap the batch of mango boxes
Truck loading international market	To load the mango batches onto the truck for export

Farms A, B and C

Farm A, farm B, and farm C shared the same operational characteristics, which include various activities such as harvesting, inspection and stem cutting, waiting for the resin to be dried (see Table 4.3), and truck loading (Figure 4.5). The operation started with farmers harvesting mangoes by climbing the mango trees. After that, they put the mangoes into a basket and then moved it to an inspection yard. Next, the farmers removed the cover from mangoes and conducted inspection as well as cutting the stem. Afterwards, the farmers determined the grades of the mangoes by looking at the appearance and waiting for the resin to dry. Lastly, the mangoes were loaded onto the truck. Farm A, farm B and farm C normally started their operation from 8 AM and worked until 5 PM. Moreover, there was a truck for each farm which usually came to pick up the mangoes at 11.30 AM for mangoes that were harvested in the morning, and at 8 AM for those mangoes that were harvested in the previous afternoon. The trucks delivered the harvested mangoes to processor A two times per day. Farmers had a two-hour break for lunch from 12 PM to 2 PM. Table 4.3 shows the description of Farms A, B and C activities.

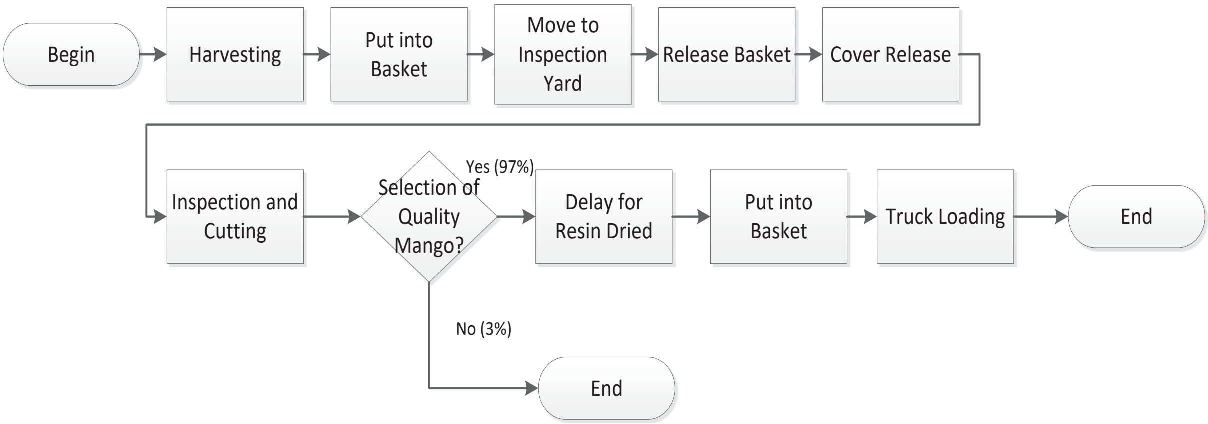


Figure 4.5 – Process plan for farms A, B and C

Table 4.3 – Explanation of mango supply chain activities at farms A, B and C

Activities	Explanation	Resources requirement
Harvesting	To cut the mangoes from the mango tree	5 persons
Put into basket	To put the mangoes into a basket upon harvesting (25 mangoes per basket)	Shared the same resources with harvesting process
Move to inspection yard	To deliver the baskets of mangoes to the yard for inspection	Shared the same resources with harvesting process
Release basket	To take the mangoes out from the baskets and lay them down on the floor	Shared the same resources with harvesting process
Cover release	To release the cover enclosing the mango placed during the growing process	2 persons
Inspection and cutting	To select good-looking mangoes for export by checking the appearance, such as the colour of the mangoes, and cutting excessive stem	2 persons
Delay for resin dried	To wait until the resin from the stems of the mangoes dry up after cutting (20 minutes as a minimum)	
Put into basket	To put the mangoes into the baskets for transportation (55 mangoes per basket)	9 persons
Truck loading	To load the baskets of mangoes onto the truck (61 baskets per truck)	Shared the same resources with harvesting process and one truck

Farms D and E

Farm D shared the same operation characteristics with farm E. The operation started with harvesting by farmers climbing the mango trees. Then, the farmers decided on the grade of mangoes by looking at the appearance. After that, the mangoes were put into the basket for truck loading (Figure 4.6). Two trucks for each farm would arrive to load the mangoes and deliver these to processor B for farm D and to processor C for farm E. Due to the short distance between the farms and the processors, the trucks usually came to pick up the mangoes approximately 28 times for each farm each day. Farm D and farm E shared the same working hours, from 8 AM to 5 PM, as those of the other three farms. However, they used only one hour, between 12 PM and 1 PM, for lunch break. Table 4.4 provides a description of the activities involved.

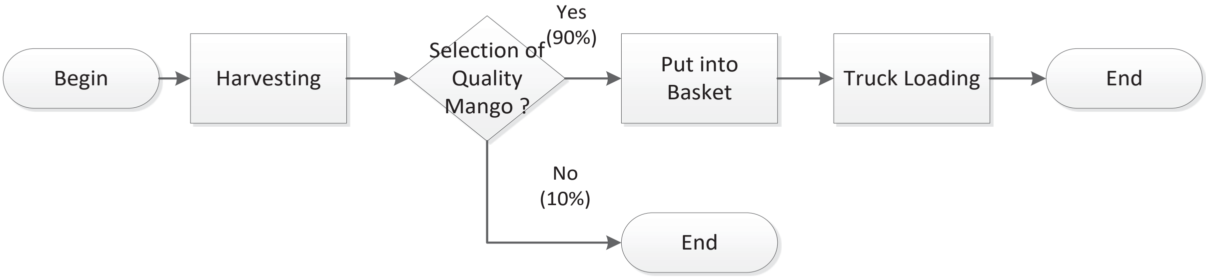


Figure 4.6 – Process plan for farms D and E

Table 4.4 – Explanation of mango supply chain activities at farms D and E

Activities	Explanation	Resources requirement
Harvesting	To cut the mangoes from the mango tree	14 persons
Selection of quality mango	To select the mangoes that still have a cover	Shared the same resources with harvesting process
Put into basket	To put the mangoes into baskets upon harvesting (45 mangoes per basket)	Shared the same resources with harvesting process
Truck loading	To load the baskets of mangoes onto the truck (13 baskets per truck)	Two trucks and two persons (One person for each truck)

Processor A

For this supply chain member, the operation consisted of unloading, weighing, grading, packing, and wrapping (Figure 4.7). Firstly, staff of processor A unloaded the mango baskets from the farm's truck for weighing. After that, they moved the mango baskets to the grading yard for grading. Mangoes were graded by size. For example, Grade AA is the biggest size, followed by Grades A, B and C. Next, the staff packed the mangoes into the boxes by grade. The weight was set at ten kilograms per box. In the case of being over or under the target weight, the staff made a weight adjustment manually until the weight was close to ten kilograms per box. Then, processor A staff moved the mango boxes to the cover box yard for covering and wrapping. Working time of this system was between 8 AM and 5 PM. This also included a lunch break from 12 PM to 1 PM. Table 4.5 provides a description of the activities involved for processor A.

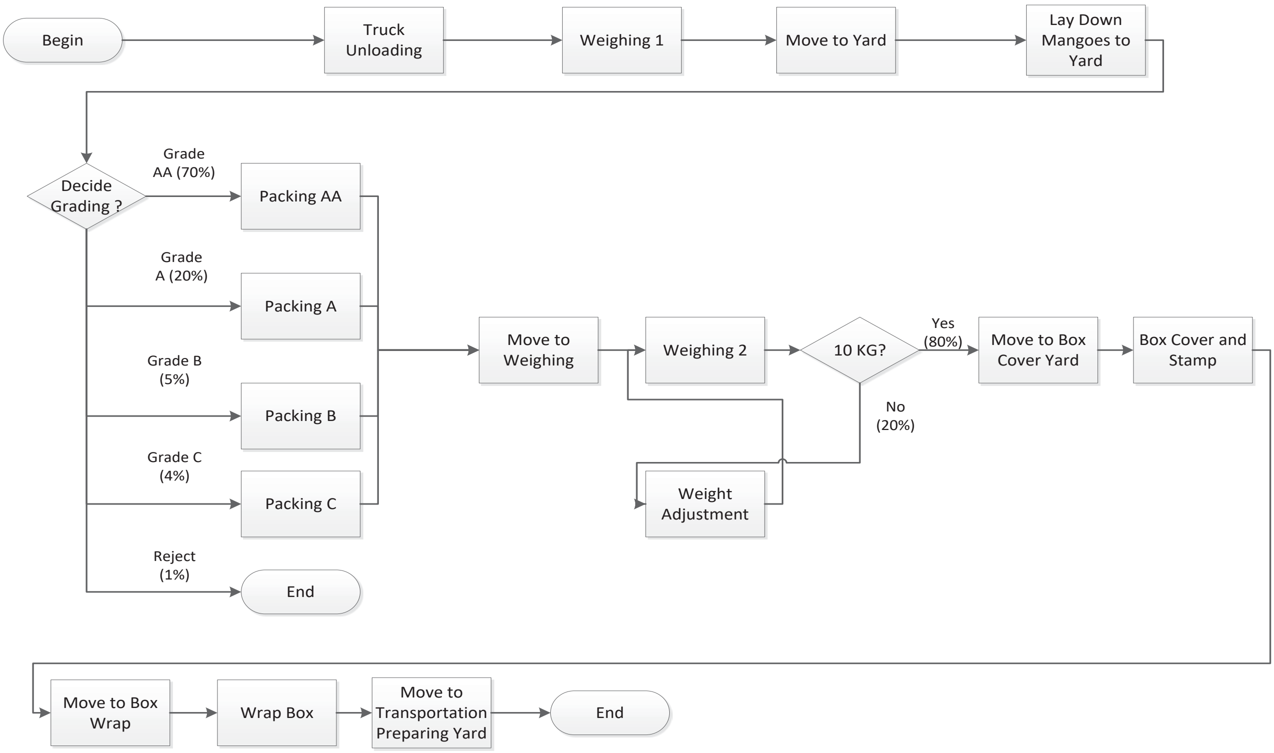


Figure 4.7 – Process plan for processor A

Table 4.5 – Explanation of mango supply chain activities at processor A

Activities	Explanation	Resources requirement
Truck unloading	To unload the baskets of mangoes from the truck (3 baskets per one round)	2 persons
Weighing 1	To check the weight of the baskets for paying to the farmer the value of the mangoes.	1 person
Move to Yard	To deliver the baskets of mangoes to the yard	2 persons
Lay down mangoes to yard	To lay down the mangoes upon the floor.	2 persons
Decide grading	To grade the mangoes by size (3 mangoes per one round)	2 persons
Packing AA	To pack grade AA mangoes into the boxes (25 mangoes)	1 person
Packing A	To pack grade A mangoes into the boxes (28 mangoes)	1 person
Packing B	To pack grade B mangoes into the boxes (33 mangoes)	1 person
Packing C	To pack grade C mangoes into the boxes (35 mangoes)	1 person
Move to weighing	To move the mango boxes to the weighing station	2 persons
Weighing 2	To check the weight of the mango boxes to ensure 10 kg/box.	1 person
Weight adjustment	To adjust the number of mangoes to ensure 10 kg/box	Shared the same resources with weighing 2 process
Move to box cover yard	To move the mango boxes to yard for covering	Shared the same resources with weighing 2 process
Box cover and stamp	To put a box cover and stamp the name of processor and the grades of mangoes on the boxes	2 persons
Move to box wrap	To move the mango boxes to the wrapping station	Shared the same resources with box cover and stamp process
Wrap box	To wrap the boxes	1 person
Move to transportation preparing yard	To move the mango boxes to the transportation yard	2 persons

Processors B and C

Processor B and processor C followed the same processes but involved several operations different from processor A, such as mango basket unloading, cover removing, inspection and cutting, appearance grading, size grading, putting plastic bubble cover, packing, weighing, mango box cover, and stamp and box wrapping. Before the formal grading step, some mangoes were rejected because of the obvious lower quality based on the appearance (see Figure 4.8). Processors B and C sell the rejected mangoes to local people to make dried candied mango. The system operated between 8 AM and 5 PM. They also had a break time from 12 PM to 1 PM. There was one hand lift to move the pallet close to the transporter's truck at each of the sites of processors B and C during the truck loading operation. Table 4.6 provides a description of the activities involved for processor B and processor C.

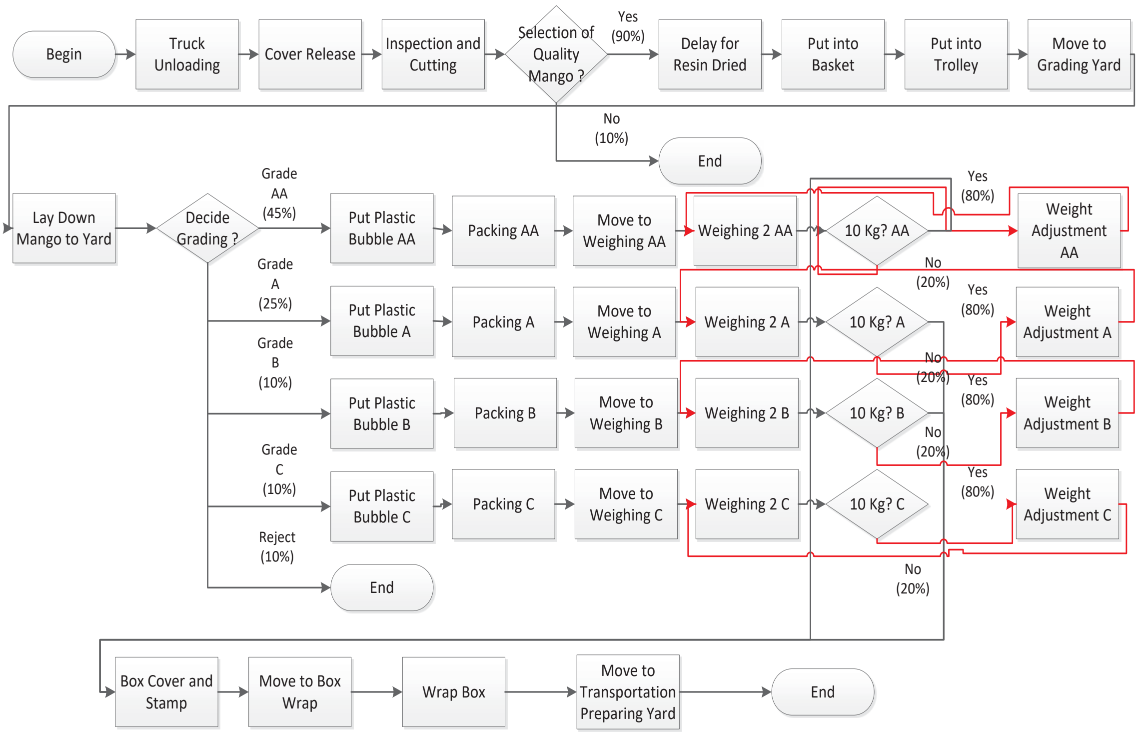


Figure 4.8 – Process plan for processors B and C

Table 4.6 – Explanation of mango supply chain activities at processors B and C

Activities	Explanation	Resources requirement
Truck unloading	To unload the baskets of mangoes from the truck	2 persons from farm
Cover release	To release the cover enclosing the mango placed during the growing process	4 persons
Inspection and cutting	To select good-looking mangoes for export by checking the appearance, such as the colour of the mangoes, and cutting excessive stem	2 persons
Delay for resin dried	To wait until the resin from the stem of the mango dries up after cutting (3 hours)	-
Put into basket	To put the mangoes into the baskets (25 mangoes per basket) (To do at 8 AM and after finished truck loading to middleman firm)	3 persons
Put into trolley	To put the mango baskets onto the trollies (3 baskets per trolley) (To do at 8 AM and after finished truck loading to middleman firm)	Shared the same resources with put into basket process
Move to grading yard	To move the baskets of mangoes to the yard (To do at 8 AM and after finished truck loading to middleman firm)	1 person
Lay down mango to yard	To lay down the mangoes upon the floor	2 persons
Decide grading	To grade the mangoes by size	2 persons
Put plastic bubble AA	To put bubble wrapping for grade AA mango	1 person
Put plastic bubble A	To put bubble wrapping for grade A mango	Shared the same resources with put plastic bubble AA process
Put plastic bubble B	To put bubble wrapping for grade B mango	1 person
Put plastic bubble C	To put bubble wrapping for grade C mango	Shared the same resources with put plastic bubble B process
Packing AA	To pack mangoes into the boxes by grade (25 mangoes)	1 person
Packing A	To pack mangoes into the boxes by grade (28 mangoes)	1 person
Packing B	To pack mangoes into the boxes by grade (33 mangoes)	1 person
Packing C	To pack mangoes into the boxes by grade (35 mangoes)	1 person
Move to weighing AA	To move the mango boxes to the weighing station	Shared the same resources with Packing AA process
Move to weighing A	To move the mango boxes to the weighing station	Shared the same resources with Packing A process
Move to weighing B	To move the mango boxes to the weighing station	Shared the same resources with Packing B process
Move to weighing C	To move the mango boxes to the weighing station	Shared the same resources with Packing C process

Table 4.6 – Explanation of mango supply chain activities at processors B and C (continued)

Activities	Explanation	Resources requirement
Weighing 2 AA	To check the weight of mango boxes to ensure 10 kg/box	Shared the same resources with Packing AA process
Weighing 2 A	To check the weight of mango boxes to ensure 10 kg/box	Shared the same resources with Packing A process
Weighing 2 B	To check the weight of mango boxes to ensure 10 kg/box	Shared the same resources with Packing B process
Weighing 2 C	To check the weight of mango boxes to ensure 10 kg/box	Shared the same resources with Packing C process
Weight adjustment AA	To adjust the number of mangoes to ensure 10 kg/box	Shared the same resources with Packing AA process
Weight adjustment A	To adjust the number of mangoes to ensure 10 kg/box	Shared the same resources with Packing A process
Weight adjustment B	To adjust the number of mangoes to ensure 10 kg/box	Shared the same resources with Packing B process
Weight adjustment C	To adjust the number of mangoes to ensure 10 kg/box	Shared the same resources with Packing C process
Box cover and stamp	To put a box cover and stamp the name of the processor and the grades of the mangoes on the box	1 person
Move to box wrap	To move the mango boxes to the wrapping station	2 persons
Wrap box	To wrap the boxes	1 person
Move to transportation preparing yard	To move the mango boxes to the transportation yard, and putting on the pallet (50 boxes/pallet)	1 person

Transporter

The middleman firm hired a transportation service provider. The capacity of the truck is 1,000 mango boxes. The transporter started from the market at 2 PM, located in the same province as that of processors A, B and C. Empty trucks were sent to processor B to pick up the mango boxes first. Then, they went to processor C and processor A to pick up the mango boxes there. Finally, the trucks delivered the mango boxes to the middleman firm (Figure 4.9). Table 4.7 provides a description of the activities involved for transportation.

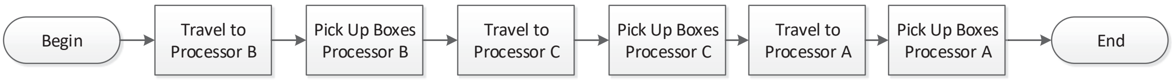


Figure 4.9 – Process plan for transporter

Table 4.7 – Explanation of mango supply chain activities at the transporter

Activities	Explanation	Resources requirement
Travel to processor B	To deliver to processor B	-
Pick up boxes processor B	To pick up mango boxes from processor B	7 persons and one hand lift
Travel to processor C	To deliver to processor C	-
Pick up boxes processor C	To pick up mango boxes from processor C	Shared the same resources with pick up boxes processor B process
Travel to processor A	To deliver to processor A	
Pick up boxes processor A	To pick up mango boxes from processor A	Shared the same resources with pick up boxes processor B process but no hand lift

Middleman firm

The operation of the middleman firm was to receive and sort the mango boxes by country and grade the mangoes for export. The sorting is required to facilitate the export operation. After the sorting, staff would label and stamp the mango boxes. They would then be loaded onto temperature-controlled trucks and delivered to the specified countries (Figure 4.10). The truck delivery to country A used the middleman company trucks, usually two trucks per day departing at 11 AM. However, the middleman firm used the transportation company for delivery to country B, which deployed a truck per day departing at 4 PM. The middleman firm had two forklifts and one hand lift to move the mango box pallets. They also operated between 8 AM and 5 PM, with break time from 12 PM to 1 PM. Table 4.8 provides a description of the activities involved for processor A.

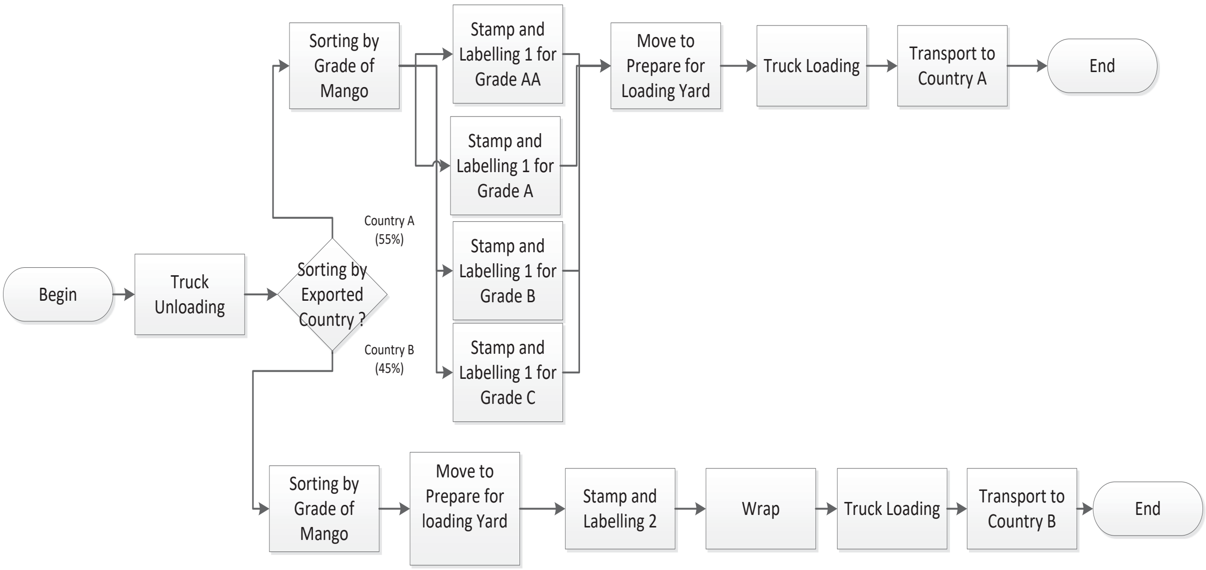


Figure 4.10 – Process plan for middleman firm

Table 4.8 – Explanation of mango supply chain activities at the middleman firm

Activities	Explanation	Resources requirement
Truck unloading	To unload mango boxes from the truck	2 persons
Sorting by exported country	To sort the mango boxes by country for export (60 mango boxes per pallet)	9 persons
Sorting by grade of mango	To sort the mango boxes by the grades of the mangoes (60 mango boxes per pallet)	Shared the same resources with sorting by exported country process
Stamp and labelling 1 for Grade AA	To stamp and label the name of the middleman firm (Grade AA)	2 persons
Stamp and labelling 1 for Grade A	To stamp and label the name of the middleman firm (Grade A)	Shared the same resources with stamp and labelling 1 for Grade AA
Stamp and labelling 1 for Grade B	To stamp and label the name of the middleman firm (Grade B)	Shared the same resources with stamp and labelling 1 for Grade AA
Stamp and labelling 1 for Grade C	To stamp and label the name of the middleman firm (Grade C)	Shared the same resources with stamp and labelling 1 for Grade AA
Stamp and labelling 2	To stamp and label the name of the middleman firm (A pallet). Normally done after finishing truck loading for country A	1 person
Wrap	To wrap the batches of mango boxes	Shared the same resources with stamp and labelling 2 process
Move to prepare for loading yard	To move the batches of mangoes to the yard to prepare for loading and putting on the pallet (60 boxes per pallet)	2 Folk lifts
Truck loading	To load the mango batches onto the truck for export (To start at 11 AM for Country A and at 4 PM for Country B)	3 persons and 1 hand lift

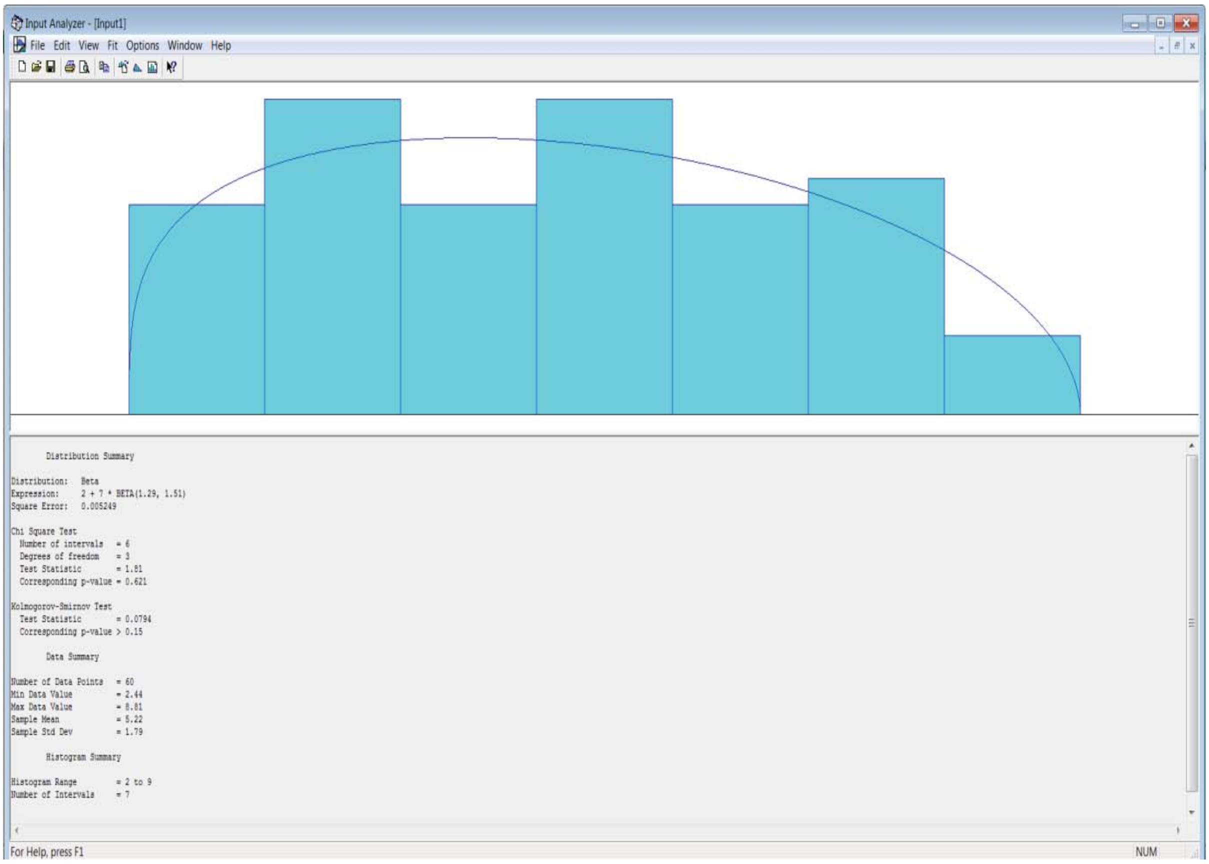
4.3.2 Input parameters

In this stage, actual data recorded during the site observations were fed into the Input Analyzer module of ARENA for analysis. The purpose of this step was to obtain the parameters for the statistical distributions used for simulating various activities (Abed *et al.* 2008). The recorded data provide a pattern for long-term simulation, which is then translated into a mathematical formula to generate the data as input. This is based on the assumption that long-term running of the system is basically a repetition of what is actually happening in the short term, provided that the recorded data are representative of the normal operation. Input Analyser is a tool that comes with the ARENA software. It is generally used to determine an appropriate statistical distribution for raw data, such as process time, which can be used in the model to enable simulation (Alzahrani 2011).

4.3.3 Goodness-of-fit test distributions

The ARENA Input Analyzer was used to determine the theoretical distributions that best fit a sample of data. To determine the reliability or goodness of fit, Chi-Square tests and Komogorov-Smirnov (K-S) goodness-of-fit hypothesis tests are provided by the Input Analyzer. In these tests, the null hypothesis is that the chosen distribution is a sufficiently good fit to the sample data (Altiok & Melamed 2007; Alzahrani 2011).

The sample of data were fit to all distributions in the Input Analyzer of ARENA. The squared error values were calculated and ranked in ascending order. Squared error is the criterion to measure the distribution that best fits the data (Rossetti 2015). "Squared error is defined as the sum over the intervals of the squared difference between the relative frequency and the probability associated with each interval" (Rossetti 2015, p.271). In addition, ARENA Input Analyzer reports the corresponding *p*-value, which takes values between 0 and 1. A large *p*-value means better fit of the theoretical distribution to the data. For example, if the *p*-value is greater than 0.05, it means the null hypothesis of a good fit at 95% confidence level can be rejected. The *p*-value is the probability determining whether the theoretical distribution fits the data collected in the real-world environment. Figure 4.11 shows the output of the Input Analyzer for the farm A harvesting processing time.



```
        Distribution Summary

Distribution:   Beta
Expression:     2 + 7 * BETA(1.29, 1.51)
Square Error:   0.005249

Chi Square Test
  Number of intervals   = 6
  Degrees of freedom    = 3
  Test Statistic        = 1.81
  Corresponding p-value = 0.621

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0794
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 60
Min Data Value          = 2.44
Max Data Value          = 8.81
Sample Mean             = 5.22
Sample Std Dev          = 1.79

        Histogram Summary

Histogram Range         = 2 to 9
Number of Intervals     = 7
```

Figure 4.11 – Input Analyzer output for farm A harvesting processing time

Every data file was run by the ARENA Input Analyzer. The input Analyzer created the likelihood distribution functions used to offer a baseline approximation of the transition interval for every step of the process. The resulting distributions and *p*-values are summarised in Appendix B. Table B.1 is for farms A, B and C, Table B.2 for farms D and E, Table B.3 for processor A, Table B.4 for processors B and C, Table B.5 for the transporter, and Table B.6 for the middleman firm.

4.3.4 Model translation to ARENA

In this step, the conceptual model was translated to an ARENA DES simulation model. The individual modules representing the farms, processors, transport and the middleman firm, as shown in Figure 4.2, were created on ARENA – the DES software package used in this research. Input distributions as well as input parameters derived using the Input Analyzer of ARENA, as shown in Tables B.1-6 of Appendix B, were then set in the modules for test runs and validation. Once the individual modules were validated, they were put together to form the whole system to be validated again. Figure B.1 of Appendix B shows a screenshot of the ARENA model for farm A, Figure B.2 for farm B, Figure B.3 for farm C, Figure B.4 for farm D, Figure B.5 for farm E, Figure B.6 for processor A, Figure B.7 for processor B, Figure B.8 for processor C, Figure B.9 for the transporter, and Figure B.10 for the middleman firm.

4.3.5 Performance metrics

Evaluating the performance of a cold chain for perishable produce is difficult, because it has several features that are different from other categories of supply chain, such as physical product characteristics including appearance and taste, seasonality in production, and long production throughput time (Joshi, Banwet & Shankar 2011; Joshi *et al.* 2012). Fearne, Barrow and Schulenberg (2006) and Joshi, Banwet and Shankar (2011) suggest that the appropriate performance indicators may include the products' amount, quality, timeliness, and cost. Using this suggestion as reference, the simulation model for the mango supply chain under study generates, among others, five major KPIs as detailed in Table 4.9. They comprise total operating cost of running the entire supply chain, shelf life, lead time, wastage, and throughput. These outputs are compared against the actual figures during the model validation process.

Table 4.9 – **Definition of key performance indicators used in the simulation model**

Key performance indicator	Definition	Unit of measurement	How it is calculated in the simulation model
Lead time	Total time required to deliver the fruit produce from the farm to the supermarket shelf	Hours	Value of the difference between the time an entity enters and exits the system
Shelf life	Total time the fruit produce stays on the supermarket shelf until it becomes unsuitable for consumption and has to be trashed	Number of days	Difference between the best before date (BBD) – time taken for the fruit to spoilage after harvest under certain temperatures (see Figure B.21) – and the lead time
Wastage	Percentage of fruit produce of which the best before date (BBD) is not yet reached but that has to be trashed due to bacterial infection or yeast contamination which render the fruit unsuitable for consumption	Percentage	Percentage of entities to be marked as waste due to natural spoilage (see Figure B.22 and Figure B.23)
Throughput	The amount of fruit produce that can be handled during a certain period of time in a fruit supply chain	Number of boxes	Total number of entities that entered and exited the system during the model running time
Total operating cost	Total cost incurred along the entire fruit supply chain, including labour cost, transportation cost, and electricity cost	Thai Baht	Summation of all operating costs associated with the processing of entities during the running of the system

Lead time

Lead time, or processing time, in the simulation refers to the time taken from harvesting the mangoes to shipping them to international markets. For multiple runs, it is taken as the average of the time an entity stays in the system which is the difference between the entry and the exit times.

Shelf life

According to Moomin (2010), the shelf life of mangoes upon harvesting is usually around 10 days at ambient temperature. In the base model simulating the actual situation, shelf life refers to the time the mangoes can stay on the shelf at the market, and is calculated using the difference between the shelf life upon harvesting (10 days, according to Moomin 2010) and the processing time. As there are limited sample data to determine the actual distribution of the mango shelf life in this case, a triangular distribution of TRIA (9,10,11) days is used in the simulation model to introduce some natural randomness. This is because, in reality, there can be a slight difference in shelf life for each mango, even though they are harvested at the same time.

Research reveals that the best temperature for preserving mangoes is around 13 degrees Celsius, which can extend the shelf life by more than 200% compared to the situation when the mangoes are placed in ambient temperature (Kader 2008). Therefore, in the simulation model incorporating the cold chain designs, the shelf life of mangoes upon harvesting is taken to be 25 days in a cold chain (refer to Figure B.21). As such, the shelf life upon reaching the market is calculated using the difference between shelf life upon harvesting and the processing time of the cold supply chain. Again, in the simulation model, a triangular distribution of TRIA (24,25,26) days is used to introduce some natural randomness.

Wastage

Liu, Wang and Young (2014) develop a decay index for mangoes at room temperature (see Figure B.22). Together with the Moomin (2010) calculation of shelf life (10 days), it can be seen that the average wastage of mangoes at room temperature is about 5 percentage in 10 days. Assuming the decay is uniform at the early stage, we can work out that the percentage of wastage for mango is about 0.5 % per day at ambient temperature. This rate is used in the simulation model.

Abou-Aziz *et al.* (1976) develop a decay index for mangoes at 10-15 degrees Celsius (see Figure B.23). It can be seen that, at 15 degrees Celsius, the decay of mangoes starts on the 9th day after harvest. At 10 degrees Celsius, decay starts on the 14th day. Both indices indicate that, for mangoes, there is very little or even no decay at these two temperatures for the first nine days after harvest if there is no temperature abuse in the delivery process. As the lead time in the mango supply chain being simulated is less than three days, this means that a zero percent wastage can be assumed if a consistent cold chain arrangement is adopted across the entire mango supply chain.

Throughput

This refers to the number of mangoes harvested and processed during a harvesting cycle (from tree to market), which can last from one to three days. In the model, it is calculated by counting the number of mango boxes that have exited the system during the model running time. A box contains 25 mangoes for grade AA, 28 mangoes for grade A, 33 mangoes for grade B, or 35 mangoes for grade C.

Total operating cost

This refers to the total operating cost of the mango supply chain being simulated. In the model, it is computed by calculating the running cost, starting from harvesting the mangoes to sending them to the international markets. The running cost includes, among others, worker salary, truck fuel and insurance, electricity, the cost of packaging boxes, the cost of bubble wraps, and shipment cost.

4.4 Phase 3: model validation

A number of model verification and validation techniques can be used to verify and validate simulation models (Sargent 2005). In the present study, three verification and two validation techniques were adopted to check the validity of the developed simulation model. These are discussed as follows.

4.4.1 Model verification

4.4.1.1 Process maps

Before constructing the simulation model, all process maps involving the overall logic of the mango supply chain system and the relevant flowcharts were reviewed by the manager of the middleman firm. Each process map representing a particular process was discussed with a senior employee working in that process. In the case of any omission or difference in depiction, the maps have been revised and reconfirmed with the senior managers for accuracy prior to finalisation.

4.4.1.2 2D animation

Initial verification of the model was done by observing the animation of movement of the simulated entities (*i.e.*, mangoes) to ensure that they were travelling to the right location in accordance with the entity flow diagram as reflected in the process maps. The combined simulation model for the entire system was verified by checking the sequence of the simulated process. The process flow was tracked to see whether the entities created in the model were moving exactly as in the actual supply chain process. Screen shots of model animation are provided as Figures B.11 – B.20 in Appendix B showing the movement of the entities in the system.

4.4.1.3 The ARENA debugger

Prior to running the model, any programming or logical errors were identified using the ARENA debugger. The steps were to run the model and, if any error was encountered, the ARENA debugger would locate the area in the model where the error occurred so that appropriate correction could be made (Alzahrani 2011).

4.4.2 Model validation

4.4.2.1 Comparison with the real system

As a base model for investigating the performance of various cold chain designs, the output of the simulation model has to be similar to the actual output of the mango supply chain in reality. The validation method used in this study was to determine whether the operating cost, processing time, throughput, shelf life, and wastage for each process in the simulation model matched with the actual figures. It was also important to check the mango supply chain member process for the convergence of results with the "As-Is" outputs (Kelton, Sadowski & Sturrock 2004).

To compare the means of two independent samples, the independent *t*-test is used for this study (Huang, Kuo & Wu 2007). The independent *t*-test at 99% significant level is used to investigate the hypothesis that the dissimilarity between the means of the two samples is basically zero. The null hypothesis is rejected when the *p*-value is less than 0.01 and the decision is that the two means vary significantly (Urdan 2016).

After running the simulation model on a 72-hour (1 cycle) period for 100 replications, the average results were compared against the actual figures by using a two-sample *t*-test to determine whether there was any significant difference. The real data for comparison include the number of boxes created (throughput), Country A processing time (CA processing time), Country B processing time (CB processing time), and total operating cost (in Thai Baht). Furthermore, the model also used some KPIs to account for the shelf life and the wastage of the fruit. For shelf life, this was calculated upon the fruit arriving at the international markets in Country A (CA) and Country B (CB). For the percentage of wastage, this was calculated from harvest at farm group A (farms A, B, and C) and farm group B (farms D and E) to the shipment of fruit to Country A and Country B.

Table 4.10 shows the output of the base model compared against actual performance of the mango supply chain being simulated. The statistics reveal that the outcome of the base model is close to the actual performance at 99% significance level (see Tables B.7-18 for more details about the *t*-test results).

Table 4.10 – Comparison between simulated output and actual data

KPIs	Actual mean	Base model mean	*t* statistic	*p*-value
Number of Boxes	1,705	1,698**	-1.27	0.92
Country A Processing time (Hours)	59.5	59.57**	0.14	0.91
Country B Processing time (Hours)	70.5	70.25**	-0.50	0.70
Operating Cost (Thai Baht)	243,589	241,817**	-0.30	0.82
Farms group A (A, B and C) to CA (Country A) shelf life (Days)	7.02	7.52**	1.72	0.18
Farms group B (D and E) to CA (Country A) shelf life (Days)	7.02	7.49**	1.61	0.20
Farms group A (A, B and C) to CB (Country B) shelf life (Days)	6.56	7.07**	1.76	0.18
Farms group B (D and E) to CB (Country B) shelf life (Days)	6.56	7.05**	1.68	0.19
Farms group A (A, B and C) to CA (Country A) wastage (Percentage of decay)	1.24	1.24**	0.42	0.75
Farms group B (D and E) to CA (Country A) wastage (Percentage of decay)	1.24	1.26**	1.97	0.30
Farms group A (A, B and C) to CB (Country B) wastage (Percentage of decay)	1.47	1.47**	-0.09	0.93
Farms group B (D and E) to CB (Country B) wastage (Percentage of decay)	1.47	1.48**	1.15	0.46

** Significant at $\alpha = .01$

Based on the statistical results, it can be concluded that there is no significant difference between the modelled outcome and the actual performance of the supply chain. In other words, the model is able to simulate the actual system and produce outputs similar to reality. Therefore, the base model can be seen as representative of the real system, and can be used to model different cold chain designs and explore a suitable cold chain design for developing countries.

4.4.2.2 Sensitivity analysis

Following the common practices of structure validation through parameter variability test, this study employed sensitivity analysis to validate the structure of the model. The sensitivity analysis tests serve two purposes: (i) to determine whether small changes in certain factors would result in significant variations in the responses; and (ii) to check whether the changes in the responses are in the expected direction according to the model logic (Rossetti 2015). The rationale is that variations in the value of certain critical parameters would generate changes in the output of the model but should show a consistent pattern that is in line with the underlying assumption. Chaotic changes would suggest problems with the model logic that need to be identified and resolved.

The first step of the sensitivity test is to identify and select the input parameters to modify, so as to generate changes to the model output. These input parameters have to impact significantly on all the KPIs used to gauge the model. The other selection criterion is that the changes are likely to happen in real life. For example, the number of mangoes harvested per day is not an appropriate input parameter for sensitivity analysis because it depends primarily on weather and is basically constant (Léchaudel *et al*. 2005). Despite the minor daily variations due to natural randomness, the impact on the model, particularly in throughput, is not significantly changed if there is no increase in the number of farms.

Based on previous studies reported in the literature, a list of the candidate input parameters to change was compiled. Ge (2006), Kara, Rugrungruang and Kaebernick (2007), Parthanadee and Buddhakulsomsiri (2014), Rodrigues (2004) and Wijewickrama and Takakuwa (2005) test the effect of increase in incoming goods. As discussed, this parameter is not suitable for this study, because it is not feasible to suddenly increase the mango output without setting up new farms. Some studies looked at the effect of increase in transportation or labour cost on model output (Goldsby, Griffis & Roath 2006; Kara, Rugrungruang & Kaebernick 2007). However, this parameter is also not appropriate for sensitivity analysis in the present study, because the change would not generate significant impact on the performance of the model, as it would affect only the operating cost. Jayaswal and Chhabra (2005) use the percentage of product disposal in sensitivity analysis. Again, this parameter is not appropriate for this study, because wastage is an output instead of an input. In the end, truck loading/unloading time (Bouzada 2009; Kara, Rugrungruang & Kaebernick 2007) and transportation delay (Rodrigues 2004) were selected as input parameters for the sensitivity analysis in this study, because they would affect all the five KPIs and also would be likely to happen in real life. If the model logic is correct, increase in truck loading/unloading time and transportation delay would increase processing time and wastage but reduce shelf life. In addition, throughput and operating cost would change drastically if the delay exceeded certain thresholds resulting in disruption of the one-day harvest-to-export cycle. Table 4.11 summarises the input parameters identified and selected for sensitivity analysis in this study.

Table 4.11 – Input parameters identified and selected for sensitivity analysis

Input parameter identified	References	Impact on KPIs	Reason for inclusion/exclusion
Amount of Input	Ge (2006); Kara, Rugrungruang and Kaebernick (2007); Parthanadee and Buddhakulsomsiri (2014); Rodrigues (2004); Wijewickrama and Takakuwa (2005)	Throughput and operating cost	▪ Not impacting on all KPIs ▪ Big increase is unlikely to happen in reality without adding new farms
Transportation or labour cost	Goldsby, Griffis and Roath (2006); Kara, Rugrungruang and Kaebernick (2007); Zhang *et al.* (2003)	Operating cost	▪ Not impacting on all KPIs ▪ Big increase/decrease is unlikely to happen in Thailand
Percentage of disposing	Jayaswal and Chhabra (2005)	Throughput and operating cost	▪ Not impacting on all KPIs ▪ Big increase/decrease is unlikely to happen in reality
Transportation delay	Chan and Zhang (2011); Günther and Kim (2005); Rakha and Zhang (2004); Rodrigues (2004)	Throughput, processing time, shelf life, wastage and operating cost	▪ Impacting on all KPIs ▪ Big increase is likely to happen in reality due to inclement weather
Truck loading/unloading time	Bouzada (2009); Günther and Kim (2005); Jansen *et al.* (2001); Kara, Rugrungruang and Kaebernick (2007)	Throughput, processing time, shelf life, wastage and operating cost	▪ Impacting on all KPIs ▪ Big increase is unlikely to happen in reality due to heavy rain, flooding and muddy road condition

- **Change in transportation delay**

This sensitivity analysis is to investigate whether increases in transportation delay can impact significantly on the performance of the model. The increase in transportation delay can be caused by torrential rain and consequent road damage (common in tropical developing countries), because the delivery trucks have to reduce speed. The delay can impact on all the five KPIs. For example, if the delay increases significantly, some mangoes would not be shipped to the middleman firm on time and would miss the daily departures to foreign markets on the same day. As a result, throughput, operating cost, processing time, shelf life, and wastage may all be affected. Sadowski and Grabau (2003) suggest that, in simulation, an increase of 15% in value for this parameter for sensitivity analysis would be appropriate. Based on this recommendation, the present study uses increases in transportation delay at 5%, 10% and 15% of the current level to investigate the changes in performance of the model.

The sensitivity analysis test is simulated by increasing transportation delay to the truck operations at the farms, processors and middleman firm. The argument is that, with the increases in transportation delay, the processing time and wastage would increase, leading to a reduction in shelf life of the mangoes shipped. Furthermore, throughput would drastically decrease when a certain limit is exceeded. To allow for some randomness in the simulation model, a triangular distribution instead of a fixed value is used to mimic the increase in transportation delay at 5%, 10% and 15% of the current level (see Table B.19). Table 4.12 summarises the details of the sensitivity analysis test regarding change in transportation delay.

Table 4.12 – Summary of sensitivity analysis tests in terms of change in transportation delay

Sensitivity analysis test	Change made to the model	Reason for the change	Additional resource
Increase in transportation delay	• An increase in transportation delay at farms, transporter and middleman firm in the simulation model by 5%, 10% and 15% of the current value (see Table B.19).	▪ To represent an increase of transportation delay ranging from 5% to 15%	▪ Nil

Revised to incorporate an increase in transportation delay by 5%, 10% and 15%, the model was run for 100 replications on a 72-hour period for each increase. The average outcomes of the simulation runs were compared to determine the effect of increase in transportation delay on throughput, as shown in Figure 4.12, on operating cost in Figure 4.13, on country A processing time in Figure 4.14, on country B processing time in Figure 4.15, on country A shelf life in Figure 4.16, on country B shelf life in Figure 4.17, and on wastage in Figure 4.18.

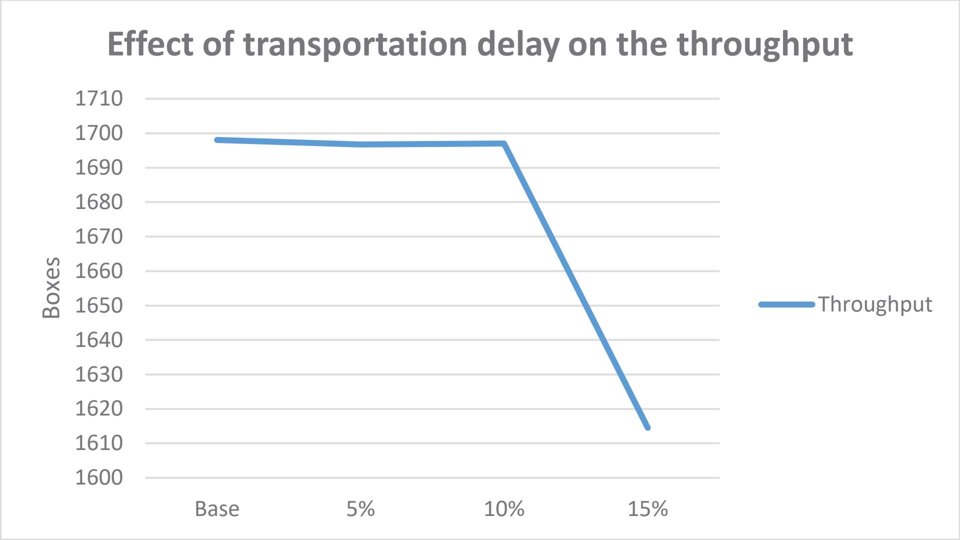


Figure 4.12 – Effect of transportation delay on the throughput

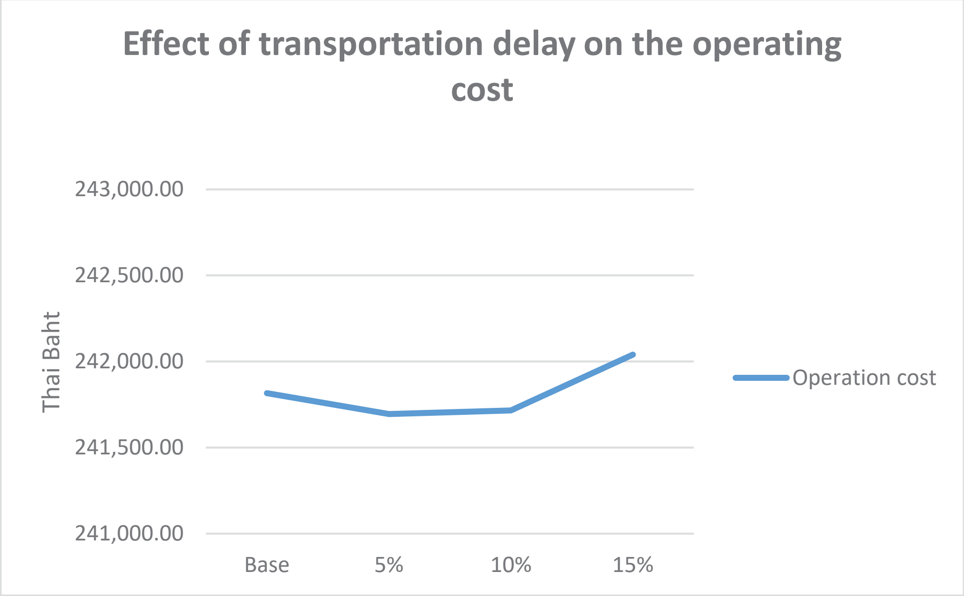


Figure 4.13 – Effect of transportation delay on the operating cost

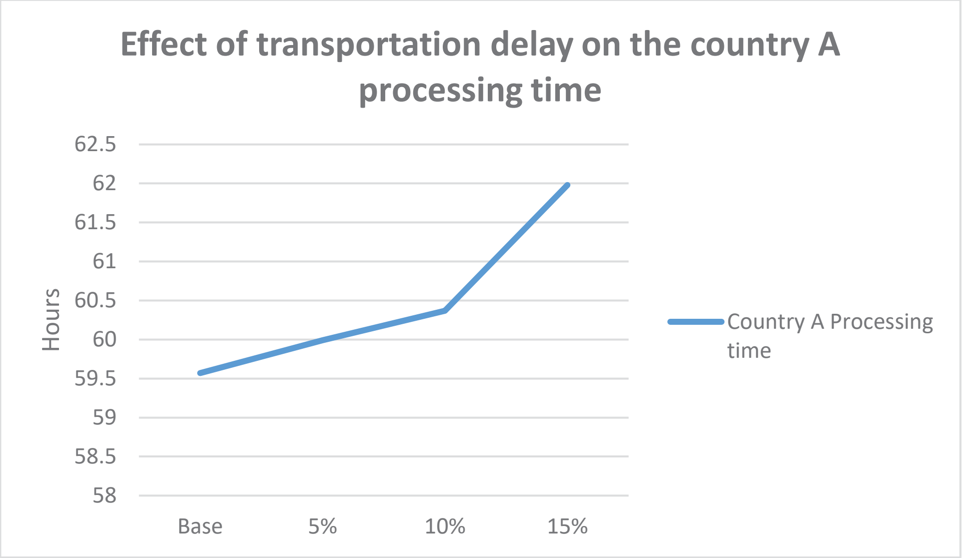


Figure 4.14 – Effect of transportation delay on the country A processing time

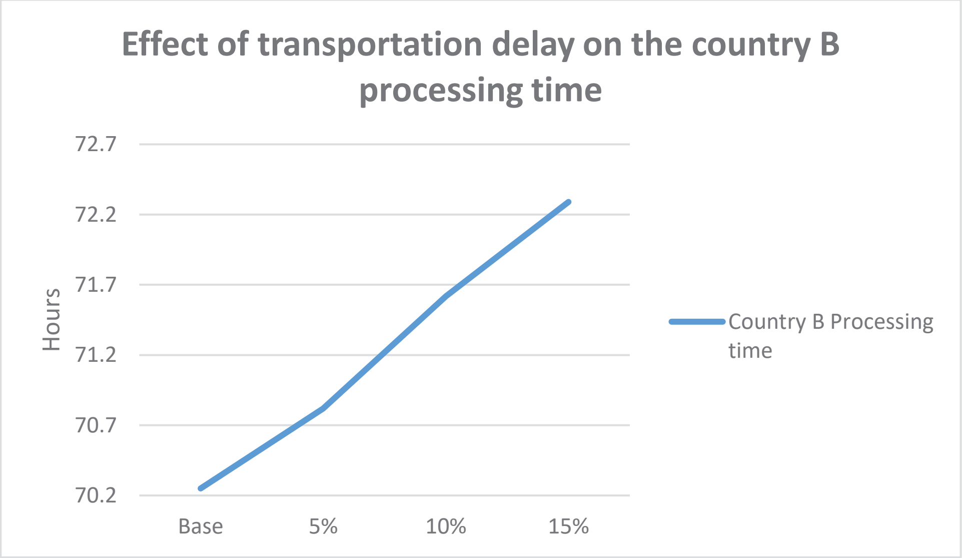


Figure 4.15 – Effect of transportation delay on the country B processing time

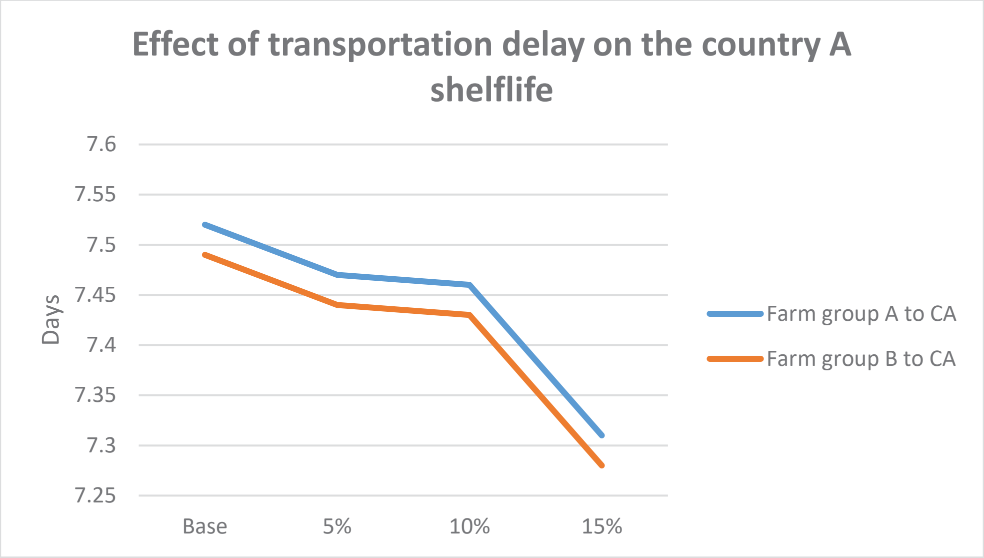


Figure 4.16 – Effect of transportation delay on the country A shelf life

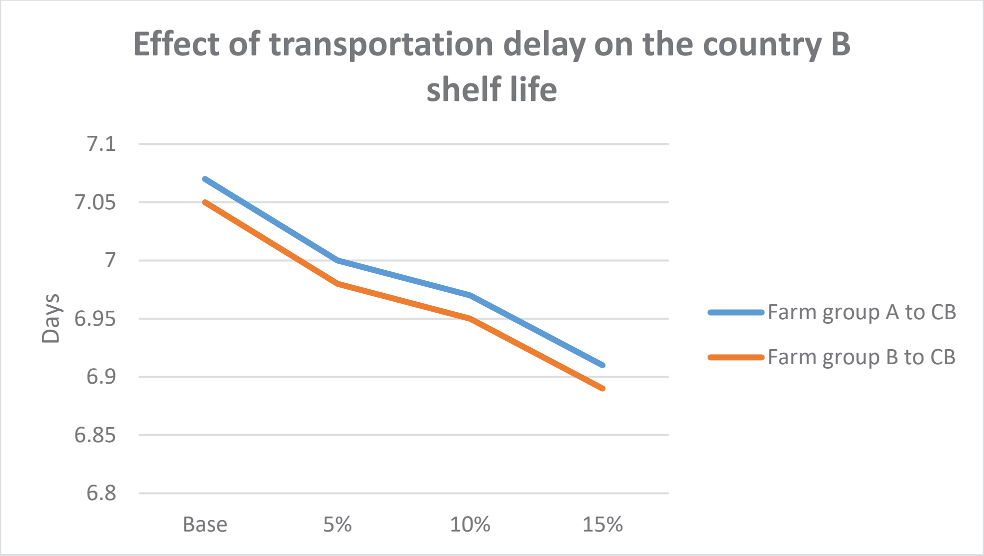


Figure 4.17 – Effect of transportation delay on the country B shelf life

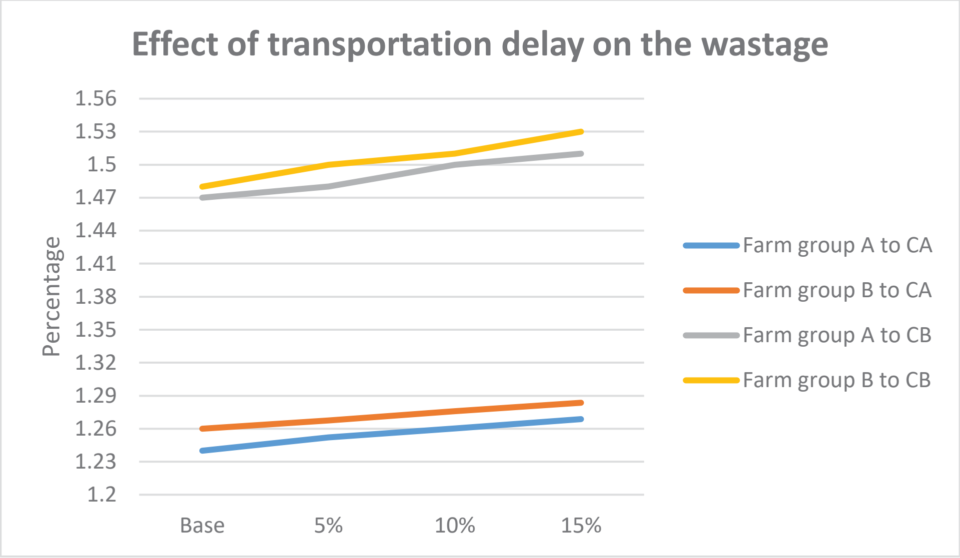


Figure 4.18 – Effect of transportation delay on the wastage

Increasing the transportation delay leads to increases in processing time (Figure 4.14 for country A and Figure 4.15 for country B) and wastage (Figure 4.18) but a decrease in shelf life (Figure 4.16 for country A and Figure 4.17 for country B), as reflected in the simulation outcome. However, some mangoes cannot be exported to the foreign markets (country A) on the same day when transportation delay increases to 15% (Figure 4.12), as the truck will then miss the daily departures for country A. This leads to an increase in processing time for country A (Figure 4.14) and operating cost (Figure 4.13). With these findings, it can be concluded that the outcome for this sensitivity analysis test is logical, because all the changes are in the expected direction.

- **Change in truck loading/unloading time**

This sensitivity test is to investigate whether the base model would operate as expected when truck loading/unloading time increases. Truck loading/unloading time is affected by several factors in reality. For example, heavy rain is one of the main causes of truck loading/unloading delay, because the truck loading/unloading operation needs to stop in torrential rain, which is not uncommon in Thailand. Significant delay in truck loading/unloading time can impact on all the five KPIs of this study, similar to that of the transportation delay discussed in the previous section. Bouzada (2009) uses a 30% increase in truck loading/unloading time for sensitivity analysis. Using this number as a reference, the present study sets a maximum of 45% increase in truck loading/unloading time to allow for extreme cases, as long-lasting torrential rain in Thailand does sometimes occur.

The model logic envisages that an increase in truck loading/unloading time will increase processing time and impact on shelf life and wastage. To mimic random fluctuations in the simulation model, again, a triangular distribution instead of a fixed value is used to generate the variations in truck loading/unloading time at 15%, 30% and 45% of the current level (see Table B.20). Table 4.13 summarises the details of the sensitivity analysis tests regarding increase in truck loading/unloading time.

Table 4.13 – Summary of sensitivity analysis test in terms of increase in truck loading/unloading time

Sensitivity analysis test	Change made to the model	Reason for the change	Additional resource
Increase in truck loading/unloading time	• An increase in truck loading/unloading time at farms, processors, transporter and middleman firm in the simulation model by 15%, 30% and 45% of the current level (see Table B.20).	▪ To represent an increase of truck loading/unloading time ranging from 15% to 45%	▪ Nil

The delay in truck loading/unloading occurs at the farms, processors, transporter and the middleman firm. The effects of changes in the percentage of truck loading/unloading time, which is modified to increase by 15%, 30% and 45%, on the throughput, operating cost, country A processing time, country B processing time, country A shelf life, country B shelf life, and wastage, are shown in Figures 4.19 to 4.25.

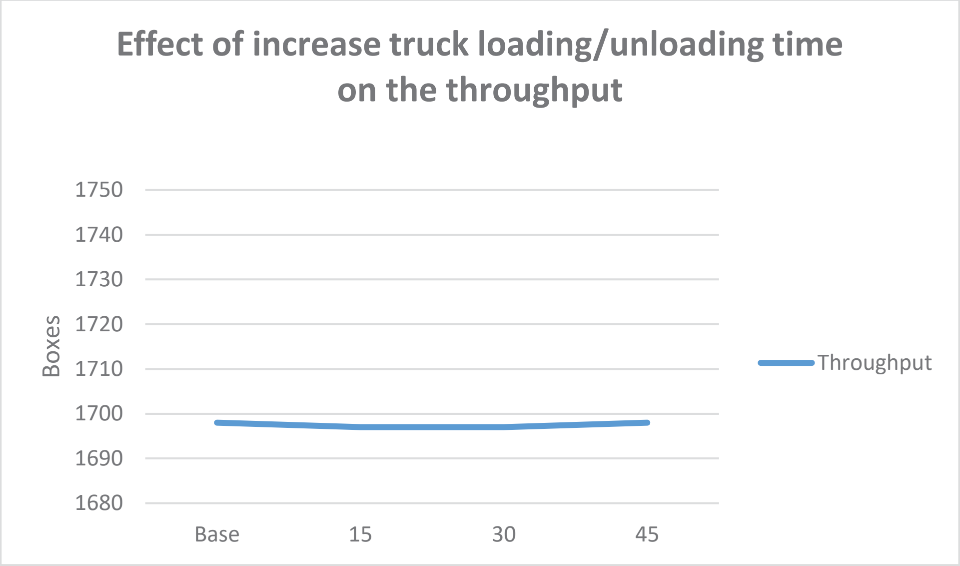


Figure 4.19 – **Effect of truck loading/unloading time on the throughput**

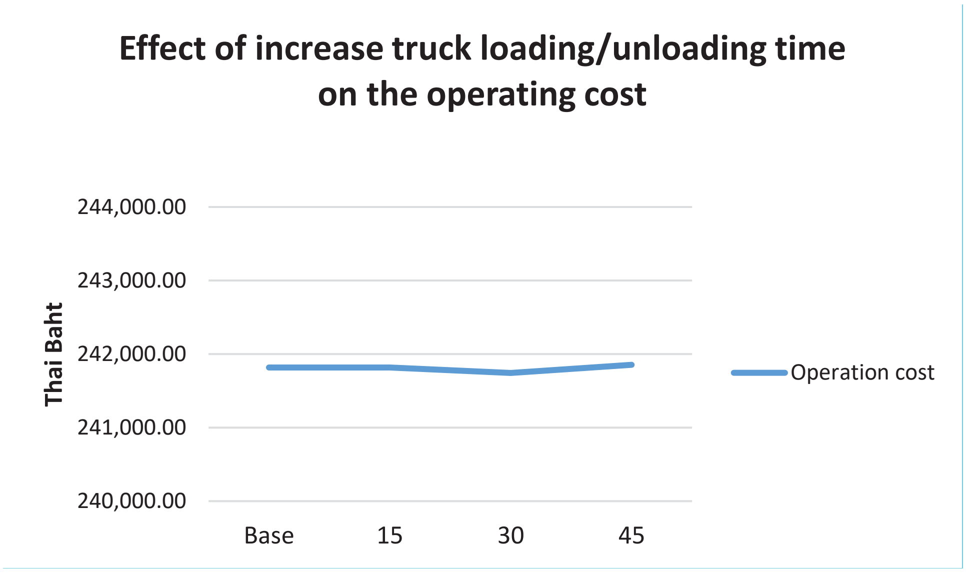


Figure 4.20 – **Effect of truck loading/unloading time on the operating cost**

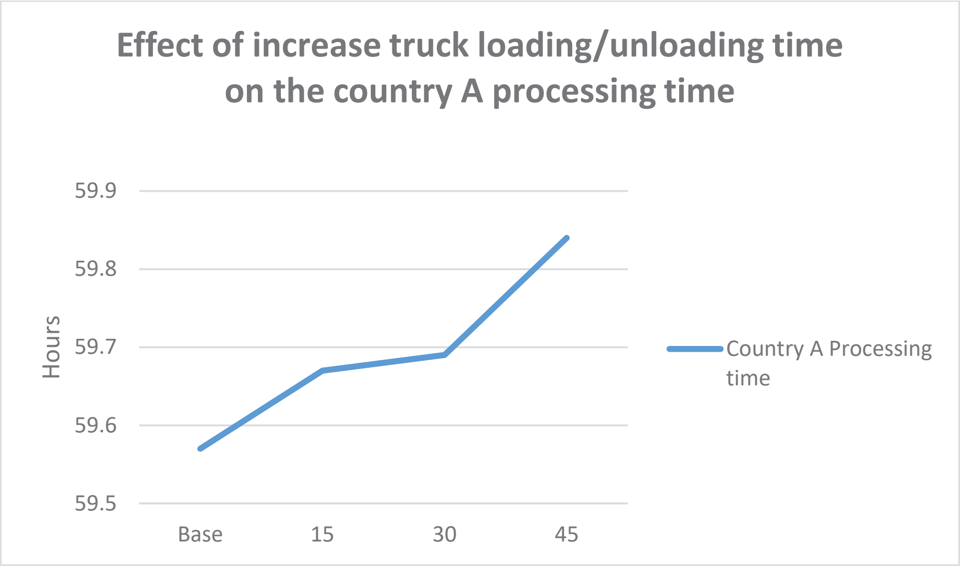


Figure 4.21 – Effect of truck loading/unloading time on the country A processing time

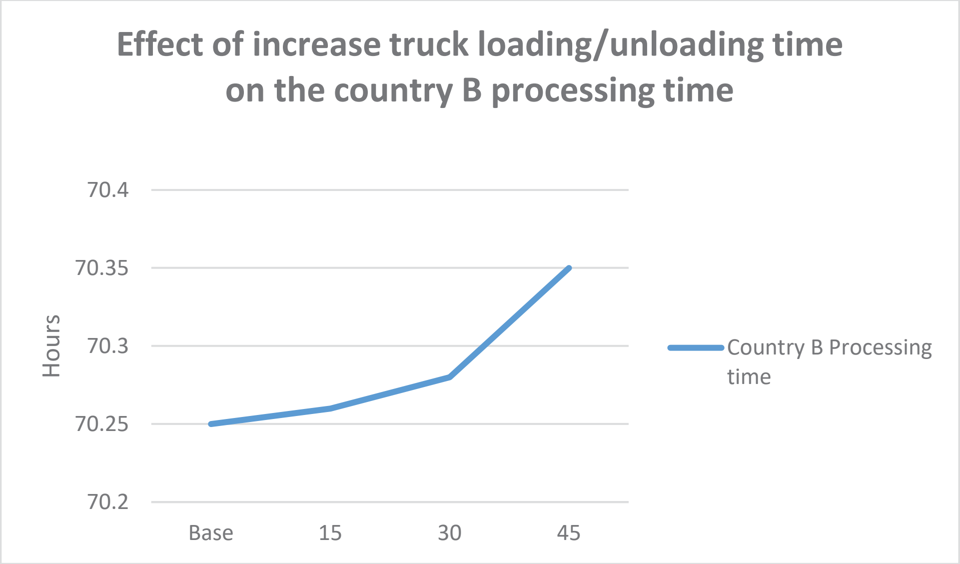


Figure 4.22 – Effect of truck loading/unloading time on the country B processing time

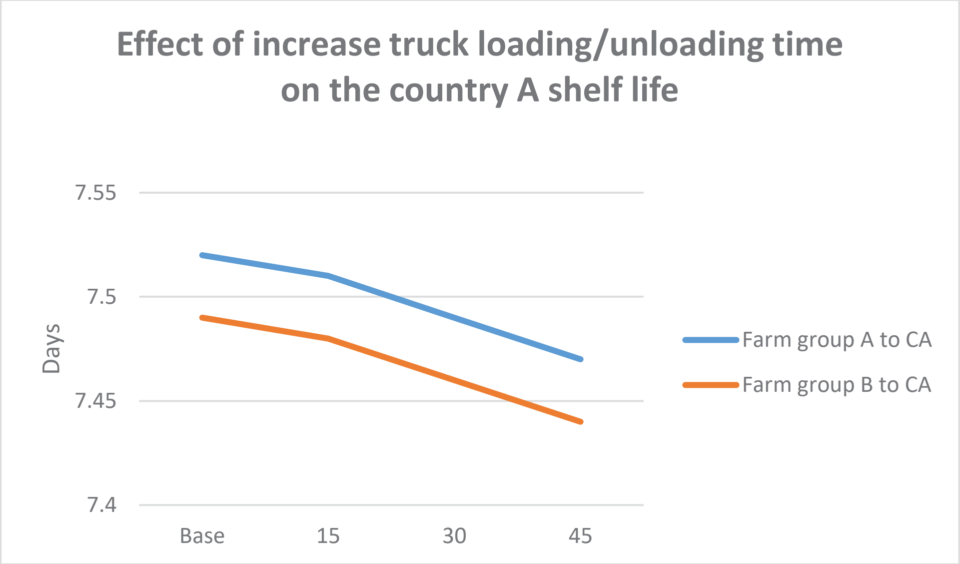


Figure 4.23 – Effect of truck loading/unloading time on the country A shelf life

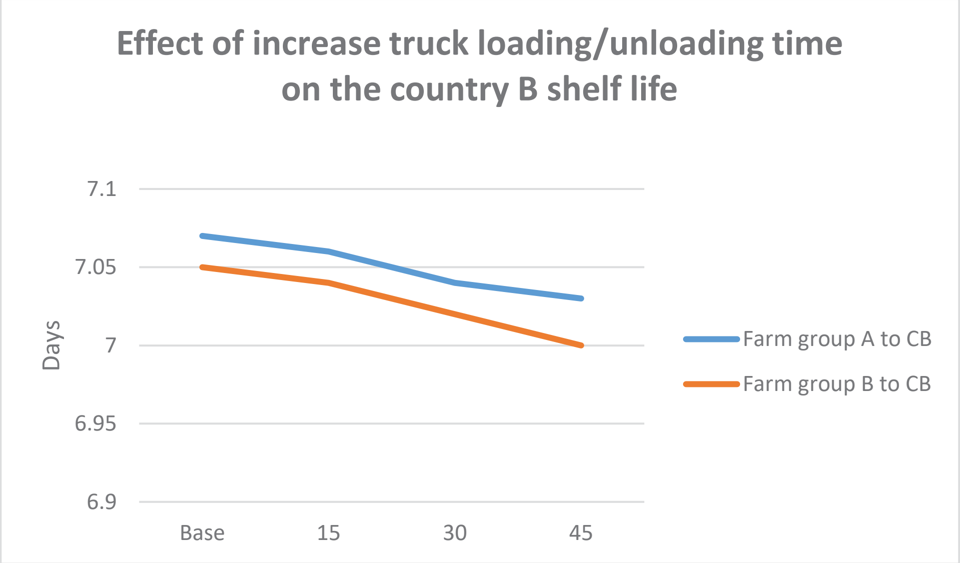


Figure 4.24 – Effect of truck loading/unloading time on the country B shelf life

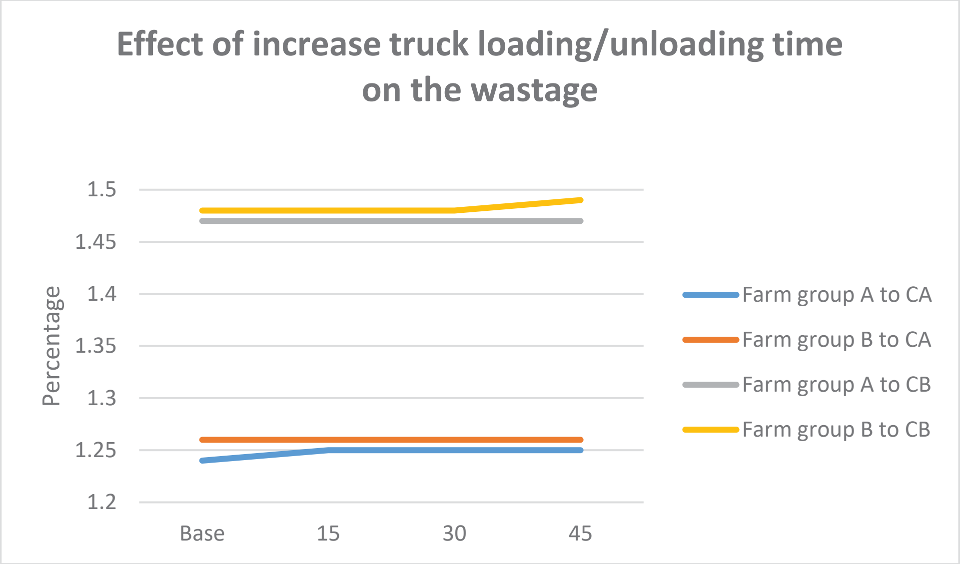


Figure 4.25 – Effect of truck loading/unloading time on the wastage

The simulation results show that an increase in truck loading/unloading time affects the processing time (Figure 4.21 for country A and Figure 4.22 for country B), shelf life (Figure 4.23 for country A and Figure 4.24 for country B) and wastage (Figure 4.25). Further delay in truck loading/unloading leads to an increase in processing time but a decrease in shelf life. The increase in processing time for both countries A and B is proportional to the increase in truck loading/unloading delay. However, wastage is not significantly affected by the increase in truck loading/unloading time, because the percentage of wastage for mangoes is about 0.5% per day at ambient temperature (Liu, Wang & Young 2014; Moomin 2010). Even though the shipments to countries A and B are delayed by one day due to the additional truck loading/unloading delay, the increase in wastage is only 0.5%. Throughput and operating cost are not affected, because the additional truck loading/unloading delay is minimal when compared to the total cycle time. All these outputs suggest that the model is working well even when an increase of truck loading/unloading time by 45% maximum is incorporated. Furthermore, all changes in output for this test are in the expected direction, suggesting that the model logic is valid.

In summary, the sensitivity analysis results reveal that the impacts on the model outcomes are minimal, even when an additional 30% in transportation delay and 45% in truck loading/unloading time are incorporated into the model. Discussions with the various supply chain partners, with onsite observations, also confirm that the mango supply chain operation under study is relatively stable, even though some delay is allowed for in the process. This finding aligns with the simulated output. Hence, it can be concluded that the sensitivity analysis results can reflect the reality. As such, the base model is considered valid and can be used to explore the appropriate cold chain approach for fresh fruit supply chains in developing countries.

4.5 Phase 4: alternative model development and scenario testing

Once validated, the validated base model developed can be used to explore the appropriate approach to cold chain design for fresh fruit supply chains in developing countries. To answer the research questions, this study has developed three scenarios for each approach. The first scenario is a change in total demand for exported fruit. The second scenario is an increase in supply uncertainty. The last scenario is an increase in operating cost. The objective of the scenario tests is to see whether the investigated cold chain design is robust and still appropriate for developing countries under different situations. Again, the five performance indicators for the model under each of the different scenarios were compared.

4.6 Chapter summary

This chapter has described the approach used in this study to create the base model. Details of the data collection and other stages of the simulation process were given. Furthermore, the output of the base model was presented, and its representativeness of the real system was validated using the *t*-test for independent samples. To test whether the model logic is valid, several sensitivity analyses through changes in transportation delay and truck loading/unloading time were conducted. The outcomes also support the validity of the model. The next chapter will present the development of the alternative models incorporating the cold chain designs and some scenario testing used to examine the robustness of the cold chain designs.

Chapter 5

EVALUATION OF ALTERNATIVE MODELS

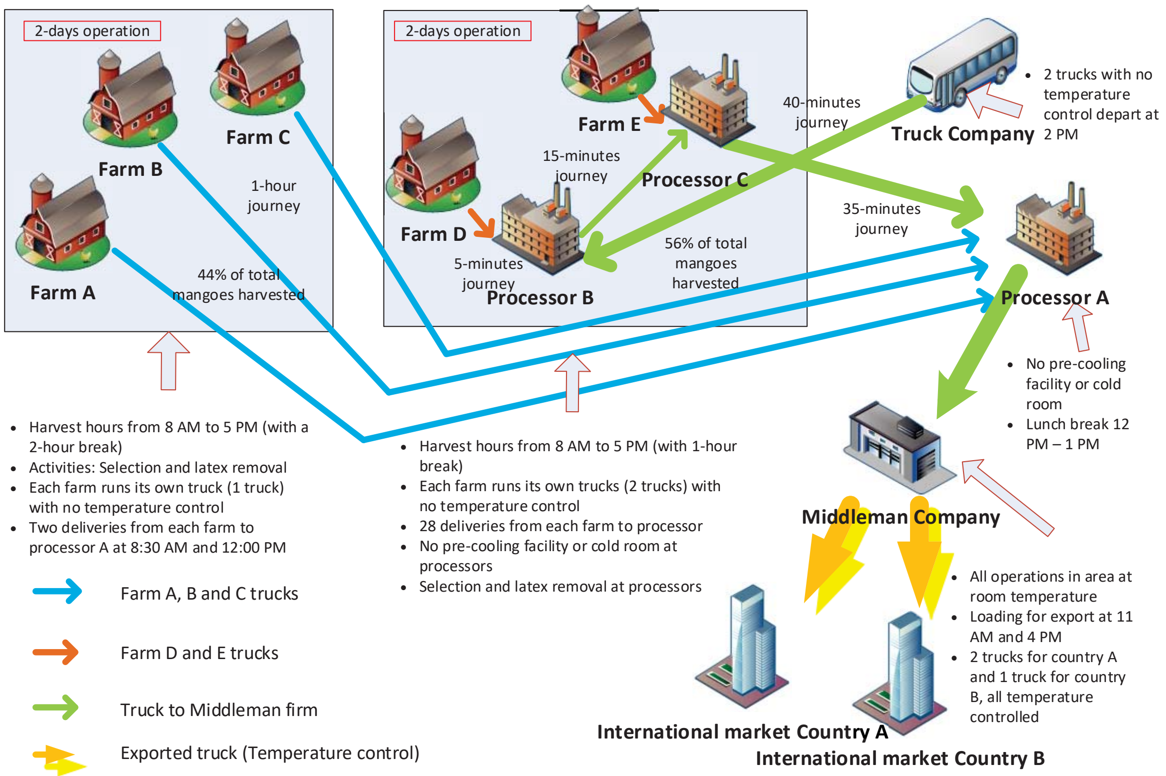
Chapter 4 explained in detail how the validated base model was developed in order to be used as a basis for building and evaluating the alternative models and scenarios. This chapter describes in detail how the alternative models were constructed to incorporate the different cold chain designs for fresh fruit supply chains in developing countries, such as Thailand. In addition, explanation of how the various scenarios were developed to test the robustness of the alternative models are given. Three scenarios were considered, which involve change in total demand, increase in supply uncertainty, and change in operating cost in the long run. In addition, simulation results of the base and the alternative models, which incorporate the individual and the consolidated cold chain designs, are compared in performance in five aspects, including throughput, processing time, operating cost, shelf life, and wastage. Outcomes of the alternative models under different scenarios are also given to show the robustness of the alternative models. Again, to maintain consistency, performances of the models in the five areas are compared.

5.1 Phase 4: alternative models development and scenario testing

In developed countries where financial resources are relatively abundant, cold chain adoption generally involves significant capital investment in equipment and technology – the so-called high-tech high-cost approach. Although changes in work practices or a redesign of the supply chain might be needed on some occasions during cold chain implementation, maintaining the existing supply chain structure and operation while investing heavily in state-of-the-art cold chain equipment is still the norm (Hodges, Buzby & Bennett 2011; Li 2006; Runzhou 2014). In developing countries, however, financial resources are usually scarce. Therefore, alternative implementation tactics combining limited capital investment in equipment and changes in work practices – or the so-called low-tech low-cost approach – need to be considered. The objective is to reduce total cost to make adoption feasible and to increase overall cost-effectiveness by leveraging other resources, such as cheap labour. With this understanding, the present study developed alternative models incorporating different cold chain designs, by not only utilising cold chain equipment but also changing work practices. This was achieved by adjusting the resources and modifying existing process modules in the base model. The same approach was used to generate the various scenarios with changes in the external business environment. Two cold chain designs, namely individual and consolidated designs, together with three scenarios, representing fluctuations in total demand, supply uncertainty, and operating cost, were investigated. To determine whether cold chain adoption in the fresh fruit supply chain under study could help improve its performance, five KPIs were used to validate the base model. Similarly, the same KPIs were used to gauge the performance of the alternative models under the different scenarios.

5.1.1 Alternative design 1: individual cold chain design

The main characteristic of individual cold chain design is that every party invests in its own part of the supply chain during implementation. For instance, the farmers, who are short of financial resources or do not have the ability to invest in cold chain technology or equipment, can still invest in labour resources to change operation times to tie in with cold chain adoption. Labour supply is usually abundant and relatively cheap in developing countries. It is, therefore, more affordable for the growers to hire labour than to invest in cold chain equipment. As a company with more resources, the processor can invest in pre-cooling and cold room facilities. Similarly, the transporter can invest in temperature-controlled trucks. For the same reason, the middleman company can invest in setting up a temperature-controlled area for storage of fresh fruits prior to exporting them overseas. Figure 5.1 presents an overview of the individual cold chain design (bottom half of the figure) represented by the alternative model (model 1) in comparison with the current supply chain design (top half of the figure) represented by the base model. Descriptions in red font in the alternative model represent the changes made to the current situation in order to incorporate the cold chain design.



- 2 trucks with no temperature control depart at 2 PM

- Harvest hours from 8 AM to 5 PM (with a 2-hour break)
- Activities: Selection and latex removal
- Each farm runs its own truck (1 truck) with no temperature control
- Two deliveries from each farm to processor A at 8:30 AM and 12:00 PM

- Harvest hours from 8 AM to 5 PM (with 1-hour break)
- Each farm runs its own trucks (2 trucks) with no temperature control
- 28 deliveries from each farm to processor
- No pre-cooling facility or cold room at processors
- Selection and latex removal at processors

- No pre-cooling facility or cold room
- Lunch break 12 PM – 1 PM

- All operations in area at room temperature
- Loading for export at 11 AM and 4 PM
- 2 trucks for country A and 1 truck for country B, all temperature controlled

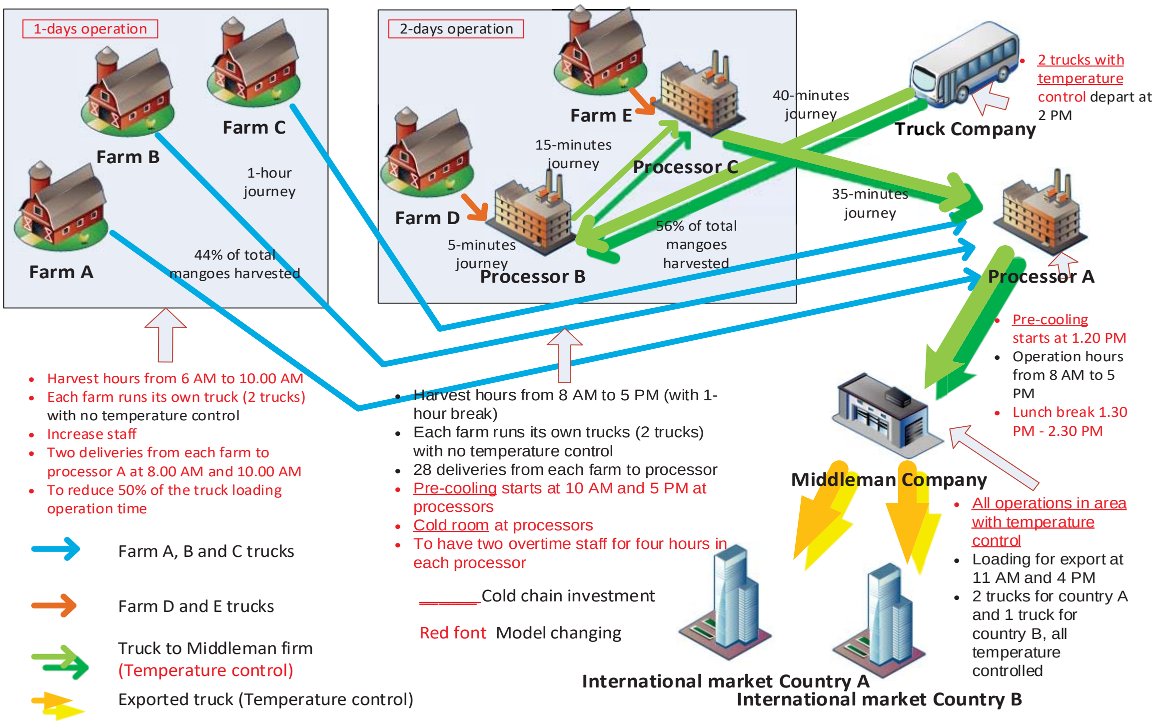
Farm A, B and C trucks

Farm D and E trucks

Truck to Middleman firm

Exported truck (Temperature control)

Overview of the current mango supply chain operation



- 2 trucks with temperature control depart at 2 PM

- Harvest hours from 6 AM to 10.00 AM
- Each farm runs its own truck (2 trucks) with no temperature control
- Increase staff
- Two deliveries from each farm to processor A at 8.00 AM and 10.00 AM
- To reduce 50% of the truck loading operation time

- Harvest hours from 8 AM to 5 PM (with 1-hour break)
- Each farm runs its own trucks (2 trucks) with no temperature control
- 28 deliveries from each farm to processor
- Pre-cooling starts at 10 AM and 5 PM at processors
- Cold room at processors
- To have two overtime staff for four hours in each processor

- Pre-cooling starts at 1.20 PM
- Operation hours from 8 AM to 5 PM
- Lunch break 1.30 PM - 2.30 PM

- All operations in area with temperature control
- Loading for export at 11 AM and 4 PM
- 2 trucks for country A and 1 truck for country B, all temperature controlled

Farm A, B and C trucks

Farm D and E trucks

Truck to Middleman firm (Temperature control)

Exported truck (Temperature control)

Cold chain investment

Red font Model changing

Overview of the mango supply chain using individual cold chain design

Figure 5.1 – Overview of the alternative model 1 versus the base model

The individual cold chain design (alternative model 1) requires only minor modifications to the base model. For example, the harvesting time of farms A, B and C has changed from the original 8.00 AM – 5.00 PM to 6.00 AM – 10.00 AM, as ambient temperature in the early morning is lower (Brecht *et al.* 2010; Mango Research Station & University of Agriculture Faisalabad 2015; Siddiqui 2015). The harvested mangoes can be protected from exposure to direct sunlight (Brecht *et al.* 2010), and the advanced harvesting time reduces the need for cooling and the electricity cost (which can be up to a 37% reduction) of the pre-cooling process (Thompson, Mejia & Singh 2010; Sargent, Talbot & Brecht 1988). To advance and shorten the harvesting time of farms A, B and C, it is necessary to increase the manpower by hiring more workers. However, no temperature-controlled truck to transport the harvested mangoes to the processor is needed, because the ambient temperature is not high in early morning (see Appendix C, Table C.1). The advancement of harvesting time also enables the pre-cooling of the harvested mangoes at processor A to be completed on the same day. By the time the pre-cooling process finishes, the transporter's temperature-controlled truck arrives to collect the cooled mangoes and deliver them to the middleman firm. As such, there is no need for a cold room at processor A for storage. However, the harvesting time at farms D and E remains unchanged because they are substantially closer to processors B and C than the other three farms are. It takes only about five minutes to transport the harvested mangoes to processor B from farm D and to processor C from farm E, whereas it takes approximately one hour for the other farms (A, B, and C) to deliver the harvested mangoes to processor A. As such, without advancing and shortening the harvesting time, thereby avoiding the need for additional labour, pre-cooling of the mangoes harvested at farms D and E can still be done on the same day of harvest.

For the pre-cooling of mangoes at the processors, portable forced air cooling equipment is used because it is suitable for cooling fresh fruit while the investment cost is not high compared with that of other pre-cooling technologies (Brecht *et al.* 2010; Kitinoja 2013; Kitinoja & Thompson 2010; Quaye 2011; Winrock International 2009). Upon completion of the harvest at 10.00 AM and after the mangoes have been packed, the pre-cooling process at processor A starts at 1.20 PM so that it can finish before the transporter's truck arrives to collect and deliver the pre-cooled mangoes to the middleman company. To make this happen, it is necessary to change the lunch time at processor A, from 12.00 PM-1.00 PM to 1.30 PM-2.30 PM. For processors B and C, the process commences at 5.00 PM on the harvest day and 10.00 AM on the following day. Running the pre-cooling process two times is necessary. The first pre-cooling at 5.00 PM is suitable for mangoes that are harvested before 2.00 PM on the day. It starts at 5.00 PM when the latex-reduction process, which takes three hours, finishes. Upon pre-cooling, the mangoes are placed in a cold room overnight. A walk-in CoolBot^{TM} cold room can be equipped at each of the processors B and C, as it is cheaper than other types of cold room (Kitinoja & Thompson 2010; Store It Cold Limited 2016). To place the pre-cooled mangoes in the cold room, two workers are required to work overtime for 4 hours at both processors B and C. The second pre-cooling starts at 10.00 AM on the following day. This is for the mangoes that are harvested after 2.00 PM on the previous day. The temperature at night is low, and therefore the harvested mangoes are kept at ambient temperature until the morning of the next day before they are pre-cooled. The pre-cooling finishes just before the transporter's truck arrives to transport the mango boxes to the middleman company.

Under the individual cold chain design, the transporter is also required to invest in temperature-controlled trucks which are used to transport the cooled mangoes from the processors to the middleman company. Refrigerated container trucks are preferred because they are more energy efficient than small refrigerated vehicles (Winrock International 2009). When the trucks arrive at the middleman company, all operations, such as truck unloading and mango sorting, are conducted in a temperature-controlled area which is a walk-in, CoolBot^{TM}-equipped cold room. Compared to other cold room designs, the walk-in, CoolBot^{TM}-equipped cold room is usually a cheaper option (Kitinoja & Thompson 2010; Store It Cold Limited 2016). In this case, additional cost will be incurred for building a cold room to sort and store the packed mango boxes before they are exported to international markets. Table 5.1 summarises the design of the cold chain model in this study using the individual cold chain design approach.

Table 5.1 – Details of the individual cold chain design

Fruit supply chain members	Changes made to base model	Reason for the change	Additional resource
Farms A, B and C	• To harvest in the morning from 6 AM to 10 AM instead of from 8 AM to 5 PM	• To protect the harvested mangoes from direct sunlight and keep the temperature low so as to reduce the time and energy for pre-cooling	• 9 persons at each farm • 1 non-temperature-controlled truck at each farm
	• To increase staff for harvesting from 9 persons to 18 persons	• To tie in with the advancement of harvesting time	
	• To reduce the truck loading time by half	• Due to increase in manpower	
	• To increase the number of trucks from 1 to 2 at each farm	• To transport harvested mangoes to the pre-cooling facility as quickly as possible	
	• To change truck loading time from 11.30 AM on the harvest day and 8.00 AM on the following day to 7.30 AM and 9.20 AM on the same day	• To tie in with the advancement of harvesting time	
Farms D and E	• Nil	• Nil	• Nil
Processor A	• To add a pre-cooling process starting at 1.20 PM (see Table C.2)	• To cool the mangoes after harvest as quickly as possible • Mangoes are usually cooled for 2-4 hours • Harvesting in early morning can help reduce pre-cooling time and electricity cost by 37% • To finish pre-cooling before the arrival of the temperature-controlled trucks from the transporter	• 1 portable forced air-cooling facility
	• To change lunch time of staff from 12.00 PM-1 PM to 1.30 PM-2.30 PM	• To place the harvested mangoes in the pre-cooling facility at the processor sites	

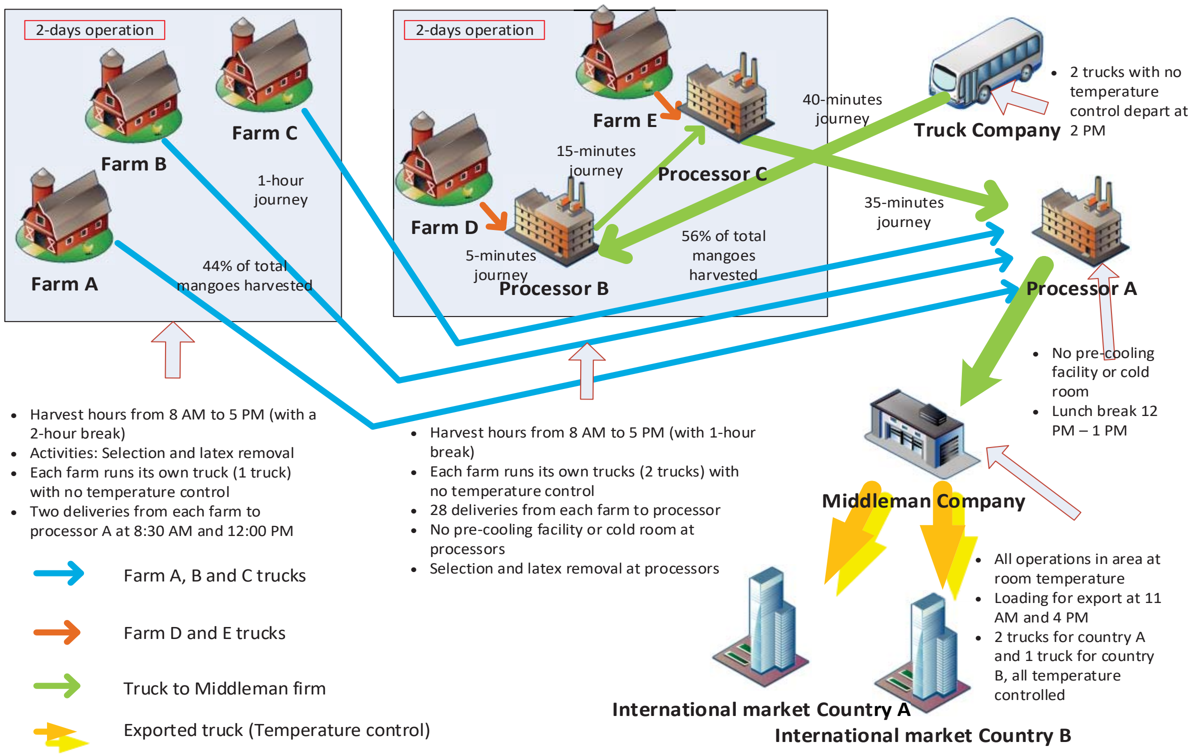
Table 5.1 – Details of the individual cold chain design (continued)

Fruit supply chain members	Changes made to base model	Reason for the change	Additional resources
Processors B and C	• To run a pre-cooling at 5 PM on the harvest day and another one at 10 AM on the following day, for 2-4 hours	• It is necessary to run pre-cooling two times because harvesting time of farm D and farm E remains unchanged • The 5 PM run is for the mangoes harvested before 2 PM on the harvest day, whereas the 10 AM run on the following day is for the mangoes harvested after 2 PM on the previous day • Pre-cooling starts at 5 PM because it has to wait until the latex-reduction process is completed • The second pre-cooling starts at 10 AM the next morning because the temperature is low at night • Harvested mangoes are usually cooled for 2-4 hours	• 1 portable forced air-cooling facility in each processor • 1 walk-in cold room CoolBot™-equipped facility in each processor • 2 overtime staff working for four hours at each processor
	• To operate a temperature-controlled room store for the mangoes pre-cooled at 5 PM	• To hold the mangoes in the cooler before shipment	
	• To have two overtime staff working for 4 hours	• To move the mangoes to the cold room at each processor site when the pre-cooling process finishes	
Transporter	• To use temperature-controlled trucks to deliver the cooled mangoes from the processor sites to middleman firm	• To link up the cold chain	• 2 refrigerated container trucks
Middleman firm	• To operate temperature-controlled area	• To link up the cold chain	• 1 walk-in cold room CoolBot™-equipped facility

5.1.2 Alternative design 2: consolidated cold chain design

Instead of having all supply chain members investing individually in their own cold chain equipment, supply chain members can coordinate their operations and share the use of cold chain equipment and infrastructure to operate the cold chain at a lower cost. For example, all farms can shift the mango harvest time to the early morning to reduce pre-cooling needs and cost. Processors A and B can share a common pre-cooling facility located at Processor B to maximise usage of the facility. The transporter and the middleman company can change their operation time to tie in with the processor's operation. Figure 5.2 shows an overview of the consolidated cold chain design represented by the alternative model (model 2) in comparison with the current supply chain design represented by the base model. Again, the top half of the figure shows the current situation while the bottom half shows the consolidated cold chain design. The changes made are shown in red font for easy understanding.

In the consolidated cold chain design (alternative model 2), shift of harvest time to early morning and increase in the number of staff at farms A, B and C are identical to those of the individual cold chain design (see Table C.3). The harvested mangoes are still transported to processor A, but it will be relocated to the same site as that of processor B. This is because the distance between farms A, B, and C and processor B is much shorter than that between the original position of processor A and the farms (see Figure C.1). The relocation will significantly reduce the travelling distance, time and fuel of the transporter's truck which collects the cooled mangoes from the processors for delivery to the middleman company. Such an arrangement is possible in developing countries, such as Thailand, because the middleman firm, being a company with more resources, usually has the greatest power over other supply chain members, who are usually small firms with very limited assets. Therefore, the middleman company can arrange and facilitate collaboration among supply chain members for the benefit of all parties (Vellema *et al.* 2005). By relocating processor A to the same site of processor B, the two processors can share pre-cooling facilities, thereby reducing total investment cost as well as maximising utilisation of resources. Because of this arrangement, mangoes harvested from farms A, B and C are pre-cooled at 3.00 PM together with mangoes harvested from farm D. Mangoes harvested from farm E will go to processor C for pre-cooling, again at 3.00 PM. As such, it is necessary to shift the harvest time of farms D and E to the early morning (AT Kearney Limited 2005; Aswaney 2007; Brecht *et al.* 2010; Mango Research Station & University of Agriculture Faisalabad 2015; Zhu *et al.* 2014). This enables the pre-cooling process for all harvested mangoes to start at the same time, *i.e.*, 3.00 PM, on the day of harvest and finish before the temperature-controlled trucks from the transporter arrive to transport the cooled mangoes to the middleman company (Thompson, Meijia & Singh 2010). To do this, farms D and E are required to increase the number of workers from 14 to 28 persons and to add two more trucks (see Table C.4) at each farm. The harvesting time will also change from 8.00 AM-5.00 PM to 6.00 AM-10.00 AM.



- Harvest hours from 8 AM to 5 PM (with a 2-hour break)
- Activities: Selection and latex removal
- Each farm runs its own truck (1 truck) with no temperature control
- Two deliveries from each farm to processor A at 8:30 AM and 12:00 PM

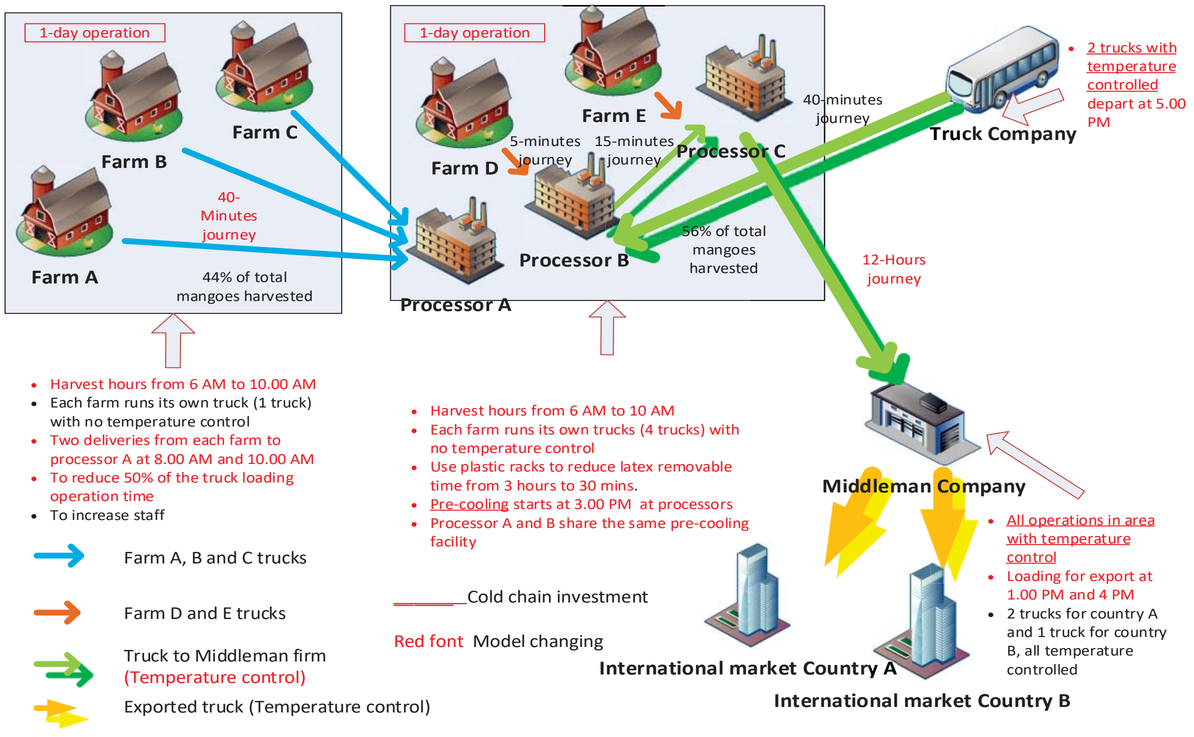
- Harvest hours from 8 AM to 5 PM (with 1-hour break)
- Each farm runs its own trucks (2 trucks) with no temperature control
- 28 deliveries from each farm to processor
- No pre-cooling facility or cold room at processors
- Selection and latex removal at processors

- 2 trucks with no temperature control depart at 2 PM

- No pre-cooling facility or cold room
- Lunch break 12 PM – 1 PM

- All operations in area at room temperature
- Loading for export at 11 AM and 4 PM
- 2 trucks for country A and 1 truck for country B, all temperature controlled

Overview of the current mango supply chain operation



- Harvest hours from 6 AM to 10.00 AM
- Each farm runs its own truck (1 truck) with no temperature control
- Two deliveries from each farm to processor A at 8.00 AM and 10.00 AM
- To reduce 50% of the truck loading operation time
- To increase staff

- Harvest hours from 6 AM to 10 AM
- Each farm runs its own trucks (4 trucks) with no temperature control
- Use plastic racks to reduce latex removable time from 3 hours to 30 mins.
- Pre-cooling starts at 3.00 PM at processors
- Processor A and B share the same pre-cooling facility

- 2 trucks with temperature controlled depart at 5.00 PM

- All operations in area with temperature control
- Loading for export at 1.00 PM and 4 PM
- 2 trucks for country A and 1 truck for country B, all temperature controlled

________Cold chain investment

Red font Model changing

Overview of the mango supply chain using consolidated cold chain design

Figure 5.2 – Overview of the base model versus summary of consolidated cold chain design

To tie in with the advancement of harvesting time of farms D and E, processors B and C have to increase the number of staff and advance the operation time of inspecting and cutting the harvested mangoes from 8.00 AM-5.00 PM to 6.00 AM-12.00 PM (see Table C.5). A plastic rack can be used in the latex-removal process to reduce the processing time from the original three hours to 30-60 minutes (Mango Research Station & University of Agriculture Faisalabad 2015). Due to the shortening of the latex-removal operation, the next step of moving the de-latexed mangoes to the grading yard can be expedited from two times to three times per day. By advancing harvesting time, using plastic racks to quicken latex removal from the harvested mangoes, expediting the grading process, and sharing pre-cooling facilities to maximise usage, this design does not require any cold room for storage of mangoes during waiting, due to improved coordination of activities. The pre-cooling process completes just before the transporter trucks arrive to the processor sites to pick up the cooled mangoes and transport them to the middleman company for sorting and export. The mango boxes upon pre-cooling wait inside the pre-cooling room for pickup, thereby avoiding the need for a separate cold room.

As with the individual cold chain design, the transporter needs to invest in two temperature-controlled trucks to transport the mangoes. However, under the consolidated cold chain design, the transporter will arrange the two temperature-controlled trucks to depart at 5.00 PM instead of the original 2.00 PM, to tie in with completion of the pre-cooling process at the processor sites. The routing of the trucks also needs to be revised. Instead of going to processor B first and then to processors C and A, as in the base model, the trucks will travel to processors A and B (located at the same site) first to pick up the mango boxes, and then to processor C to pick up the mango boxes. After that, the trucks drive directly to the middleman company (Figure 5.3).

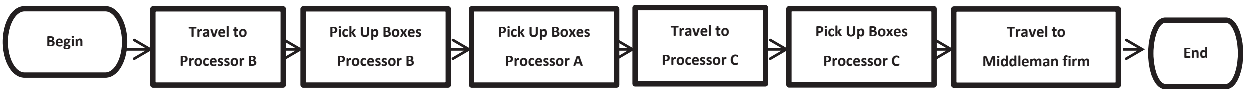


Figure 5.3 – Transporter's process under the consolidated cold chain design

Due to the postponement of the transporter trucks' departure time, even though the distance from processor C to the middleman company is shorter than that from processor A, it is still necessary to delay the departure time of the country A truck at the middleman company, from 11.00 AM to 1.00 PM, to tie in with the arrival of the transporter trucks. Again, all the operations at the middleman company site will be done in a temperature-controlled cold room, which needs to be built. Table 5.2 summarises the design of the consolidated cold chain design for this study.

Table 5.2 – Details of the consolidated cold chain design

Fruit supply chain members	Changes made to base model	Reason for the change	Additional resource
Farms A, B and C	• To harvest in the early morning from 6 AM to 10 AM, instead of from 8 AM to 5 PM	• To protect the harvested mangoes from direct sunlight and keep the temperature low so as to reduce the time and energy for pre-cooling	• 9 persons at each farm
	• To increase the number of staff for harvesting from 9 to 18 persons	• To tie in with the advancement of the harvesting time	
	• To reduce 50% of the truck-loading operation time	• Due to increase in workforce	
	• To change truck-loading time from 11.30 AM on the harvest day and 8.00 AM on the following day, to 7.30 AM and 9.20 AM on the same day	• To tie in with the advancement of the harvesting time	
	• To transport harvested mangoes to processor B instead of processor A (see Table C.6)	• Due to relocation of processor A to the same site as processor B	
Farms D and E	• To harvest in the early morning from 6 AM to 10 AM	• To protect the harvested mangoes from direct sunlight and keep the temperature low so as to reduce the time and energy for pre-cooling	• 16 persons at each farm • 2 trucks at each farm
	• To increase the number of staff for harvesting from 16 to 32 persons	• To tie in with the advancement of harvesting time	
	• To increase the number of trucks from 2 to 4 at each farm	• To move the harvested mangoes to the cooling facility as quickly as possible • To tie in with the advancement of harvesting time	
Processor A	• To run the pre-cooling process at 3.00 PM (see Table C.6)	• To cool the harvested mangoes as soon as possible • To cool the harvested mangoes for 2-4 hours • To harvest in the morning to help to reduce the pre-cooling time and electricity used by 37% • To finish pre-cooling prior to transportation from processors to the middleman firm	• Sharing the pre-cooling facility with processor B
	• To relocate to the same site as processor B	• To share cold chain infrastructure between processor B and processor A • To reduce processing time	

Table 5.2 – Details of the consolidated cold chain design (continued)

Fruit supply chain members	Changes made to base model	Reason for the change	Additional resource
Processors B and C	• To run the pre-cooling process at 3 PM (see Table C.6)	• To cool the harvested mangoes as soon as possible • To cool the harvested mangoes for 2-4 hours • To harvest in the morning to help to reduce the pre-cooling time and electricity used by 37% • To finish pre-cooling prior to transportation from processor to arrival of middleman firm	• 1 portable forced air-cooling at each processor site • 6 persons at each processor site
	• To reduce the time for latex removal from 3 hours to 30-60 minutes, by using plastic racks to quicken the process	• To reduce processing time	
	• To change the time of moving the harvested mangoes to grading yard from 8.00 AM and after finishing transporter truck loading, to 8.00 AM, 10.00 AM and 1.00 PM	• To tie in with the advancement of harvesting time and reducing the latex-removal time • To tie in with the pre-cooling at 3.00 PM	
	• To advance the processes of cover release and inspection, from 8.00 AM-5.00 PM to 6.00 AM-12.00 PM	• To tie in with the advancement of harvesting time • To tie in with the pre-cooling at 3.00 PM	
	• To increase the number of staff for cover release and inspection from 6 to 12 persons	• To tie in with the advancement of harvesting time • To tie in with the pre-cooling at 3 PM	
Transporter	• To use temperature-controlled trucks to deliver the cooled mangoes from the processors to middleman firm	• To link up the cold chain	• 2 refrigerated containers trucks
	• To change the truck departure time from 2.00 PM to 5.00 PM	• To tie in with the pre-cooling starting at 3.00 PM	
	• To revise the delivery route, to transport directly to the middleman firm upon picking up the cooled mangoes from processor C (see Table C.6)	• To tie in with the relocation of processor A to the same site as processor B	
Middleman firm	• To operate in the temperature-controlled area	• To link up the cold chain	• 1 walk-in cold room CoolBot equipped facility
	• To postpone the departure time of country A truck, from 11.00 AM to 1.00 PM	• To tie in with postponing transporter truck departure time	

To summarise, the individual cold chain design requires each supply chain member to invest in cold chain technologies on its own. For the supply chain under study, this design requires three pre-cooling facilities, two cold rooms, two temperature-controlled trucks, and one temperature-controlled packing area at the middleman firm location. In contrast, the consolidated cold chain design emphasises the sharing of cold chain equipment and infrastructure among supply chain members to reduce total investment cost. It leverages changes in work practices and coordination of activities to reduce the need for cooling and to maximise usage of resources. As a result, it needs only two pre-cooling facilities, two temperature-controlled trucks, and one temperature-controlled packing area. In short, the individual design involves fewer changes in work practices compared to the consolidated design. However, it requires greater investment in cold chain equipment and is a more costly option. Table 5.3 summarises the cold chain investment of the individual and the consolidated cold chain designs.

Table 5.3 – Details of cold chain investment for each of the two alternative models

Additional resource	Current situation	Individual cold chain design	Consolidated cold chain design
Cold chain investment	• Nil	• 3 pre-cooling facilities • 2 cold rooms • 2 refrigerated trucks • Temperature-controlled sorting and storing area	• 2 pre-cooling facilities • 2 refrigerated trucks • Temperature-controlled sorting and storing area

5.2 Simulation results of the alternative models

Once the alternative models were developed, they were run for 100 times each, and the average model outputs were compared with the outputs from the base model to determine which cold chain design is more suitable for fresh fruit supply chains in developing countries.

Table 5.4 shows the output of the two alternative models (each represents a different cold chain design), compared to the actual performance of the mango supply chain being simulated. The statistics reveal that, while maintaining the same throughput, the performances of the two alternative models excel that of the current supply chain by a significant margin. The processing time for the consolidated cold chain design is significantly reduced. Furthermore, there is a significant difference between the actual and the alternative models with different cold chain designs in shelf-life period and the percentage of wastage. The percentage of mango wastage decreases to basically zero in both alternative models. In addition, the shelf life of mangoes in both alternative models increases by almost three times the current shelf life.

Table 5.4 – Actual and alternative model KPIs comparison

KPIs	Actual	Individual cold chain (ICC)	Consolidated cold chain (CCC)
Number of Boxes	1,705	1,708	1,700
Country A Processing time (Hours)	59.50	59.53	37.58
Country B Processing time (Hours)	70.50	70.23	46.20
Operating cost (Thai Baht)	243,589	247,220	233,478
Farms group A (A, B and C) to CA (Country A) shelf life (Days)	7.02	23.34	23.15
Farms group B (D and E) to CA (Country A) shelf life (Days)	7.02	22.57	23.20
Farms group A (A, B and C) to CB (Country B) shelf life (Days)	6.56	22.82	22.83
Farms group B (D and E) to CB (Country B) shelf life (Days)	6.56	22.12	22.88
Farms group A (A, B and C) to CA (Country A) wastage (Percentage of decay)	1.24	0*	0*
Farms group B (D and E) to CA (Country A) wastage (Percentage of decay)	1.24	0*	0*
Farms group A (A, B and C) to CB (Country B) wastage (Percentage of decay)	1.47	0*	0*
Farms group B (D and E) to CB (Country B) wastage (Percentage of decay)	1.47	0*	0*

* At 15 degrees Celsius, decay of mangoes starts on the 9th day upon harvest. At 10 degrees Celsius, decay starts on the 14th day. As the cycle time of the simulated supply chains is only two to three days, there is basically little decay when the fruit reaches the market.

The comparison in Table 5.4 is categorised into two groups: (1) actual and individual cold chain design model; (2) actual and consolidated cold chain design model. The first group shows that the individual cold chain design can improve the shelf-life period and reduce the percentage of wastage of mangoes. For this design, shelf life increases almost three times compared to the base model, from approximately 7 days to around 22 days. Furthermore, there is a reduction in wastage. It can be seen that the wastage of mangoes for the actual situation is approximately 1.2-1.5%, whereas the wastage for the alternative model is basically zero. Throughput of the individual cold chain design model is similar to that of the actual system, because the individual cold chain design is created by simply incorporating the cold chain technologies, such as pre-cooling, into the base model without altering the model structure or logic. However, the operating cost has increased because of the electricity consumption for cooling and refrigerating the mangoes.

The second group compares the outputs for the consolidated cold chain design and the actual performance. For wastage and throughput, the results are similar to those of the model for the individual cold chain design. However, the shelf-life period for this design is higher than that of the individual cold chain design from farm group B to country A and from farm group B to country B. It has improved from approximately 7 days to 23 days. Moreover, the consolidated cold chain design reduces the operating cost by approximately 13,000 Thai Baht, and lead time by around one day for country A and country B. Through sharing of cold chain infrastructure, changing of current work practices, and coordination of activities, the model incorporating the consolidated cold chain design succeeds in reducing the operation time from approximately three days to two days.

In summary, simulation results show that cold chain adoption, using either individual or consolidated design, can improve the performance of the investigated mango supply chain in terms of longer shelf life and lower wastage (Table 5.5). As other fruit supply chains in Thailand are operating under similar conditions as the mango supply chain being investigated, it is contended that the modeled cold chain design can be implemented for other high-value and fast-perishing fruit supply chains, thereby bringing considerable benefits to the economy of Thailand (and other developing countries), which depends on exporting its fresh fruits to nearby developed countries. However, the model output also shows that operating costs will increase for the individual cold chain design, as investment in cold chain technologies needs to be made by all members of the supply chain. In the consolidated cold chain design model, however, cold chain infrastructure is shared among supply chain members, thereby reducing the total operating cost while increasing the usage of resources. The design requires changes in work practices and tight coordination and collaboration among supply chain members across the entire supply chain. If done properly and successfully, overall lead time can be reduced to make the supply chain more efficient. In view of these advantages, the consolidated cold chain design appears to be more desirable.

Table 5.5 – Summary of benefits of each cold chain design model

KPIs	Current situation	Individual cold chain design	Consolidated cold chain design
Throughput	• About 1,700 Boxes	• Same as current	• Same as current
Processing time	• Three days per cycle	• Three days per cycle	• Two days per cycle
Total operating cost	• About 243,589 Thai Baht per cycle	• About 247,220 Thai Baht per cycle	• About 233,478 Thai Baht per cycle
Shelf life	• 6 - 7 days	• About 22 days	• About 23 days
Wastage	• 1.2 – 1.4 %	• Basically 0%	• Basically 0%

5.3 Scenario simulations

To determine whether cold chain adoption is appropriate for the fresh fruit export industry in developing countries in the long run, the performance of the alternative models incorporating the two cold chain designs under different scenarios was evaluated. Several scenarios with variations in the external business environment were tested. These variations include change in total demand for exported fruit, increase in supply uncertainty, and change in operating cost, which are the most likely changes to occur in developing countries. Again, the five KPIs were used to evaluate the performance of the simulated cold chains under the different scenarios to determine the robustness of the different cold chain designs. Findings of the scenario testing can help answer the second subsidiary research question.

5.3.1 Change in total demand

This scenario is to explore whether the proposed cold chain designs could handle changes in aggregate demand for fruits from developing countries, such as Thailand, in the long term. Several factors affect the demand for fresh fruits exported from Thailand. For instance, confidence of the customers in the quality and safety of the product is a major challenge faced by the industry at the moment (Pornsiripratharn 2011; Somboonsuk *et al.* 2013). To address this issue, cold chain adoption for the fresh fruit supply chain becomes more relevant and urgent. In general, demand is increasing. However, demand for fresh fruits from Thailand can also be affected by competition from neighbouring fruit exporting countries, such as Vietnam or the Philippines (Cooperative Promotion Department 2014). Together, these factors have led to an observed increase in demand for fresh fruit exports from Thailand of approximately 61.33% from 2011 to 2016 (Ministry of Commerce 2017). In other words, the average annual increase is about 12-15%. Based on this observation and allowing for further growth, an increase of 100% in demand is used to create this scenario.

In reality, when demand for mangoes increases, there will be more farms to grow the fruit, because it is a high-value product which will generate more income for the farmers (Pannee 2013; Phavaphutanon 2015). Therefore, in the simulation model, this scenario is represented by increasing the number of farms in the two groups. Assuming that the new farms are operating at the same scale of operation as the existing ones, the additional farms in the first group – farms AA, BB and CC – are created by replicating farms A, B and C. Similarly, the second group – farms DD and EE – are replicated from farms D and E. In addition, transportation resources will also increase from two to four trucks, together with an adjustment to the number of staff for truck loading. Similarly, the number of trucks transporting the packed mangoes from the middleman firm site to international markets will increase to three trucks (two for country A and another one for country B). The number of staff for the truck-loading operation will also be adjusted. Table 5.6 summarises the details of the change in the total demand scenario and the corresponding changes to the models.

Table 5.6 – Details of change in total demand scenario test

Scenario test	Change made to the model	Reason for the change	Additional resource
Change in total demand	• To increase the number of farms in the simulation model from 5 to 10	• There will be more farms to grow the fruit, thereby meeting the increases in demand, assuming the new farms are operating at the same scale of operation as the existing ones	• Farms AA, BB, CC, DD and EE are created which are replicated from farms A, B, C, D and E
	• To increase the number of trucks from 2 to 4 at the transporter	• To tie in with the increase in mangoes harvested	• 2 refrigerated container trucks
	• To increase staff for truck loading from 7 to 14 persons at the transporter	• To tie in with the increase in mangoes harvested	• 7 persons for transporter truck loading
	• To increase the number of country A trucks from 2 to 4 at the middleman firm	• To tie in with the increase in mangoes harvested	• 2 country A trucks
	• To increase the number of country B trucks from 1 to 2 at the middleman firm	• To tie in with the increase in mangoes harvested	• 1 country B truck
	• To increase staff for country A truck loading from 3 to 6 at the middleman firm	• To tie in with the increase in mangoes harvested	• 3 persons for country A truck loading
	• To increase staffs for country B truck loading from 3 to 6 at the middleman firm	• To tie in with the increase in mangoes harvested	• 3 persons for country B truck loading

5.3.1.1 Simulation results of change in total demand for exported fruits

For this scenario, it is assumed that there is no substantial change in other attributes that may result in major changes in the fresh fruit supply chain in Thailand. Only growth in total demand is considered. This scenario can be investigated using the simulation model, incorporating the cold chain designs with long-term fluctuations in demand. The simulation outcome will help determine which cold chain design could better handle changes in total demand for fruit exported from developing countries, such as Thailand, in the long run. Table 5.7 shows the outputs of the base model and the alternative models with both the individual and the consolidated cold chain designs, subject to the same change in total demand.

Table 5.7 – Comparing the base model and alternative model outputs for change in demand

KPIs (Change in total demand)	Base model	Individual cold chain (ICC)	Consolidated cold chain (CCC)
Number of Boxes	3,405	3,422	3,409
Country A Processing time (Hours)	59.55	59.54	37.58
Country B Processing time (Hours)	70.24	70.26	46.23
Operating Cost (Thai Baht)	457,752	467,189	451,390
Farms group A (A, B and C) to Country A shelf life (Days)	7.41	23.21	23.18
Farms group B (D and E) to Country shelf life (Days)	7.39	22.56	23.21
Farms group A (A, B and C) to Country B shelf life (Days)	6.96	22.77	22.74
Farms group B (D and E) to Country B shelf life (Days)	6.95	22.08	22.76
Farms group A (A, B and C) to Country A wastage (Percentage of decay)	1.28	0*	0*
Farms group B (D and E) to Country A wastage (Percentage of decay)	1.29	0*	0*
Farms group A (A, B and C) to Country B wastage (Percentage of decay)	1.51	0*	0*
Farms group B (D and E) to Country B wastage (Percentage of decay)	1.51	0*	0*

* At 15 degrees Celsius, decay of mangoes starts on the 9th day upon harvest. At 10 degrees Celsius, decay starts on the 14th day. As the cycle time of the simulated supply chains is only two to three days, there is basically little decay when the fruit reaches the market.

Apart from the increase in the number of boxes created and total operating cost, other outputs of the three models – base model, individual design, and consolidated design – under the rising demand scenario show a similar pattern as those found in the base model. This means that the alternative models, of both individual cold chain design and consolidated cold chain design, are able to handle changes in total demand for exported fruits. Nevertheless, performance of the model of consolidated cold chain design is better than that of individual cold chain design in terms of processing time and operating cost.

5.3.2 Increase in supply uncertainty

This scenario is to investigate whether the proposed cold chain designs could still operate efficiently when supply uncertainty for fruit in developing countries, such as Thailand, increases in the long term. Supply uncertainty for fresh fruit exported from Thailand is affected by inclement weather, and devastating fruit epidemics (Cooperative Promotion

Department 2014; Worasatit *et al.* 2017). For example, torrential rainfall and widespread epidemic caused by thrips affected fruit production (Aydinalp & Cresser 2008) and led to a reduction in mango supply by 20-30% in 2016 (Kehakaset 2017). In other words, annual supply of fresh mangoes can drop by an average of 25% due to weather or a plant epidemic. Using this figure as a reference and allowing for extreme situations, a decrease of 30-50% in harvested mangoes is used to create this scenario.

This scenario is simulated by introducing some perturbations to the model input in terms of entity generation, which represents the number of mangoes to be harvested. The argument is that, with the changes in supply, the harvested mangoes will also vary in number (Tiwong *et al.* 2013; Wijewickrama & Takakuwa 2005). This can happen on a regular basis, meaning that it can occur in every harvesting cycle. To mimic this random fluctuation in the simulation model, a variation in supply from 50% to 70% (see Table C.7) of the current level is created by multiplying a random factor between 0.5 and 0.7 to the hourly entities created to enter the system. Table 5.8 summarises the details of the increase in supply uncertainty scenario, and the corresponding changes to the models.

Table 5.8 – Details of increase in supply uncertainty scenario test

Scenario test	Change made to the model	Reason for the change	Additional resources
Increase in supply uncertainty	• A decrease of supply to 50% to 70% of the current level is effected by limiting the hourly entities created to enter the system (see Table C.7)	• To represent a decrease of supply to 50% to 70% of the current level	• Nil

5.3.2.1 Simulation results of increase in supply uncertainty

Under this scenario, it is assumed that only an increase in supply uncertainty is considered. Supply uncertainty can be affected by inclement weather, global climate change, and a devastating fruit epidemic (Cooperative Promotion Department 2014; Worasatit *et al.* 2017). This scenario is to explore whether the two cold chain designs were able to handle increases in supply uncertainty for fresh fruit in developing countries, such as Thailand, on a regular basis. Table 5.9 shows the output of the base model, the individual cold chain design model, and the consolidated cold chain design model, under this scenario.

Table 5.9 – Comparing between the base model and alternative model outputs for change in supply uncertainty

KPIs (Supply uncertainty)	Base model	Individual cold chain (ICC)	Consolidated cold chain (CCC)
Number of Boxes	1,023	1,025	1,015
Country A Processing time (Hours)	59.57	59.54	37.55
Country B Processing time (Hours)	70.26	70.24	46.21
Operating Cost (Thai Baht)	168,563.68	169,078.44	155,331.82
Farms group A (A, B and C) to Country A shelf life (Days)	7.46	23.27	23.16
Farms group B (D and E) to Country shelf life (Days)	7.45	22.56	23.20
Farms group A (A, B and C) to Country B shelf life (Days)	7.01	22.80	22.73
Farms group B (D and E) to Country B shelf life (Days)	7.01	22.09	22.78
Farms group A (A, B and C) to Country A wastage (Percentage of decay)	1.28	0*	0*
Farms group B (D and E) to Country A wastage (Percentage of decay)	1.28	0*	0*
Farms group A (A, B and C) to Country B wastage (Percentage of decay)	1.50	0*	0*
Farms group B (D and E) to Country B wastage (Percentage of decay)	1.50	0*	0*

* At 15 degrees Celsius, decay of mangoes starts on the 9th day upon harvest. At 10 degrees Celsius, decay starts on the 14th day. As the cycle time of the simulated supply chains is only two to three days, there is basically little decay when the fruit reaches the market.

The most significant change in model output under this scenario is the reduction in throughput and operating cost. Other outputs regarding shelf life, wastage and processing time are similar to those of the previous scenario. The findings show that the two cold chain design models can handle regular uncertainty in supply without issues, although the cold chain equipment might be under-utilised when supply is low. It appears that the two cold chain designs are not particularly costly to run when compared to the no cold chain situation, even when subject to increase in supply uncertainty for export. However, the benefits of cold chain adoption in terms of lengthened shelf life and reduced wastage still prevail, which can be critical to the competitiveness of the industry in situations of reduced supply. Again, the consolidated cold chain design performs better than the individual cold chain design under this scenario, as reflected in lower operating cost, longer shelf life, and lower processing time required.

5.3.3 Change in operating cost

This scenario is to determine whether the proposed cold chain designs are still financially viable when the operating cost for fresh fruit in developing countries, such as Thailand, increases in the long term. The increase in operating cost can be caused by rises in labour cost, fuel cost, and electricity cost. For example, wages of labour have remained unchanged for a long time in Thailand as the government has not approved an increase of the minimum wage for a long time. Then, in 2012, the Thai government passed a bill to increase the minimum wage in every province by an average of 47.67% (Siksamat 2011). This means that labour cost would increase despite that this is not happening on a regular basis. The same applies to electricity cost, which, again, seldom changes in Thailand. However, it also escalated by about 12.42% in 2016 (Electricity Tariffs and Business Division 2017). Fuel cost, on the other hand, fluctuates with global oil prices. From 2007 to 2017, fuel cost in Thailand has grown, on average, by 10.58% (Bangchak Corporation Public Company Limited 2017). These figures are used as references to create the scenario with increases in operating cost in the long run.

The scenario is represented by increasing the unit operating cost in the model. The argument is that changes in labour, fuel and electricity costs increase the total operating cost. To mimic this increase in the simulation model with some randomness, a rise of labour cost between 150% and 200% of the current level is set by multiplying a random factor (see Table C.8) to the original value in the models. Similarly, the same technique is used to increase the current levels of electricity and fuel costs between 150% and 200%. Table 5.10 summarises the details of the scenarios and the corresponding changes to the models.

Table 5.10 – Details of change in operating cost scenario test

Scenario test	Change made to the model	Reason for the change	Additional resource
Change in operating cost	• An increase of labour cost to 150% to 200% of the current level is effected by inflating the input parameter (see Table C.8) • An increase of electricity cost to 150% to 200% of the current level is effected by inflating the input parameter (see Table C.8) • An increase of fuel cost to 150% to 200% of the current level is effected by inflating the input parameter (see Table C.8)	• To represent an increase of labour cost to 150% to 200% of the current level • To represent an increase of electricity cost to 150% to 200% of the current level • To represent an increase of fuel cost to 150% to 200% of the current level	• Nil

5.3.3.1 Simulation results of change in operating cost

Under this scenario, it is assumed that there is no significant change in demand for export. Only operating cost increase is considered. This scenario attempts to explore whether the cold chain designs could handle changes in operating cost of fresh fruit supply chains in developing countries, such as Thailand, in the long term. Table 5.11 shows the outputs of the base model, the individual cold chain design model, and the consolidated cold chain design model, under this scenario.

Under this scenario, outputs of the three models show a similar pattern as those of the base model despite an increase in the total operating cost in all the models. The findings suggest that cold chain designs are performing consistently under this scenario and are not inferior to the as-is situation. In other words, the designs are relatively robust to an increase of the operating cost in the long run. It can be seen that performance of the consolidated cold chain design is, again, better than that of the individual cold chain design under this scenario, as reflected in lower operating cost and processing time.

Table 5.11 – Comparing the base model and alternative model outputs for change in operating cost

KPIs (Increase operating cost)	Base model	Individual cold chain (ICC)	Consolidate cold chain (CCC)
Number of Boxes	1,698	1,709	1,700
Country A Processing time (Hours)	59.57	59.58	37.54
Country B Processing time (Hours)	70.24	70.19	46.23
Operating Cost (Thai Baht)	366,202	377,374	352,377
Farms group A (A, B and C) to Country A shelf life (Days)	7.55	23.28	23.13
Farms group B (D and E) to Country shelf life (Days)	7.52	22.57	23.17
Farms group A (A, B and C) to Country B shelf life (Days)	7.09	22.80	22.74
Farms group B (D and E) to Country B shelf life (Days)	7.07	22.14	22.79
Farms group A (A, B and C) to Country A wastage (Percentage of decay)	1.24	0*	0*
Farms group B (D and E) to Country A wastage (Percentage of decay)	1.26	0*	0*
Farms group A (A, B and C) to Country B wastage (Percentage of decay)	1.47	0*	0*
Farms group B (D and E) to Country B wastage (Percentage of decay)	1.48	0*	0*

* At 15 degrees Celsius, decay of mangoes starts on the 9th day upon harvest. At 10 degrees Celsius, decay starts on the 14th day. As the cycle time of the simulated supply chains is only two to three days, there is basically little decay when the fruit reaches the market.

5.3.4 Summary of the simulation results under different scenarios

To summarise, the simulation results show that, when total demand for exported fruit increases, both alternative models produce the highest number of boxes of mangoes. In contrast, they produce the lowest number of boxes of mangoes when there is increase in supply uncertainty. However, the throughput of the two models in the other scenario is similar to that of the base model. It can be concluded that both alternative models are viable in the long run and perform better than the base model. This means that cold chain adoption is suitable for developing countries despite the possibilities of change in demand, supply uncertainty, and increase in operating cost in the long term. Operating cost of the model with the consolidated cold chain design, however, is lower than that of the base model and that of the individual cold chain design. Performance of the model with the consolidated cold chain design was in general the best among the three under various scenarios. Therefore, it can be concluded that the simulation results suggest that the consolidated cold chain design, which represents a low-tech low-cost approach, is most appropriate for fresh fruit supply chains in developing countries. It excels in operating cost, processing time, and shelf life, when compared with the individual cold chain design, which represents the high-tech high-cost approach.

5.4 Chapter summary

This chapter has described how cold chain adoption for the fresh mango supply chain under study was simulated by modifying the base model to incorporate two different designs, namely individual and consolidated designs. Three scenarios depicting long-term changes in demand, supply and operating costs were also generated to test the robustness of the alternative models incorporating the cold chain designs. The characteristics of the designs and scenarios, together with the rationale behind the changes, were discussed. The necessary modifications to the base model and resource requirements to effect the changes were also explained. Furthermore, this chapter has presented the simulation results of cold chain adoption using both the individual and the consolidated cold chain designs under different scenarios. The next chapter will discuss the implications of the findings.

Chapter 6

RESULTS AND DISCUSSION

Chapter 5 evaluated the alternative models with different cold chain designs for the mango supply chain under study, and presented the simulation findings in terms of performance of the base model and the alternative models under different scenarios. This chapter discusses the implications of the findings from the perspective of their contributions to knowledge and actual practice, with a view to promoting cold chain adoption in developing countries. In this regard, a proposed framework for cold chain adoption in developing countries is also presented.

6.1 High-tech high-cost approach versus low-tech low-cost approach

Previous studies have shown that cold chain adoption can address the various issues of fresh fruit supply chains in developing countries, such as high wastage, low quality, and limited shelf life. This is because, by reducing the temperature of fresh fruits and maintaining them in the same temperature condition throughout the entire supply chain, cold chain implementation can help reduce natural deterioration rate (Defraeye *et al*. 2014; Joshi, Banwet & Shankar 2011; Xu, Lan & Ruijiang 2010), preserve the quality of the fruits (Kang *et al*. 2012; Zanoni & Zavanella 2012), and extend their shelf life (Flick *et al*. 2012; Qi *et al*. 2014). However, the literature review also reveals that cold chain adoption requires heavy investment in infrastructure and technology (Kitinoja 2013; Yang *et al*. 2012). To ensure standardised practices and minimise temperature abuses along the entire supply chain, adequate technical knowledge and training for operational staff is also required (Hou, Xie & Wang 2015; Joshi, Banwet & Shankar 2009). This so-called high-tech high-cost approach is commonly adopted in developed countries, and has proven to be effective. However, it may not be appropriate for developing countries due to limitations in capital resources, knowledge and skills, as well as experience in adopting and running cold chains (Li 2006).

Studies on issues with cold chain adoption in developing countries reveal many challenges, including the high cost of applying cold chain technology, lack of infrastructure, and lack of technical knowledge (Heap 2006; Joshi, Banwet & Shankar 2009; Kitinoja 2013; Salin & Nayga

2003; Yahia 2009). These constraints hinder, to a large extent, the ability of less developed countries to invest in the latest cold chain technology. Even if developing countries could invest an enormous amount of money in cold chain infrastructure and technology, operational staff might not be able to use the infrastructure and technology in compliance with the latest cold chain protocols, due to lack of staff training (Kitinoja 2013; Yahia 2009). All these barriers suggest that, although the high-tech high-cost approach proves to be effective in developed countries, developing countries are still a long way from being able to adopt it. Obviously, an alternative way to promote cold chain adoption in developing countries has to be used to overcome the initial hurdles. When cold chain adoption in the developing countries becomes widespread, with an accumulation of knowledge, skills and experience, the high-tech high- cost approach could then be gradually adopted to advance cold chain implementation to the next stage.

Previous studies show that there are alternative cold chain technologies that are more suitable for developing countries. These include portable forced air cooling and CoolBot^{TM}-equipped walk-in cold rooms, which are simpler in design, easier to use, and less expensive than many high- cost cold chain technologies, such as vacuum cooling and mechanical refrigeration (Dubey 2011; Global Cold Chain Alliance 2016; Kitinoja 2013; Kitinoja & Thompson 2010). Furthermore, there are studies suggesting a shift of focus in developing countries from infrastructure and technology to other attributes of cold chain adoption. It is contended that operating cost of a cold chain can be reduced with improvements in service quality through collaboration among the supply chain members and reduction in lead time through integration of logistics activities (AT Kearney Limited 2005; Billiard 2003; Lan, Liu & Wang 2010; Lan *et al.* 2014; Qiu *et al.* 2009).

Based on the findings of previous research, the present study contends that, to promote cold chain adoption in developing countries where capital resources and technical knowledge and skills are relatively scarce, the high-tech high-cost cold chain adoption approach commonly used in developed countries is not appropriate. In contrast, an alternative approach that utilises other resources and the flexibility of work practices through collaboration among supply chain members might be more suitable. Such an arrangement can be regarded as a low-tech low-cost approach which leverages cheap labour, changes in work practices, and the use of proven and less-expensive technologies to serve the purpose. In developing countries, such as Thailand, power within a fresh fruit supply chain is often asymmetrical (Bijman 2008; Dolan & Humphrey 2000; Matopoulos *et al.* 2007). The middleman company, being the one with the most abundant resources to drive the entire supply chain, usually has the greatest power over other supply chain members such as farmers, processors and transporters. Therefore, without much difficulty, the middleman company can arrange and facilitate collaboration among supply chain members for the benefit of all parties (Vellema *et al.* 2005). In addition, instead of using expensive state-of-the-art cold chain technology and equipment, fresh fruit supply chains in developing countries can invest in economical, simple and robust cold chain technologies, such as portable-forced air cooling and the CoolBot^{TM}-equipped walk-in cold room. Simulation results suggest that such a low-tech low-cost approach is completely feasible and excels in performance when compared with the high-tech high-cost approach focusing on investment in infrastructure and technologies.

6.2 Findings of the simulation study

Table 6.1 (second and third columns) shows the output of the base model in five areas, throughput, processing time, operating cost, product shelf life, and wastage, compared with the actual system. All the outcomes are close to the actual performance, at 99% significance level, meaning that the base model is representative of the actual situation. Therefore, the base model can be used to explore the various cold chain designs under various scenarios, in order to identify the appropriate cold chain design for fresh fruit supply chains in developing countries.

Table 6.1 – Comparison of simulation results with actual performance

KPIs	Actual	Base model	Alternative model with high-tech high-cost design	Alternative model with low-tech low-cost design
Throughput (Boxes)	• About 1,700	• About 1,700 **	• Same as base model	• Same as base model
Processing time (Days per cycle)	• Three	• Three**	• Three	• Two
Operating cost (Thai Baht per cycle)	• About 243,589	• About 241,817 **	• About 247,220	• About 233,478
Shelf life (Days)	• 6-7	• About 7**	• About 22	• About 23
Wastage (Percentage)	• 1.2 – 1.4	• 1.2 – 1.4 **	• Basically zero*	• Basically zero*

** Significant at $\alpha = .01$

*At 15 degrees Celsius, decay of mangoes starts on the 9th day upon harvest. At 10 degrees Celsius, decay starts on the 14th day. As the cycle time of the simulated supply chains is only two to three days, there is basically little decay when the fruit reaches the market.

Next, the base model was used to create the alternative cold chain designs which were established based on a comprehensive literature review. The cold chain design can be classified into two groups: (1) individual cold chain design (which can be seen as a high-tech high-cost approach), and (2) consolidated cold chain design (which can be seen as a low-tech low-cost approach). Individual cold chain design refers to the adoption of cold chain technologies by all members of the supply chain separately. Consolidated cold chain design is about collaboration among supply chain members by sharing cold chain technology and infrastructure among participants. The simulation results in Table 6.1 (fourth and fifth columns) show that, regardless of design, cold chain adoption is desirable because it can improve the fresh fruit supply chain performance. For example, the implementation of cold chain in both designs helps increase the period of shelf life by almost three times and decrease the percentage of wastage to almost zero, compared with the no cold chain situation. Therefore, it can be concluded that cold chain adoption is a way to address fresh fruit supply chain issues in developing countries.

The objective of this study is to find an appropriate approach to cold chain design for fresh fruit supply chains in developing countries. The simulation results in Table 6.1 show that product shelf life of the cold chain using the low-tech low-cost design is slightly longer than that of the high-tech high-cost design. In addition, operating cost and processing time of the low-tech low-cost design are also lower than those of the design using the high-tech high-cost approach. This means that the low-tech low-cost approach to cold chain design is preferable for developing countries.

Next, this study investigated the robustness of the cold chain designs in the long run by running three scenario tests that could happen in the future. These comprise change in total demand for exported fruits, increase in supply uncertainty, and change in operating cost. Table 6.2 compares the model outputs of the high-tech high-cost approach and low-tech low-cost approach under the different scenarios.

Table 6.2 – Comparison of simulation results between the high-tech high-cost approach and the low-tech low-cost approach under different scenarios

KPIs	**Change in total demand for exported fruits**		**Increase in supply uncertainty**		**Increase in operating cost**	
	High-tech high-cost	Low-tech low-cost	High-tech high-cost	Low-tech low-cost	High-tech high-cost	Low-tech low-cost
Throughput (Boxes)	About 3,400	About 3,400	About 1,000	About 1,000	About 1,700	About 1,700
Processing time (Days per cycle)	Three	Two	Three	Two	Three	Two
Operating cost (Thai Baht per cycle)	About 467,189	About 451,390	About 169,078	About 155,332	About 377,374	About 352,377
Shelf life (Days)	About 22	About 23	About 22	About 23	About 22	About 23
Wastage (Percentage)	Basically zero*	Basically zero*	Basically zero*	Basically zero*	Basically zero*	Basically zero*

*At 15 degrees Celsius, decay of mangoes starts on the 9th day upon harvest. At 10 degrees Celsius, decay starts on the 14th day. As the cycle time of the simulated supply chains is only two to three days, there is basically little decay when the fruit reaches the market.

The simulation results in Table 6.2 again show that the model using a low-tech low-cost design performs better than the one with a high-tech high-cost design, in processing time, operating cost, and shelf life, under various situations, such as increase in total demand for exported fruits, growth in supply uncertainty, and increase in operating cost. The simulation results provide empirical evidence to support the argument that cold chain adoption for fresh fruit supply chains in developing countries using the low-tech low-cost approach is feasible and preferable. In the next section, some critical implications of the findings from both the academic and the managerial perspectives will be discussed.

6.3 Theoretical implications

The findings of the present study state that cold chain adoption is the right approach for a fresh fruit supply chain because it can address various issues, such as reducing wastage and increasing shelf life. However, as the literature reveals, the high-tech high-cost cold chain approach that is normally used in developed countries predominantly focuses on the use of state-of-the-art technology. This approach might not be appropriate for developing countries due to limitations in capital resources and cold chain knowledge. Therefore, this study proposes the use of an alternative way to implement a cold chain. This so-called low-tech low-cost approach emphasises collaboration among supply chain members, changes in work practices, and the use of less expensive cold chain technology. The simulation outcomes show that the low-tech low-cost approach is feasible and performs better than the high-tech high-cost approach (see Table 6.1 and Table 6.2). The outcome of this study thus opens up a new direction for research on how to optimise the low-tech low-cost cold chain approach to generate the maximum benefit and to promote cold chain adoption in developing countries.

Secondly, the simulation outcomes corroborate the suitability of using the network theory (NT) and the theory of constraints (TOC) to underpin cold chain adoption and, in particular, the consolidated cold chain design. NT accounts for the collaboration among supply chain members, and the TOC explains the investment in resources needed to overcome the constraints. This research is among the first attempts to explore alternative cold chain designs in developing countries, and does so from two different theoretical perspectives. Results of the study suggest that the two theories chosen for this study are appropriate. For example, the simulation results indicate that working together and changing work practices to tie in with cold chain adoption can improve efficiency. In addition, investment in cold chain technologies that are affordable and effective but not necessarily expensive and state-of-the-art can still achieve the purpose of overcoming the constraints in temperature control along the entire fresh fruit supply chain, leading to improvement of performance in waste reduction and extension of shelf life.

6.4 Practical implications

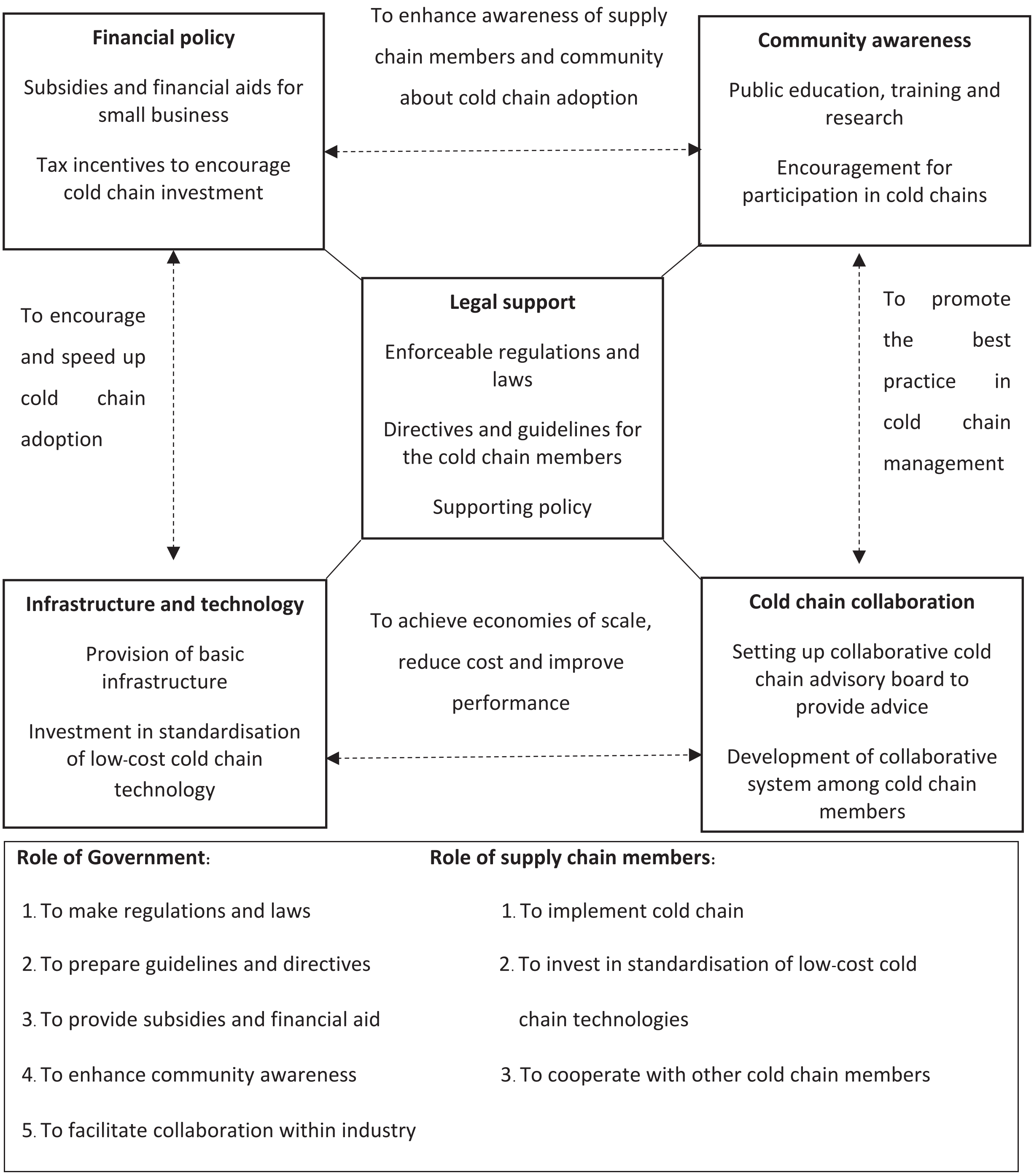
The findings in this research have numerous managerial implications for business organisations and governments of developing countries in cold chain adoption for the fresh fruit industry. Firstly, the study provides empirical evidence on the benefits of cold chain adoption using a low-tech low-cost approach. It shows to decision makers that such an approach can help promote cold chain adoption in developing countries, thereby bringing great value to industries. The findings could be used as a guide for developing best practices for setting up fresh fruit cold chains in developing countries.

Secondly, the findings of this study show that, while the low-tech low-cost cold chain design is a feasible approach for fresh fruit supply chains in developing countries, successful implementation still requires strong support by the government as well as business organisations. These supports are needed to overcome many obstacles, including initial capital investment, low awareness, knowledge and skill transfer, legislation to ensure sharing of rewards and risks, and issues associated with collaboration. In this regard, this study proposes a framework in the next section to assist supply chain members and the governments of developing countries in formulating appropriate strategies for cold chain implementation in fresh fruit supply chains.

6.5 A framework for cold chain adoption in developing countries

Based on the simulation outcomes, it can be concluded that the low-tech low-cost approach to cold chain adoption is the preferred option for the fresh fruit industry in developing countries. To promote cold chain adoption in developing countries, supply chain members and governments need to work together to remove the obstacles to cold chain adoption identified in Chapter 2. These include high cost (Joshi, Banwet & Shankar 2009; Maxwell Agyapong 2013; Yahia 2009), lack of equipment (Greis 2011; Joshi *et al.* 2012; Salin & Nayga 2003), lack of knowledge and training (Bledsoe 2009; Li 2006; Yahia 2009), lack of awareness

(Joshi, Banwet & Shankar 2009; Stephen 2009), lack of collaboration (Joshi, Banwet & Shankar 2009; Negi & Anand 2015; Wang & Zhang 2008), and lack of government support (Jing & Jian 2015; Shane 2016). Following the approach taken by Lau and Wang (2009) to formulating strategies for promotion of reverse logistics in China, the present study proposes some managerial guidelines for cold chain adoption in developing countries which are entirely based on the findings of the study. Aiming to remove barriers to the adoption of cold chains in developing countries, these guidelines comprise five dimensions: financial policy, infrastructure and technology, community awareness, cold chain collaboration, and legal support. Financial policy refers to the mitigation of the high-cost challenge through financial support from the government. Infrastructure and technology refers to solving equipment issues through the use of proven and relatively less expensive technology. Community awareness refers to the removal of awareness barriers through the provision of knowledge and training. Cold chain collaboration refers to overcoming the collaboration obstacle through coordinated restructuring of the supply chain, led by the focal company. Legal support refers to the strengthening of government support through development of relevant policies and subsidies. A framework to promote cold chain adoption in developing countries is presented in Figure 6.1.



Role of Government:

1. To make regulations and laws
2. To prepare guidelines and directives
3. To provide subsidies and financial aid
4. To enhance community awareness
5. To facilitate collaboration within industry

Role of supply chain members:

1. To implement cold chain
2. To invest in standardisation of low-cost cold chain technologies
3. To cooperate with other cold chain members

Source: Adapted from Lau and Wang (2009)

Figure 6.1 – A proposed framework for accelerating cold chain logistics development in developing countries

6.5.1 Financial policy

Unlike in developed countries, cold chain adoption for the fresh fruit industry in developing countries, such as Thailand, is still not widespread, due to the high cost of cold chain equipment such as pre-cooling, cold storage facilities and refrigerated trucks (Joshi, Banwet & Shankar 2009; Stephen 2009; Zeng & Yu 2011). According to International Trade Administration (2016), cost is the most challenging obstacle for cold chain adoption in developing countries. For example, the costs of temperature-controlled vehicles and warehouses are three to five times those of normal warehouses and vehicles for dry products in both developed and developing countries (Wang & Luo 2012). To implement cold chains in developing countries, governments can support the sourcing of funds for small businesses to invest in cold chain technology (Ji & Guo 2009; Joshi, Banwet & Shankar 2009; Kitinoja 2013; Yang *et al*. 2012). In addition, governments may introduce supporting policy that is beneficial to cold chain members. For example, the government could introduce a policy to reduce taxes for those supply chain members who are willing to invest in cold chain technology and infrastructure (Joshi, Banwet & Shankar 2009; Li 2006). Therefore, small businesses would have the funding to invest in cold chain technology and infrastructure, which will expedite cold chain adoption in developing countries.

6.5.2 Infrastructure and technology

Developing countries are not successful in cold chain adoption at the moment due to a lack of cold chain infrastructure and technology (Joshi, Banwet & Shankar 2009; Wang & Luo 2012; Xie & Zhao 2016). Cold chain infrastructure can be categorised into two parts. The first part is internal infrastructure, which includes pre-cooling technologies, cold storage, and refrigerated transportation. The second part is external infrastructure, which relates to road conditions, and the availability of power and ports (Negahban & Smith 2014). The lack of cold chain technology and infrastructure can cause a cold chain to break. Cold chain breakage can quickly lead to fruit spoilage and deteriorated cold chain performance (Australian Food and Grocery Council 2013; Joshi *et al*. 2012). To take India as an example, the lack of cold chain technology and infrastructure has led to a 40% loss of agricultural produce (Bharti 2014; Negi

& Anand 2015). To remedy such a situation, the government, together with the middleman companies, should invest in cold chain infrastructure and technology related to pre-cooling, cold storage and temperature-controlled transportation for small-size fresh fruit supply chain members (Joshi, Banwet & Shankar 2009; Kitinoja 2013; Li 2006), because they are the ones who have the greatest difficulties in sourcing the necessary funds. It is very important that the government should assist them in overcoming the initial difficulties. Furthermore, the government and the middleman companies should invest in the standardisation of low-cost cold chain technology and share the technology with other supply chain members to lessen the financial issues and to achieve economies of scale (Global Cold Chain Alliance 2016; Kitinoja 2013). In addition, governments should provide public infrastructure, such as roads, electricity, and ports, to support the operation of the cold chain for fresh fruit supply chains in developing countries to help improve cold chain efficiency (Kitinoja 2013; Kuo & Chen 2010; Sharma & Pai 2015; Yahia & Smolak 2014). In doing so, cold chain infrastructure and technology in developing countries will gradually increase in usage and maturity.

6.5.3 Community awareness

Hindrance to cold chain adoption due to lack of awareness can be categorised into two groups: (1) lack of awareness of using cold chain; and (2) lack of knowledge and training for staff to maintain continuous cold chain operation (Hou, Xie & Wang 2015; Joshi, Banwet & Shankar 2009; Viswanadham 2006). Generally speaking, a cold chain process involves extremely labour-intensive work, including many tasks taken care of by handlers, such as carrying the products, monitoring the product quality, and preparing paperwork. The efficiency of the handlers determines the flow of the products during handling activities, such as transit and storage, which has a major impact on the effectiveness of a cold chain. It is very important to have well-trained staff to handle these tasks (Bharti 2014; Sharma & Pai 2015). In this regard, the government should offer crucial services, such as education, to enhance awareness of the handlers about cold chain operation (Yahia & Smolak 2014). For example, the government can organise and introduce education programs at every level, including primary, secondary and higher education, to promote the value of cold chains (Drame &

Meignien 2016; Kitinoja 2013; Yang *et al*. 2012). Given time, public awareness about the benefits of cold chains will increase, which will certainly benefit cold chain implementation. Furthermore, the government can also provide instructions for appropriate cold chain adoption and prepare guidelines for all levels of industry (Stephen 2009). This is critical to ensuring constant temperature control across the entire chain, as cold chain staff know the best practices and standards of cold chain management (Global Cold Chain Alliance 2016). The government should also support research and development of appropriate low-cost cold chain technologies, such as low-cost precooling technology, focusing on the needs of small businesses (Drame & Meignien 2016; Yahia & Smolak 2014). To increase the chances of success in cold chain adoption, the fresh fruit industry should work together with the government to provide training to new adopters based on the successful experiences of large businesses. This is especially critical to helping small businesses or SMEs understand the best practices in cold chain implementation (Global Cold Chain Alliance 2016; Jie 2010). Fresh fruit supply chain members will then be aware of the benefits and the proper process of the cold chain operation, which will lead to widespread cold chain adoption in the long run.

6.5.4 Cold chain collaboration

Lack of proper collaboration planning among companies in a supply chain to manage the flow of goods can be an issue in cold chain implementation in developing countries. This is because the companies will be unable to ensure consistent temperature control throughout the entire cold chain process (Joshi, Banwet & Shankar 2009; Negi & Anand 2015; Wang & Zhang 2008). Such lack of collaboration can cause serious negative impacts on cold chain performance. Therefore, it is necessary to have coordinated cold chain logistics control to ensure that the products are at appropriate temperatures throughout the entire process (Ko *et al*. 2015; Runzhou 2014; van der Hulst 2004). To ensure success, the government should function as an organiser to assist industry in establishing collaborative cold chain logistics systems. It could set up a collaborative advisory board to provide information and advice to supply chain members on collaborative cold chain adoption. The purpose of this is to enhance cold chain performance and decrease operating cost for small businesses, through proper collaboration planning and economies of scale by sharing cold chain technology and infrastructure among supply chain members (Jie 2010; Joshi, Banwet & Shankar 2009; Yang *et al*. 2012). In addition, industries can work together with cold chain partners and companies on integration of policies and action plans in order to ensure a continuous cold chain (Sharma & Pai 2015; Yahia & Smolak 2014). For example, a cooperative conference of all the partners of a cold chain, held at regular intervals, may be beneficial to overcoming issues arising from misaligned operations (Joshi, Banwet & Shankar 2009). Cold chain members can also set up alliances with other cold chain logistics companies to share basic facilities or resources, which can increase the competitiveness of all the participating parties (Jie 2010; Li 2006). Therefore, with proper planning and initiatives, cold chain collaboration among supply chain members in developing countries can be achieved, leading to improved cold chain performance.

6.5.5 Legal support

As previous studies revealed, one of the major barriers to cold chain logistics in developing countries is the lack of comprehensive laws and regulations to support cold chain development (Jing & Jian 2015; Joshi, Banwet & Shankar 2009; Shane 2016). Cold chain members need to comply with regulations that are specific to various aspects, such as transfer of fresh fruit products and safety. Consequently, impacts of laws and regulations on cold chain adoption cannot be overlooked (Sharma & Pai 2015). To remedy the situation, the government should provide legal support, such as legislation to promote, control, and standardise cold chain logistics practices (Global Cold Chain Alliance 2016; Joshi, Banwet & Shankar 2009; Viswanadham 2005; Yahia & Smolak 2014). For example, the government could set up stringent regulations to regulate cold chain members, such as farms, processors, transporters and middleman companies, to enable temperature control along the entire supply chain (Li 2006). Regulations and laws also should be developed based on standards that align with national food security policies and adopted by international markets (Global Cold Chain Alliance 2016; Yahia & Smolak 2014). In addition, the government should introduce beneficial policies to support the needs of the fresh fruit industry. For example, the government can set up regulations and play the role of facilitator or coordinator to promote the sharing of risks and duties among cold chain members (Jie 2010; Kitinoja 2013; Yahia & Smolak 2014).

To promote the development of cold chain logistics in developing countries, attempts need to be made to encourage financial support from the government, investment in cold chain technology and infrastructure by the government and middleman companies, increased awareness of the public through education, knowledge and skill training to cold chain members, improved collaboration among businesses, and introduction of legislation beneficial to supply chain members for cold chain development. However, to be successful, each dimension has to link together with other dimensions. For example, beneficial financial policies introduced by the government can increase the tendency for cold chain technology and infrastructure investment by supply chain members. This is because, generally speaking, cold chain technology requires a significant amount of money for investment. It is very difficult for small businesses to invest in cold chain infrastructure and technology without supporting financial aid from the government. Moreover, investment in cold chain infrastructure and technology can lead to an increased tendency for cold chain collaboration, because cold chain collaboration cannot take place if the supply chain members have no cold chain infrastructure and equipment. Cold chain collaboration also supports further investment of infrastructure and technology when cold chain members obtain the benefits from collaboration, such as reducing operating cost and improving performance. In addition, cold chain collaboration promotes public awareness. As companies are aware of the benefits of cold chain collaboration, they would like to understand and follow the process of successful cold chain collaboration. Public awareness also promotes cold chain collaboration because, with adequate cold chain education or training, people would become aware how to implement the process and benefit from cold chain collaboration. Next, public awareness can support financial policy, because education will increase knowledge of supply chain members about the benefits of cold chain adoption. Then, they will be more interested in obtaining financial aid from the government to invest in cold chain infrastructure and technology. Without understanding the benefits of cold chains, people may not be interested in investing in cold chain technology, even when the government provides financial support for cold chain investment. Financial policy can also impact on community awareness. For example, tax incentive policies to encourage cold chain investment may increase public awareness about the importance of a cold chain to supply chain members. Lastly, all the four dimensions, namely financial policy, infrastructure and technology, cold chain collaboration, and community awareness, need to be supported by regulations, laws and government policies which act like glue holding the other four tightly together. Without the support of relevant laws and regulations, a cold chain implemention might not be successful. Tax incentive policy, provision of necessary infrastructure, provision of advice on cold chain collaboration from the government, and provision of public education and training, are all important as they are linked together.

The success of all these improvements depends on the support from the government and the supply chain members. There are several roles that the government and the supply chain members should take. To begin with, it is essential that the government should introduce enforceable cold chain regulations and laws and provide guidelines and directives for the supply chain members as soon as possible (Global Cold Chain Alliance 2016; Sharma & Pai 2015). A government should provide financial aid to small businesses to help them implement the initiatives of cold chain infrastructure and technology (Ji & Guo 2009; Kitinoja 2013). The government should also enhance community awareness of cold chains through education and training (Jie 2010; Yang *et al*. 2012). It should also set up collaborative cold chain advisory boards to provide advice to the supply chain members and facilitate collaboration among them (Ji & Guo 2009; Yang *et al*. 2012). On the other hand, middleman companies with more resources and stronger capabilities should take the lead in investing in cold chains, setting the direction for small businesses, such as farms, processors, and transporters (Lau & Wang 2009). Supply chain members should invest in the standardisation of cold chain technologies, because they can collaborate by sharing cold chain technology with other cold chain members (Ji & Guo 2009). Lastly, supply chain members should be willing to cooperate with other cold chain members to ensure an unbroken cold chain and improve cold chain performance (Joshi, Banwet & Shankar 2009).

6.6 Conclusion

In summary, this study contends that simulation outcomes support the use of cold chain adoption for the fresh fruit industry in developing countries, because of the resulting extension of shelf life and reduction in wastage and processing time. This study has explored two cold chain designs based on the findings of previous studies. The simulation results show that, in general, consolidated cold chain design (which can be seen as a low-tech low-cost approach) is more beneficial than individual cold chain design (which can be seen as a high-tech high-cost approach). The superior performance of the consolidated design persists under various scenarios, which include change in total demand for exported fruits, increase in supply uncertainty, and increase in operating cost in the long run. These findings support the arguments of previous studies on the benefits of collaboration (AT Kearney Limited 2005; Joshi, Banwet & Shankar 2009; Lan *et al*. 2014; Salin & Nayga 2003; Sharma & Pai 2015), change in work practices for reducing processing time (Qiu *et al*. 2009; Zhu *et al*. 2014), and using more economical cold chain technology (Dubey 2011; Kitinoja 2013) for cold chain design. The present thesis contends that collaboration and change in work practices can play a primary role in cold chain design for the fresh fruit industry in developing countries. This is supported by the sharing of infrastructure and the use of proven and less-expensive cold chain technologies without the need for excessive knowledge and skills. With the significant hurdles in cold chain adoption being overcome using the aforementioned arrangement, it is considered that cold chain adoption in the fresh fruit industry in developing countries can be promoted and expedited. Once the necessary capital resources and knowledge and skills for the use of more sophisticated cold chain technologies are available, the high-tech high-cost approach can then be adopted to further enhance operational efficiency and responsiveness.

6.7 Chapter summary

This chapter has discussed the implications of the research findings and confirmed the feasibility of using the low-tech low-cost approach to implement cold chains for the fresh fruit industry in developing countries, such as Thailand. To put the proposed approach into practice, a framework to expedite the development of cold chain adoption in developing countries using the low-tech low-cost approach was also presented and discussed. The following chapter will conclude the study by discussing the contributions of the study and pointing out its limitations as well as the directions for future research.

Chapter 7

CONCLUSION

The previous chapters provided the justification for the study, stated the research problem and questions, reviewed the relevant literature, described the methodology adopted, presented the findings and discussed their implications. This chapter provides a conclusion to the study and highlights the contributions of this research from both the academic and the management perspectives. Lastly, limitations of the study and directions for future research in this field are discussed.

7.1 Conclusions

Cold chain adoption is a well-recognised practice in developed countries, such as the USA and EU countries, for fresh fruit supply chains to lengthen shelf life and reduce wastage. However, due to hot weather and lack of cold chain management, fresh fruit supply chains in many developing countries suffer from issues such as short shelf life, high wastage, and low quality. Implementation of cold chains in developing countries is limited because of the high cost of cold chain technology, lack of equipment and infrastructure, inadequate knowledge and training, lack of collaboration, and absence of government support. To promote cold chain adoption in developing countries, this study examined an alternative cold chain design for fresh fruit supply chains by borrowing insights from the theory of constraints (TOC) and network theory (NT). A discrete-event simulation methodology was employed to model the operation of an existing typical mango supply chain in Thailand, a developing country, comprising five farms, three processors, one transporter, and one middleman company, as a case study. Verification and validation techniques, namely process maps, 2D animation, and the simulation software debugger, were used to compare the output from the simulation model against that of the real system. Statistical tools and sensitivity analysis were also used to validate the representativeness of the base model to the actual situation. Upon validation, the base model was used to explore the alternative cold chain designs.

Extant studies on cold chain designs suggest that there are two groups of cold chain design: (1) individual cold chain design (which can be seen as a high-tech high-cost approach); and (2) consolidated cold chain design (which can be seen as a low-tech low-cost approach). Individual cold chain design, which is often found in developed countries, refers to the adoption of cold chain technology by each member of the supply chain. Consolidated cold chain design refers to the sharing of cold chain technologies, infrastructure and knowledge among supply chain members so as to overcome the entry barrier. Through discrete-event simulation, this study incorporated the two designs in the simulation model and compared their performance using common key performance indicators, namely throughput, processing time, operating cost, shelf life, and wastage. The findings indicate that cold chain adoption can help improve the performance of the existing fresh fruit supply chain under study in terms of extended shelf life and reduced wastage. The simulation results also reveal that, regardless of design, the fresh fruit supply chain under study performs better with cold chain adoption than without, in the long term. Furthermore, when comparing the performance of two alternative cold chain designs, the simulation outcomes suggest that consolidated cold chain design is more appropriate for developing countries than individual cold chain design. The simulation results also show that the consolidated cold chain design is robust in the long run when subject to fluctuations in demand and other uncertainties.

The research findings suggest that the journey to cold chain adoption for the fresh fruit industry in developing countries such as Thailand using a high-tech high-cost cold chain approach will be a long one. Many barriers, such as high start-up cost, lack of infrastructure and technology, and lack of knowledge, have to be overcome. Therefore, an advanced cold chain leveraging state-of-the-art technologies, as found in developed countries, cannot be accomplished in the short term. It is considered that a low-tech low-cost cold chain approach is the most feasible transitional arrangement for cold chain development in developing countries, until they have accumulated, in time, the necessary resources, knowledge and experience for adopting the high-tech high-cost approach.

To promote the low-tech low-cost cold chain adoption approach in developing countries, this study also proposed a framework to serve as a guide for governments and the supply chain members in developing countries to develop cold chain management for fresh fruit industries.

In the following section, the contributions of the present study, from both the academic and the managerial perspectives, will be discussed.

7.2 Academic contributions

The outcomes from this thesis have several significant academic implications. Firstly, the most important contribution the present study makes to the literature in the area of cold chain adoption is that it opens up a new scope for cold chain design in developing countries by leveraging technology, collaboration and changes in work practices.

Secondly, the simulation outcomes of this study corroborate the use of the theory of constraints (TOC) and the network theory (NT) as underpinning theories for the study of cold chain adoption. This is because the success of the alternative cold chain design relies very much on supply chain members working together and sharing resources to overcome constraints. The two underpinning theories account for these mutually beneficial behaviours among supply chain members, which are not uncommon in developing countries.

7.3 Managerial contributions

Firstly, this study provides empirical evidence to support the use of a low-tech low-cost approach to cold chain adoption for fresh fruit supply chains in developing countries. From a managerial perspective, collaboration and change in work practices are relatively more feasible than is capital investment, in developing countries with limited financial resources. This is in contrast to the heavy reliance on cold chain technologies in developed countries.

Secondly, the research findings could also assist supply chain members and governments in formulating appropriate strategies for cold chain adoption for fresh fruit supply chains in developing countries, to address the issues of short shelf life, high wastage, and low quality of fruit.

7.4 Limitations of the study

Despite the contributions this research has made to the literature on fresh fruit cold chains, there are several limitations of the study that need to be noted. Firstly, the scope of this study is confined to the upstream and the midstream of the investigated fresh fruit supply chain.

The system boundary is from farm to international markets in different countries. Downstream logistics, *i.e.*, how the fresh fruits are handled after reaching the markets, is not included in this study. As cold chain implementation should be from end to end, *i.e.*, from farms to consumers, research analysing alternative cold chain designs that includes all stages would be valuable.

Secondly, this research used a mango supply chain as case study. Although the concept of low-tech low-cost cold chain adoption should be applicable to other supply chains, the outcomes may not be generalisable to certain other industries, such as pharmaceutical products, meat and flowers. In this regard, future studies could use other supply chains as samples to investigate whether the alternative cold chain design is appropriate for other industries.

7.5 Directions for further research

Despite the above limitations, this research assists as a reference point to guide upcoming study in the field of cold chain adoption.

The concept of a low-tech low-cost approach should be applicable to most developing countries, in particular Asia, because the lifestyle and weather are more or less the same throughout the region. Therefore, future research might repeat this study in other developing countries in the region, such as Vietnam, Malaysia, and Indonesia, to compare with the results of the present research. The purpose is to gain more evidence to support the proposed approach and generalise the applicability of the low-tech low-cost approach to all developing countries.

Another direction for future study is to use other simulation methodologies to investigate cold chain adoption in developing countries. Since the low-tech low-cost approach relies very much on collaboration among supply chain members involving behaviourial interactions, it can be simulated using agent-based simulation to investigate how agents can work in the negotiation between supply chain members. As government plays a vital role in formulating policies to help communities in developing countries in various aspects to implement cold chain, future study could also use a system dynamic simulation technique to investigate the effectiveness of various policies for cold chain adoption.

7.6 Chapter summary

This chapter concluded the study by highlighting the academic and the managerial contributions of the outcomes of the present study. It also identified the limitations of the study, and recommended several directions for future research.

REFERENCES

AT Kearney Limited 2005, *China cold chain Is heating up*, AT Kearney Limited, Illinois.

Abad, E, Palacio, F, Nuin, M, Zárate, AGd, Juarros, A, Gómez, JM & Marco, S 2009, 'RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain', *Journal of Food Engineering*, vol. 93, no. 4, pp. 394-9.

Abed, SY, Mastorakis, N, Mladenov, V, Bojkovic, Z, Simian, D, Kartalopoulos, S, Varonides, A, Udriste, C, Kindler, E & Narayanan, S 2008, 'Improving productivity in food processing industries using simulation- a case Study', paper presented to 12th WSEAS International Conference on SYSTEMS, Heraklion, Greece, 22-24 July, 2008.

Abou-Aziz, AB, El-Nataway, SM, Adel-Wahab, FK & Kader, AA 1976, 'The effect of storage temperature on quality and decay percentage of 'Pairi'and 'Taimour'mango fruit', *Sci. Hortic*, vol. 5, no. 1, pp. 65-72.

Ahumada, O & Villalobos, JR 2009, 'Application of planning models in the agri-food supply chain: A review', *European Journal of Operational Research*, vol. 196, no. 1, pp. 1-20.

Altiok, T & Melamed, B 2007, *Simulation modeling and analysis with Arena*, Academic press, San Diego.

Alzahrani, MJ 2011, 'Using modeling and simulation to improve oral health services delivery in Hampton Roads, Virginia', PhD thesis, Old Dominion University, Virginia.

Anjum Asim Shahid Rahman Limited 2009, *Establishment of cool chain system along the national trade corridor under public private partnership preliminary information memorandum*, Grant Thornton International Limited, Islambad.

Arduino, G & Parola, F 2010, 'Cold chain in the shipping industry: Bulk versus container in the banana trade', paper presented to 12th WCTR World Conference on Transport Research, Lisbon, Portugal, 11-15 July, 2010.

Asadi, G & Hosseini, E 2014, 'Cold supply chain management in processing of food and agricultural products', *Sci. Pap. Ser. D Anim. Sci*, vol. 57, pp. 223-7.

Aswaney, M 2007, 'Forced-air precooling of fruits and vegetables', *Air Conditioning Refrig J*, pp. 57-62.

Aung, MM & Chang, YS 2014, 'Temperature management for the quality assurance of a perishable food supply chain', *Food Control*, vol. 40, pp. 198-207.

Aung, MM, Chang, YS & Kim, WR 2012, 'Quality monitoring and dynamic pricing in cold chain management', *International Journal of Industrial and Manufacturing Engineering*, vol. 6, no. 2, pp. 454-8.

Australian Food and Grocery Council 2013, *Australian cold chain guidelines for food 2013*, Australian Food and Grocery Council, Australia.

Axelsson, B & Easton, G 1992, *Industrial networks: a new view of reality*, Routledge, London.

Aydinalp, C & Cresser, MS 2008, 'The effects of global climate change on agriculture', *Am Eurasian J Agric Environ Sci*, vol. 3, no. 5, pp. 672-6.

Balci, O 1998, 'Verification, validation, and testing', in J Banks (ed.), *Handbook of simulation*, Wiley, New York, pp. 335-93.

Bangchak Corporation Public Company Limited 2017, *Historical retail oil prices*, Bangchak Corporation Public Company Limited, Viewed 22 July 2017, <https://www.bangchak.co.th/th/OilPrice/>.

Banks, J 1998, *Handbook of simulation: principles, methodology, advances, applications, and practice*, John Wiley & Sons, New York.

Banks, J, Carson, JS, Nelson, BL & Nicol, DM 2010, *Discrete-event system simulation*, Prentice Hall, New Jersey.

Bharti, MA 2014, 'Examining market challenges pertaining to cold chain in the frozen food industry in Indian retail sector', *Journal of Management Sciences and Technology*, vol. 2, no. 1, pp. 33-40.

Bijman, J 2008, *Contract farming in developing countries: An overview*, Wageningen University, Netherlands.

Billiard, F 2003, 'New developments in the cold chain: Specific issues in warm countries', *Ecolibrium*, vol. 7, pp. 10-4.

Bishara, RH 2006, 'Cold chain management-an essential component of the global pharmaceutical supply chain', *American Pharmaceutical Review*, vol. 9, no. 1, pp. 105-9.

Bishop, C 2013, *Cold chain and postharvest sector in Pakistan Final report for the agribusiness project*, the United States Agency for International Development, USA.

Blanco, AM, Masini, G, Petracci, N & Bandoni, JA 2005, 'Operations management of a packaging plant in the fruit industry', *Journal of Food Engineering*, vol. 70, no. 3, pp. 299-307.

Bledsoe, G 2009, *Cold chain and storage action plan*, United States Agency for International Development, USA.

Bogataj, M, Bogataj, L & Vodopivec, R 2005, 'Stability of perishable goods in cold logistic chains', *International Journal of Production Economics*, vol. 93–94, pp. 345-56.

Bouzada, MAC 2009, 'Scenario analysis within a call center using simulation', *Journal of Operations and Supply Chain Management*, vol. 2, no. 1, pp. 89-103.

Brecht, J, Sargent, S, Kader, A, Mitcham, E, Maul, F, Brecht, P & Menocal, O 2010, *Mango postharvest best management practices manual*, Gainesville: Univ. of Fla. Horticultural Sciences Department, USA.

Bruckner, S, Albrecht, A, Petersen, B & Kreyenschmidt, J 2012, 'Influence of cold chain interruptions on the shelf life of fresh pork and poultry', *International Journal of Food science & technology*, vol. 47, no. 8, pp. 1639-46.

Bueno-Solano, A & Cedillo-Campos, MG 2014, 'Dynamic impact on global supply chains performance of disruptions propagation produced by terrorist acts', *Transportation Research Part E: Logistics and Transportation Review*, vol. 61, pp. 1-12.

Buurma, J & Saranark, J 2006, 'Supply-chain development for fresh fruits and vegetables in Thailand', in R Ruben, M Slingerland & H Nijhoff (eds), *Agro-food chains and networks for development*, Kluwer/Springer, Verlag, Dordrecht, pp. 119-27.

Cadilhon, JJ, Moustier, P, Poole, ND, Tam, PTG & Fearne, AP 2006, 'Traditional vs. modern food systems? Insights from vegetable supply chains to Ho Chi Minh City (Vietnam)', *Development Policy Review*, vol. 24, no. 1, pp. 31-49.

Cagnon, T, Méry, A, Chalier, P, Guillaume, C & Gontard, N 2013, 'Fresh food packaging design: A requirement driven approach applied to strawberries and agro-based materials', *Innovative Food Science and Emerging Technologies*, vol. 20, pp. 288-98.

California Strawberry Commission 2011, *Maintaining quality of fresh strawberries*, California Strawberry Commission, Watsonville, California.

Carullo, A, Corbellini, S, Parvis, M & Vallan, A 2009, 'A wireless sensor network for cold-chain monitoring', *IEEE Transactions on Instrumentation and Measurement*, vol. 58, no. 5, pp. 1405-11.

Carvalho, H, Barroso, AP, Machado, VH, Azevedo, S & Cruz-Machado, V 2012, 'Supply chain redesign for resilience using simulation', *Computers & Industrial Engineering*, vol. 62, no. 1, pp. 329-41.

CDH Energy Corp 2009, *Evaluation of the CoolBot^{TM} low-cost walk-in cooler concept*, Nyserda, New York.

Cedillo-Campos, MG, Sánchez-Ramírez, C, Vadali, S, Villa, JC & Menezes, MB 2014, 'Supply chain dynamics and the "cross-border effect": The US–Mexican border's case', *Computers & Industrial Engineering*, vol. 72, pp. 261-73.

Center for Applied Economics Research 2012, *A study of the market of fresh fruits from Thailand to the people's Republic of China under the Thai trade-China*, Kasetsart University, Bangkok.

Chan, FT 2003, 'Performance measurement in a supply chain', *The International Iournal of Advanced Manufacturing Technology*, vol. 21, no. 7, pp. 534-48.

Chan, FT & Zhang, T 2011, 'The impact of collaborative transportation management on supply chain performance: A simulation approach', *Expert Systems with Applications*, vol. 38, no. 3, pp. 2319-29.

Chan, HK & Chan, FT 2010, 'Comparative study of adaptability and flexibility in distributed manufacturing supply chains', *Decision Support Systems*, vol. 48, no. 2, pp. 331-41.

Chen, H, Daugherty, PJ & Landry, TD 2009, 'Supply chain process integration: a theoretical framework', *Journal of Business Logistics*, vol. 30, no. 2, pp. 27-46.

Chen, S & Lan, H 2016, 'The cold chain logistics enterprise's green level evaluation', paper presented to 2016 International Conference on Logistics, Informatics and Service Sciences (LISS), Sydney, 24-27 July, 2016.

Chen, SJ, Hong, QZ & Lin, HT 2000, 'A study of the shelf-life of cold-stored longan fruit', *Acta Hort. (ISHS)*, pp. 353-7.

Cigolini, R, Pero, M, Rossi, T & Sianesi, A 2014, 'Linking supply chain configuration to supply chain perfrmance: A discrete event simulation model', *Simulation Modelling Practice and Theory*, vol. 40, pp. 1-11.

Cooperative Promotion Department 2014, *Fruit*, Thailand Cooperative Promotion Department, Bangkok.

Costas, J, Ponte, B, de la Fuente, D, Pino, R & Puche, J 2015, 'Applying Goldratt's theory of constraints to reduce the bullwhip effect through agent-based modeling', *Expert Systems with Applications*, vol. 42, no. 4, pp. 2049-60.

Coulomb, D 2008, 'Refrigeration and cold chain serving the global food industry and creating a better future: two key IIR challenges for improved health and environment', *Trends in Food Science & Technology*, vol. 19, no. 8, pp. 413-7.

Cox III, JF & Spencer, MS 1997, *The constraints management handbook*, CRC Press, USA.

Cruz, R, Vieira, M & Silva, C 2013, 'The impact of cold chain temperature abuses on the quality of frozen strawberries (Fragaria× ananassa)', *International Journal of Food Studies*, vol. 2, no. 1, pp. 60-8.

Cruz, RM, Vieira, MC & Silva, CL 2009, 'Effect of cold chain temperature abuses on the quality of frozen watercress (Nasturtium officinale R. Br.)', *Journal of Food Engineering*, vol. 94, no. 1, pp. 90-7.

D&B Tangram Advisory Services 2016, *Cold chain grid in India*, D&B Tangram Advisory Services, India.

De-La-Fuente, MV & Ros, L 2010, 'Cold supply chain processes in a fruit-and-vegetable collaborative network', in A Ortiz, RD Franco & PG Gasquet (eds), *Balanced automation systems for future manufacturing networks*, Springer, Berlin, Heidelberg, vol. 322, pp. 3-10.

Defraeye, T, Cronje, P, Berry, T, Opara, UL, East, A, Hertog, M, Verboven, P & Nicolai, B 2015, 'Towards integrated performance evaluation of future packaging for fresh produce in the cold chain', *Trends in Food Science & Technology*, vol. 44, no. 2, pp. 201-25.

Defraeye, T, Lambrecht, R, Delele, MA, Tsige, AA, Opara, UL, Cronjé, P, Verboven, P & Nicolai, B 2014, 'Forced-convective cooling of citrus fruit: Cooling conditions and energy consumption in relation to package design', *Journal of Food Engineering*, vol. 121, pp. 118-27.

Deng, Y-w, Wu, W-b & Yu, T-q 2012, 'Research on current development and development pattern of China's agricultural cold chain logistics', paper presented to 2012 19th International Conference on Management Science and Engineering (ICMSE), Dallas, 20-22 September, 2012.

Department of Agriculture 2011, *Storage of fruits and vegetables*, The Agricultural Co-operative Federation of Thailand Limited, Bangkok.

Department of Agriculture Extension 2010, *Mango production development plan*, Thailand Ministry of Agriculture and Cooperatives, Bangkok.

Department of International Economic Affairs 2015, *The future of Thailand's mangoes exporting*, Thailand Ministry of Foreign Affairs, Bangkok.

Department of International Trade Promotion 2011, *Thailand's exporters directory*, Thailand Ministry of Commerce, Bangkok.

Derens, E, Palagos, B & Guilpart, J 2006, 'The cold chain of chilled products under supervision in France', paper presented to 13th World Congress of Food Science & Technology, Nantes, France, 17-21 September, 2006.

Dermesonluoglu, E, Katsaros, G, Tsevdou, M, Giannakourou, M & Taoukis, P 2015, 'Kinetic study of quality indices and shelf life modelling of frozen spinach under dynamic conditions of the cold chain', *Journal of Food Engineering*, vol. 148, pp. 13-23.

Dolan, C & Humphrey, J 2000, 'Governance and trade in fresh vegetables: The impact of UK supermarkets on the African horticulture industry', *Journal of Development Studies*, vol. 37, no. 2, pp. 147-76.

Dominguez, R, Cannella, S & Framinan, JM 2014, 'On bullwhip-limiting strategies in divergent supply chain networks', *Computers & Industrial Engineering*, vol. 73, pp. 85-95.

Dos Santos, RF, Marins, FAS, Alves, JM & Moellmann, AH 2010, 'A real application of the theory of constraints to Supply chain management in Brazil', *Brazilian Journal of Operations & Production Management*, vol. 7, no. 2, pp. 81-100.

Draganić, A, Orović, I, Stanković, S, Zhang, X & Wang, X 2017, 'Compressive sensing approach in the table grape cold chain logistics', paper presented to 2017 6th Mediterranean Conference on Embedded Computing, Bar, Montenegro, 11-15 June, 2017.

Drame, D & Meignien, X 2016, *Developing the cold chain in the agrifood sector in sub-Saharan Africa*, Food and Agriculture Organization, USA.

Duan, Q & Liao, TW 2013, 'A new age-based replenishment policy for supply chain inventory optimization of highly perishable products', *International Journal of Production Economics*, vol. 145, no. 2, pp. 658-71.

Dubey, N 2011, *Use of Coolbot technology for construction of low cost - low capacity cold storages on farms*, Amity University, Uttar Pradesh, Noida.

Electricity Tariffs and Business Division 2017, *Electricity rate*, Provincial Electricity Authority of Thailand, Bangkok.

Emenike, CC, Van Eyk, NP & Hoffman, AJ 2016, 'Improving cold chain logistics through RFID temperature sensing and predictive modelling', paper presented to 2016 IEEE 19th International Conference on Intelligent Transportation Systems Rio de Janeiro, Brazil, 1-4 November, 2016.

Etikan, I, Musa, SA & Alkassim, RS 2016, 'Comparison of convenience sampling and purposive sampling', *American Journal of Theoretical and Applied Statistics*, vol. 5, no. 1, pp. 1-4.

Fearne, A, Barrow, S & Schulenberg, D 2006, 'Implanting the benefits of buyer-supplier collaboration in the soft fruit sector', *Supply Chain Management: An International Journal*, vol. 11, no. 1, pp. 3-5.

Fleisch, E & Tellkamp, C 2005, 'Inventory inaccuracy and supply chain performance: A simulation study of a retail supply chain', *International Journal of Production Economics*, vol. 95, no. 3, pp. 373-85.

Flick, D, Hoang, HM, Alvarez, G & Laguerre, O 2012, 'Combined deterministic and stochastic approaches for modeling the evolution of food products along the cold chain. Part I: Methodology', *International Journal of Refrigeration*, vol. 35, no. 4, pp. 907-14.

Focus 2008, 'Think of fruit with branding goals', *Focus*, 15 December, pp. 28-9.

Food and Agriculture Organization 2015a, *Production of 5 top producers for fruit, tropical fresh nes*, FAOSTAT Division, USA.

Food and Agriculture Organization 2015b, *Trade/Crops and livestock products*, FAOSTAT Division, USA.

Food and Agriculture Organization 2016a, *AQUASTAT country profile*, AGUASTAT Division.

Food and Agriculture Organization 2016b, *FAOSTAT-Trade crops and livestock products*, FAOSTAT Division, USA.

Freiboth, HW, Goedhals-Gerber, LL, Dodd, MC & Van Dyk, FE 2013, 'Investigating temperature breaks in the summer fruit export cold chain: A case study', *Journal of Transport and Supply Chain Management*, vol. 7, no. 1, pp. 1-7.

García-Herrero, J, Barreiro Elorza, P, Ruiz García, L & Robla Villalba, JI 2010, 'Development of smart sensing devices for ubiquitous supervision of the cold chain: Application to perishable commodities', paper presented to International Conference on Agricultural Engineerig, Clemont-Ferrand, Francia, 6-8 September, 2010.

GBD Network 2015, *World mango market supply, demand and forecast*, GBD Network, USA.

Ge, J 2006, 'Simulation modeling and benefit-cost sensitivity analysis for technology adoption on Puerto Rico-United States tomato supply chain', PhD thesis, University of Florida, USA.

Georgiadis, P, Vlachos, D & Iakovou, E 2005, 'A system dynamics modeling framework for the strategic supply chain management of food chains', *Journal of Food Engineering*, vol. 70, no. 3, pp. 351-64.

Global Cold Chain Alliance 2016, *Kenya cold chain assessment*, Global Cold Chain Alliance, Kenya.

Gogou, E, Katsaros, G, Derens, E, Li, L, Alvarez, G & Taoukis, P 2013, 'Development and application of the European cold chain database as a tool for cold chain management', paper presented to 2nd IIR International Conference on Sustainability and the Cold Chain, Paris, France, 2-4 April, 2013.

Goldratt, EM 1990, *Theory of constraints*, North River Press, Great Barrington.

Goldratt, EM 1994, *It's not luck*, North River Press, Great Barrington.

Goldratt, EM & Cox, J 1992, *The Goal*, North River Press, Great Barrington.

Goldsby, TJ, Griffis, SE & Roath, AS 2006, 'Modeling lean, agile, and leagile supply chain strategies', *Journal of Business Logistics*, vol. 27, no. 1, pp. 57-80.

Greis, NP 2011, *Managing the "cool chain" a cold chain is only as cool as its warmest link*, University of North Carolina at Chapel Hill.

Günther, H-O & Kim, KH 2005, *Container terminals and automated transport systems*, Springer-Verlag, Germany.

Gustavsson, J, Cederberg, C, Sonesson, U, Van Otterdijk, R & Meybeck, A 2011, *Global food losses and food waste: Extent, causes and prevention*, Food and Agriculture Organization, Rome.

Haasbroek, LM 2013, 'An analysis of temperature breaks in the summer fruit export cold chain from pack house to vessel', Master thesis, Stellenbosch University, South Africa.

Halldorsson, A, Kotzab, H, Mikkola, JH & Skjøtt-Larsen, T 2007, 'Complementary theories to supply chain management', *Supply Chain Management: An International Journal*, vol. 12, no. 4, pp. 284-96.

Heap, R 2006, 'Cold chain performance issues now and in the future', *Bulletin of the IIR*, no. 4, pp. 1-11.

Helal, M, Rabelo, L, Sepúlveda, J & Jones, A 2007, 'A methodology for integrating and synchronizing the system dynamics and discrete event simulation paradigms', paper presented to 25th International Conference of the System Dynamics Society, Boston, 29 July - 2 August, 2007.

Hellström, D & Nilsson, F 2006, 'Combining case study and simulation methods in supply chain management research', paper presented to 15th Annual IPSERA Conference, San Diego, CA, 6 November, 2006.

Hodges, R, Buzby, J & Bennett, B 2011, 'Postharvest losses and waste in developed and less developed countries: Opportunities to improve resource use', *The Journal of Agricultural Science*, vol. 149, no. 1, pp. 37-45.

Hou, Y-F, Xie, D & Wang, J-B 2015, 'The cold chain logistics for perishable agricultural products in China', *Advance Journal of Food Science and Technology*, vol. 8, no. 11, pp. 802-7.

Hsieh, L-F, Wang, L-H & Su, C-P 2011, 'Developing green supply chain management strategy of hotel-centered in vegetable and fruit purchasing and recycling', paper presented to 2011 IEEE 18Th International Conference on Industrial Engineering and Engineering Management (IE&EM), Changchun, China, 3-5 September, 2011.

Huang, W-C, Kuo, T-C & Wu, S-C 2007, 'A comparison of analytical methods and simulation for container terminal planning', *Journal of the Chinese Institute of Industrial Engineers*, vol. 24, no. 3, pp. 200-9.

Iannoni, AP & Morabito, R 2006, 'A discrete simulation analysis of a logistics supply system', *Transportation Research Part E: Logistics and Transportation Review*, vol. 42, no. 3, pp. 191-210.

International Trade Administration 2016, *2016 top markets report cold supply chain*, United States Department of Commerce, USA.

Jacxsens, L, Luning, P, Van der Vorst, JGAJ, Devlieghere, F, Leemans, R & Uyttendaele, M 2010, 'Simulation modelling and risk assessment as tools to identify the impact of climate change on microbiological food safety–The case study of fresh produce supply chain', *Food Research International*, vol. 43, no. 7, pp. 1925-35.

James, SJ & James, C 2010, 'The food cold-chain and climate change', *Food Research International*, vol. 43, no. 7, pp. 1944-56.

James, SJ & James, C 2011, 'Improving energy efficiency within the food cold-chain', paper presented to The 23rd IIR International Congress of Refrigeration: Refrigeration for Sustainable Development, Prague, Czech Republic, 21-26 August, 2011.

Jansen, DR, Weert, Av, Beulens, AJ & Huirne, R 2001, 'Simulation model of multi-compartment distribution in the catering supply chain', *European Journal of Operational Research*, vol. 133, no. 1, pp. 210-24.

Jarosz, L 2000, 'Understanding agri-food networks as social relations', *Agriculture and Human Values*, vol. 17, no. 3, pp. 279-83.

Jayaswal, S & Chhabra, C 2005, *Simulation study of an inbound call center*, University of Waterloo, Canada.

Jemrić, T & Ilić, Z 2012, 'Present state of cold chain and postharvest loss of fruits and vegetables in Croatia and Serbia', *Agriculturae Conspectus Scientificus (ACS)*, vol. 77, no. 1, pp. 1-4.

Ji, G & Guo, R 2009, 'Research on the security of cold-chain logistics', paper presented to 2009 ICSSSM 6th International Conference on Service Systems and Service Management, Xiamen, China, 8-10 June, 2009.

Jie, L 2010, 'Issues of food-related cold-chain logistics management in China', paper presented to 2010 International Conference on Logistics Systems and Intelligent Management (ICLSIM), Harbin, China, 9-10 January, 2010.

Jing, Z & Jian, S 2015, 'Strategy research on perfecting the cold-chain logistics system of fresh food', paper presented to International Conference on Education Technology Management and Humanities Science (ETMHS), Shannxi, China, 21-22 March, 2015.

Johnston, LM, Jaykus, L-A, Moll, D, Anciso, J, Mora, B & Moe, CL 2006, 'A field study of the microbiological quality of fresh produce of domestic and Mexican origin', *International Journal of Food Microbiology*, vol. 112, no. 2, pp. 83-95.

Jol, S, Kassianenko, A, Wszol, K & Oggel, J 2007, 'The cold chain, one link in Canada's food safety initiatives', *Food Control*, vol. 18, no. 6, pp. 713-5.

Joshi, R, Banwet, DK & Shankar, R 2009, 'Indian cold chain: Modeling the inhibitors', *British Food Journal*, vol. 111, no. 11, pp. 1260-83.

Joshi, R, Banwet, DK & Shankar, R 2010, 'Consumer link in cold chain: Indian scenario', *Food Control*, vol. 21, no. 8, pp. 1137-42.

Joshi, R, Banwet, DK & Shankar, R 2011, 'A Delphi-AHP-TOPSIS based benchmarking framework for performance improvement of a cold chain', *Expert Systems with Applications*, vol. 38, no. 8, pp. 10170-82.

Joshi, R, Banwet, DK, Shankar, R & Gandhi, J 2012, 'Performance improvement of cold chain in an emerging economy', *Production Planning & Control*, vol. 23, no. 10-11, pp. 817-36.

Jung, JY, Blau, G, Pekny, JF, Reklaitis, GV & Eversdyk, D 2004, 'A simulation based optimization approach to supply chain management under demand uncertainty', *Computers & Chemical Engineering*, vol. 28, no. 10, pp. 2087-106.

Kacimi, R, Dhaou, R & Beylot, A-L 2009, 'Using energy-efficient wireless sensor network for cold chain monitoring', paper presented to 2009 6th Consumer Communications and Networking Conference (CCNC) Las Vegas, USA, 10-13 January, 2009.

Kader, A 2008, *Mango quality attributes and grade standards: A review of available information and identification of future research needs*, Kader Consulting Services, USA.

Kang, Y-S, Jin, H, Ryou, O & Lee, Y-H 2012, 'A simulation approach for optimal design of RFID sensor tag-based cold chain systems', *Journal of Food Engineering*, vol. 113, no. 1, pp. 1-10.

Kara, S, Rugrungruang, F & Kaebernick, H 2007, 'Simulation modelling of reverse logistics networks', *International Journal of Production Economics*, vol. 106, no. 1, pp. 61-9.

Katsaliaki, K, Mustafee, N & Kumar, S 2014, 'A game-based approach towards facilitating decision making for perishable products: An example of blood supply chain', *Expert Systems with Applications*, vol. 41, no. 9, pp. 4043-59.

Kehakaset 2017, 'Update mango situation in northern Thailand ', *Kehakset*, 1 June.

Kelton, WD, Sadowski, RP & Sturrock, DT 2004, *Simulation with ARENA*, McGraw-Hill, New York.

Khan, AU 2005, 'The domestic food market: Is India ready for food processing', paper presented to Conference on SPS towards Global Competitiveness in the Food Processing Sector, Pune, India, 5 September, 2005

Kitinoja, L 2013, 'Use of cold chains for reducing food losses in developing countries', *Population*, vol. 6, pp. 45-60.

Kitinoja, L 2014, *Exploring the potential for cold chain development in emerging and rapidly industrializing economies through liquid air refrigeration technologies*, Postharvest Education Foundation, UK.

Kitinoja, L, Saran, S, Roy, SK & Kader, AA 2011, 'Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy', *Journal of the Science of Food and Agriculture*, vol. 91, no. 4, pp. 597-603.

Kitinoja, L & Thompson, JF 2010, 'Pre-cooling systems for small-scale producers', *Stewart Postharvest Review*, vol. 6, no. 2, pp. 1-14.

Ko, D, Kwak, Y, Choi, D & Song, S 2015, 'Design of cold chain application framework (CCAF) based on IOT and Cloud', paper presented to 2015 8th International Conference on u- and e-Service, Science and Technology (UNESST), Jeju, South Korea, 25-28 November, 2015.

Ko, D, Kwak, Y, Choi, D & Song, S 2015, 'Design of smart cold chain application framework based on hadoop and spark', *International Journal of Software Engineering and Its Applications*, vol. 9, no. 12, pp. 99-106.

Kochi, P 2009, *Common mistakes with cold supply chain in India*, Cross Tree: Strategy & Technical Advisors, Viewed 15 December 2017, <http://www.crosstree.info/Documents/COLDProbs3.pdf>.

Kristianto, Y, Gunasekaran, A, Helo, P & Sandhu, M 2012, 'A decision support system for integrating manufacturing and product design into the reconfiguration of the supply chain networks', *Decision Support Systems*, vol. 52, no. 4, pp. 790-801.

Kumar, A & Rahman, S 2014, 'RFID-enabled process reengineering of closed-loop supply chains in the healthcare industry of Singapore', *Journal of Cleaner Production*, vol. 85, pp. 382-94.

Kumar, S 2008, 'A study of the supermarket industry and its growing logistics capabilities', *International Journal of Retail & Distribution Management*, vol. 36, no. 3, pp. 192-211.

Kumar, S & Nigmatullin, A 2011, 'A system dynamics analysis of food supply chains–Case study with non-perishable products', *Simulation Modelling Practice and Theory*, vol. 19, no. 10, pp. 2151-68.

Kuo, J-C & Chen, M-C 2010, 'Developing an advanced multi-temperature joint distribution system for the food cold chain', *Food Control*, vol. 21, no. 4, pp. 559-66.

Laguerre, O, Hoang, HM & Flick, D 2013, 'Experimental investigation and modelling in the food cold chain: Thermal and quality evolution', *Trends in Food Science & Technology*, vol. 29, no. 2, pp. 87-97.

Lambert, GF, Lasserre, AAA, Ackerman, MM, Sánchez, CGM, Rivera, BOI & Azzaro-Pantel, C 2014, 'An expert system for predicting orchard yield and fruit quality and its impact on the Persian lime supply chain', *Engineering Applications of Artificial Intelligence*, vol. 33, pp. 21-30.

Lan, H, Liu, Z & Wang, R 2010, 'Research on food cold chain logistics system collaboration based on attribute reduction in rough set', paper presented to 21th Annual Operations in Emerging Economies Conference, Vancouver, Canada 7-10 May, 2010.

Lan, H, Xue, H & Tian, Y 2013, 'Classification and application on food cold chain collaborative distribution models', in Z Zhang, R Zhang & J Zhang (eds), *LISS 2012: Proceedings of 2nd*

International Conference on Logistics Informatics and Service Science, Springer Berlin, Heidelberg, pp. 123-8.

Lan, HJ, Zhao, L, Su, L & Liu, Z 2014, 'Food cold chain equilibrium based on collaborative replenishment', *Journal of Applied Research and Technology*, vol. 12, no. 2, pp. 201-11.

Lau, KH & Kanchanasuwan, S 2015, 'Fruit supply chain simulation: A literature review', paper presented to 20th International Symposium on Logistics, Bologna, Italy, 5-8 July, 2015.

Lau, KH & Wang, Y 2009, 'Reverse logistics in the electronic industry of China: A case study', *Supply Chain Management: An International Journal*, vol. 14, no. 6, pp. 447-65.

Le Grandois, J, Ruas, M, Kalisa, P, Jolissaint, M, Marchioni, E, Aoudé-Werner, D, Le Fur, B & Ennahar, S 2013, 'Detection of cold chain abuse in frozen and chilled salmon using the comet assay', *LWT-Food Science and Technology*, vol. 54, no. 1, pp. 242-8.

Léchaudel, M, Génard, M, Lescourret, F, Urban, L & Jannoyer, M 2005, 'Modeling effects of weather and source–sink relationships on mango fruit growth', *Tree Physiology*, vol. 25, no. 5, pp. 583-97.

Lee, C-F & Chung, C-P 2012, 'An inventory model for deteriorating items in a supply chain with system dynamics analysis', *Procedia-Social and Behavioral Sciences*, vol. 40, pp. 41-51.

Li, K & Zheng, J 2014, 'The research on the risk assessment of aquatic product cold chain based on fuzzy comprehensive evaluation', paper presented to 2014 11th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), Xiamen, China, 19-21 August, 2014.

Li, X 2006, 'Research on cold chain in food industry in China', Master thesis, World Maritime University, Sweden.

Liu, K, Wang, X & Young, M 2014, 'Effect of bentonite/potassium sorbate coatings on the quality of mangos in storage at ambient temperature', *Journal of Food Engineering*, vol. 137, pp. 16-22.

Low, C 2013, 'A model measurement system for collaborative supply chain partners', *Journal of Manufacturing Systems*, vol. 32, no. 1, pp. 180-8.

Lu, L, Zheng, W, Lv, Z & Tang, Y 2013, 'Development and application of time–temperature indicators used on food during the cold chain logistics', *Packaging Technology and Science*, vol. 26, no. 1, pp. 80-90.

Luo, H, Zhu, M, Ye, S, Hou, H, Chen, Y & Bulysheva, L 2016, 'An intelligent tracking system based on internet of things for the cold chain', *Internet Research*, vol. 26, no. 2, pp. 435-45.

Lyu, J, Ding, J-H & Chen, P-S 2010, 'Coordinating replenishment mechanisms in supply chain: From the collaborative supplier and store-level retailer perspective', *International Journal of Production Economics*, vol. 123, no. 1, pp. 221-34.

Ma, Z & Wu, M 2015, 'Optimization model of the vehicle routing of cold chain logistics based on stochastic demands', *Journal of Applied Science and Engineering Innovation*, vol. 2, pp. 356-62.

Maheshwar, C & Chanakwa, T 2006, 'Postharvest losses due to gaps in cold chain in India-a solution', *Acta Hort. (ISHS)*, pp. 777-84.

Mango Research Station & University of Agriculture Faisalabad 2015, *Codes of practices for mango farming & processing*, Government of the Punjab, Pakistan.

Martínez-Olvera, C 2009, 'Benefits of using hybrid business models within a supply chain', *International Journal of Production Economics*, vol. 120, no. 2, pp. 501-11.

Matopoulos, A, Vlachopoulou, M, Manthou, V & Manos, B 2007, 'A conceptual framework for supply chain collaboration: Empirical evidence from the agri-food industry', *Supply Chain Management: An International Journal*, vol. 12, no. 3, pp. 177-86.

Maxwell Agyapong, M 2013, 'Evaluation of the post harvest handling of mango fruit', Master thesis, Institute of Distance Learning, Department of Horticulture, Kwame Nkrumah University of Science and Technology, Ghana.

Meng, C, Xu, D, Son, Y-J, Kubota, C, Lewis, M & Tronstad, R 2014, 'An integrated simulation and AHP approach to vegetable grafting operation design', *Computers and Electronics in Agriculture*, vol. 102, pp. 73-84.

Mergenthaler, M, Weinberger, K & Qaim, M 2009, 'The food system transformation in developing countries: A disaggregate demand analysis for fruits and vegetables in Vietnam', *Food Policy*, vol. 34, no. 5, pp. 426-36.

Ministry of Commerce 2017, *Thailand Trading Report*, Thailand Ministry of Commerce, Bangkok.

Minten, B, Reardon, T, Gupta, SD, Hu, D & Murshid, K 2016, 'Wastage in food value chains in developing countries: Evidence from the potato sector in Asia', in SP Andrew, K Lynn & GS Troy (eds), *Food Security in a Food Abundant World: An Individual Country Perspective*, Emerald Group Publishing Limited, vol. 16, pp. 225-38.

Mohan, S, Gopalakrishnan, M & Mizzi, P 2013, 'Improving the efficiency of a non-profit supply chain for the food insecure', *International Journal of Production Economics*, vol. 143, no. 2, pp. 248-55.

Montanari, R 2008, 'Cold chain tracking: A managerial perspective', *Trends in Food Science & Technology*, vol. 19, no. 8, pp. 425-31.

Moomin, A 2010, 'Quality criteria for mango export in Ghana', PhD thesis, Kwame Nkrumah University of Science and Technology, Kumasi.

Nair, SDM & Lau, KH 2013, ' Postharvest food wastage reduction in fruit and vegetables through cold chain collaboration: A theoretical framework', *Acta Hort. (ISHS)*, vol. 1012, pp. 1311-5.

Narrod, C, Roy, D, Okello, J, Avendaño, B, Rich, K & Thorat, A 2009, 'Public–private partnerships and collective action in high value fruit and vegetable supply chains', *Food Policy*, vol. 34, no. 1, pp. 8-15.

National Statistical Office 2015, *Gross national product, gross domestic product and mational Income at current market prices by economic activities:2005 - 2014*, Thailand Ministry of Information and Communication Technology, Bangkok.

National Statistical Office 2016, *Summary of the labour force survey in Thailand:June 2016*, Thailand Ministry of Information and Communication Technology Bangkok.

Navita, M 2015, 'Pioneering integrated cold chain infrastructure: A case on apple industry players of northern India', *International Journal of Management*, vol. 2, no. 3, pp. 1-10.

Negahban, A & Smith, JS 2014, 'Simulation for manufacturing system design and operation: Literature review and analysis', *Journal of Manufacturing Systems*, vol. 33, no. 2, pp. 241-61.

Negi, S & Anand, N 2015, 'Issues and challenges in the supply chain of fruits & vegetables sector in India: A Review', *International Journal of Managing Value and Supply Chains*, vol. 6, no. 2, pp. 47-62.

Nissen, R, George, A, Broadley, R, Newman, S & Hetherington, S 2005, 'Developing improved supply chains for temperate fruits in transitional Asian economies of Thailand and Vietnam', *Acta Hort. (ISHS)*, pp. 335-42.

Office of Agricultural Economics 2012, *Thailand foreign agricultural trade statistics 2011*, Thailand Office of Agricultural Economics, Bangkok.

Ongkunaruk, P 2009, *Supply chain management for agricultural produce*, Kasetsart University, Bangkok.

Ovca, A & Jevšnik, M 2009, 'Maintaining a cold chain from purchase to the home and at home: Consumer opinions', *Food Control*, vol. 20, no. 2, pp. 167-72.

Özbayrak, M, Papadopoulou, TC & Akgun, M 2007, 'Systems dynamics modelling of a manufacturing supply chain system', *Simulation Modelling Practice and Theory*, vol. 15, no. 10, pp. 1338-55.

Pakistan Horticulture Development & Export Board 2007, *Establishment of cold chain system under national trade corridor improvement project*, Arch Vision, Pakistan.

Pan, C, Yu, S & Li, S 2017, 'Research on the development mode and evaluation system of green cold chain logistics in China', paper presented to 36th Chinese Control Conference (CCC), Dalian, China, 26-28 July, 2017.

Panichsakpatana, S 2013, 'Supply chain collaboration in the management of Nam Dok Mai mango exports from Thailand to Japan', PhD thesis, University of Newcastle upon Tyne, UK.

Pannee, V 2013, *Mango export*, Thailand Department of Agriculture, Bangkok.

Parthanadee, P & Buddhakulsomsiri, J 2014, 'Production efficiency improvement in batch production system using value stream mapping and simulation: A case study of the roasted and ground coffee industry', *Production Planning & Control*, vol. 25, no. 5, pp. 425-46.

Pawanexh, K 2010, *Future Direction - Cold Chain in India*, CrossTree info, Viewed 15 December 2017, <http://www.crosstree.info/Documents/Future%20DirectionCC.pdf>.

Pegels, CC & Watrous, C 2005, 'Application of the theory of constraints to a bottleneck operation in a manufacturing plant', *Journal of Manufacturing Technology Management*, vol. 16, no. 3, pp. 302-11.

Perdana, T & Kusnandar 2012, 'The triple helix model for fruits and vegetables supply chain management development involving small farmers in order to fulfill the global market demand: A case study in "value chain center (VCC) Universitas Padjadjaran"', *Procedia - Social and Behavioral Sciences*, vol. 52, pp. 80-9.

Persson, F 2011, 'SCOR template—a simulation based dynamic supply chain analysis tool', *International Journal of Production Economics*, vol. 131, no. 1, pp. 288-94.

Persson, F & Olhager, J 2002, 'Performance simulation of supply chain designs', *International Journal of Production Economics*, vol. 77, no. 3, pp. 231-45.

Phavaphutanon, L 2015, *Fruit production, marketing and research and development system in Thailand*, Food and Fertilizer Technology Center, Taiwan.

Picha, D 2006, *Guide to post harvest care of strawberries in Moldova*, United States Agency for Interational Development, USA.

Pierreval, H, Bruniaux, R & Caux, C 2007, 'A continuous simulation approach for supply chains in the automotive industry', *Simulation Modelling Practice and Theory*, vol. 15, no. 2, pp. 185-98.

Pornsiripratharn, S 2011, *Fresh fruits and vegetables exports to the European Union*, International Institute for Trade and Development of Thailand, Bangkok.

Powell, W 1990, 'Neither market nor hierarchy: Network forms of organisation', *Research in Organisation Behaviour*, vol. 12, pp. 295-336.

Prentice, BE & McLachlin, R 2010, 'Refrigerated Food Transport from Canada to Mexico: Cold Chain Challenges', *Journal of the Transportation Research Forum*, vol. 47, no. 2, pp. 119-31.

Promethean Spenta Technologies Limited 2014, *Economical cold-storage technology in India - A case study*, Promethean Spenta Technologies Limited, India.

Qi, L, Xu, M, Fu, Z, Mira, T & Zhang, X 2014, 'C2SLDS: A WSN-based perishable food shelf-life prediction and LSFO strategy decision support system in cold chain logistics', *Food Control*, vol. 38, pp. 19-29.

Qiu, Q, Zhang, Z, Song, X & Gui, S 2009, 'Application research of cross docking logistics in food cold-chain logistics', paper presented to 2009 International Conference on Information Management, Innovation Management and Industrial Engineering, Xian, China, 26-27 December, 2009.

Quaye, R 2011, 'Cold chain management of fruits in Ghana', Master thesis, University of Ghana, Ghana.

Raab, V, Bruckner, S, Beierle, E, Kampmann, Y, Petersen, B & Kreyenschmidt, J 2008, 'Generic model for the prediction of remaining shelf life in support of cold chain management in pork and poultry supply chains', *Journal on Chain and Network Science*, vol. 8, no. 1, pp. 59-73.

Rakha, H & Zhang, Y 2004, 'Sensitivity analysis of transit signal priority impacts on operation of a signalized intersection', *Journal of Transportation Engineering*, vol. 130, no. 6, pp. 796-804.

Ramanathan, U 2014, 'Performance of supply chain collaboration–A simulation study', *Expert Systems with Applications*, vol. 41, no. 1, pp. 210-20.

Rathore, J 2013, 'Cold chain management for perishable food: Issues and scope for India', *IUP Journal of Supply Chain Management*, vol. 10, no. 1, p. 7.

Rattana, S 2011, 'The restraint of big name', *Komchadluek*, 17 December, p. 22.

Rediers, H, Claes, M, Peeters, L & Willems, KA 2009, 'Evaluation of the cold chain of fresh-cut endive from farmer to plate', *Postharvest Biology and Technology*, vol. 51, no. 2, pp. 257-62.

Reiner, G & Trcka, M 2004, 'Customized supply chain design: Problems and alternatives for a production company in the food industry. A simulation based analysis', *International Journal of Production Economics*, vol. 89, no. 2, pp. 217-29.

Ren, X-P 2011, 'Notice of retraction the analysis on viable development mode of farm produce cold chain logistics industry of Henan province', paper presented to 2012 2nd

International Conference on Artificial Intelligence, Management Science and Electronic Commerce (AIMSEC), Dengleng, China, 8-10 August, 2011.

Ren, Y, Hu, Q & Huang, X 2011, 'Researching on benefit assignment of logistics system in cold chain for food', paper presented to 2011 2nd IEEE International Conference on Emergency Management and Management Sciences (ICEMMS), Beijing, China, 8-10 August, 2011.

Richardson, DG 2005, *Method of recording the temperature of perishable products in cold chain distribution*, United States Patent and Trademark Office, USA.

Rickard, BJ & Sumner, DA 2011, 'Was there policy "reform"? Evolution of EU domestic support for processed fruits and vegetables', *Food Policy*, vol. 36, no. 3, pp. 438-49.

Riem-Vis, R 2004, 'Cold chain management using an ultra low power wireless sensor network', paper presented to 2004 Workshop on Applications of Mobile Embedded Systems, Boston, 6 June, 2004.

Rijpkema, WA, Rossi, R & van der Vorst, JGAJ 2014, 'Effective sourcing strategies for perishable product supply chains', *International Journal of Physical Distribution & Logistics Management*, vol. 44, no. 6, pp. 494-510.

Ritchie, J, Lewis, J, Nicholls, CM & Ormston, R 2013, *Qualitative research practice: A guide for social science students and researchers*, Sage, London.

Robert, K, Andrew, P & John, V 2016, *Design of a small-scale, low-cost cold storage system*, Local Roots, Los Angeles.

Rockwell Automation 2018, Arena simulation software, Viewed 13 March 2018, < https://www.arenasimulation.com>.

Rodrigues, AM 2004, 'Simulation of the impact of forecasting accuracy on supply chain performance: The bias effect', PhD thesis, Michigan State University, USA.

Rodríguez, V, Amorrortu, I & Álvarez, MJ 2011, 'Setting parameters in the cold chain', *Tecnura*, vol. 15, no. 30, pp. 71-81.

Rossetti, MD 2015, *Simulation modeling and Arena*, John Wiley & Sons, USA.

Rossi, R, Rijpkema, WA & van der Vorst, JGAJ 2012, 'The impact of dual sourcing on food supply chain networks: The case of Egyptian strawberries', paper presented to 10th Wageningen International Conference on Chain and Network Management (WICaNeM 2012), Wageningen, Netherlands, 23-25 May, 2012.

Ruiz-Garcia, L & Lunadei, L 2010, 'Monitoring cold chain logistics by means of RFID', in C Turu (ed.), *Sustainable radio frequency identification solutions*, InTech, Croatia, pp. 37-49.

Runzhou, Z 2014, 'On links of cold chain logistics for dairy products enterprises', *Journal of Chemical & Pharmaceutical Research*, vol. 6, no. 7, p. 767.

Saad, N & Kadirkamanathan, V 2006, 'A DES approach for the contextual load modelling of supply chain system for instability analysis', *Simulation Modelling Practice and Theory*, vol. 14, no. 5, pp. 541-63.

Sadowski, DA & Grabau, MR 2003, 'Tips for successful practice of simulation: tips for successful practice of simulation', paper presented to Proceedings of the 35th conference on Winter simulation: Driving innovation, New Orlands, Louisiana, 7-10 December, 2003.

Salin, V & Nayga, JRM 2003, 'A cold chain network for food exports to developing countries', *International Journal of Physical Distribution & Logistics Management*, vol. 33, no. 10, pp. 918-33.

Sandhya, M 2010, 'Modified atmosphere packaging of fresh produce: Current status and future needs', *LWT-Food Science and Technology*, vol. 43, no. 3, pp. 381-92.

Sargent, RG 2005, 'Verification and validation of simulation models', paper presented to Proceedings of the 37th conference on Winter simulation, Orlando, Florida, 4-7 December, 2005.

Sargent, SA, Talbot, MT & Brecht, JK 1988, 'Evaluating precooling methods for vegetable packinghouse operations', *Eng. Sci*, vol. 23, pp. 1147-55.

Schriber, TJ & Brunner, DT 2007, 'Inside discrete-event simulation software: How it works and why it matters', paper presented to Proceedings of the 39th conference on Winter simulation: 40 years! The best is yet to come, Washington D.C., 9-12 December, 2007.

Serrano, E 2005, 'Postharvest management of fruit and vegetables in the Asia-Pacific region: Philippines country report', *Asian Productivity Organization (APO); Food and Agriculture Organization (FAO)*, pp. 216-26.

Setyaningsih, S & Basri, M 2013, 'Designing inventory policy for formula and enteral food in hospital using simulation', *International Journal of Economics & Management*, vol. 7, no. 2, pp. 376-95.

Shane, Z 2016, *Shanghai cold chain logistics: Exporting food to China*, University of Southern Queensland, Toowoomba, Queensland.

Sharma, S & Pai, SS 2015, 'Analysis of operating effectiveness of a cold chain model using Bayesian networks', *Business Process Management Journal*, vol. 21, no. 4, pp. 722-42.

Shih, C-W & Wang, C-H 2016, 'Integrating wireless sensor networks with statistical quality control to develop a cold chain system in food industries', *Computer Standards & Interfaces*, vol. 45, pp. 62-78.

Siddiqui, MW 2015, *Postharvest biology and technology of horticultural crops: Principles and practices for quality maintenance*, Apple Academic Press, Canada.

Siksamat, S 2011, *The impact of the minimum wage increasing to 300 baht*, Bank of Thailand, Bangkok.

Simatupang, T, Hurley, S & Evans, A 1997, 'Revitalizing TQM efforts: A self-reflective diagnosis based on the theory of constraints', *Management Decision*, vol. 35, no. 10, pp. 746-52.

Simatupang, T, Wright, A & Sridharan, R 2004, 'Applying the theory of constraints to supply chain collaboration', *Supply Chain Management: An International Journal*, vol. 9, no. 1, pp. 57-70.

Skjoett-Larsen, T 2000, 'Third party logistics–from an interorganizational point of view', *International Journal of Physical Distribution & Logistics Management*, vol. 30, no. 2, pp. 112-27.

Smith, JN 2005, 'Specialized logistics for a longer perishable supply chain', *World Trade*, vol. 18, no. 11, p. 46.

Somboonsuk, B, Dhammasaccakarn, W, Kanchanasuwan, S, Sukabot, S, Prapruit, P, Jindabot, T & Dhammasaccakarn, A 2013, *Thai vegetable and fruit markets system to Malaysia and Singapore markets, under Asean Economic Community (AEC)*, Thai Research Funding, Bangkok.

Stahl, V, Ndoye, F, El Jabri, M, Le Page, J, Hezard, B, Lintz, A, Geeraerd, A, Alvarez, G & Thuault, D 2015, 'Safety and quality assessment of ready-to-eat pork products in the cold chain', *Journal of Food Engineering*, vol. 148, pp. 43-52.

Steins, K 2010, 'Discrete-event simulation for hospital resource planning: Possibilities and requirements', PhD thesis, Linköping University, Sweden.

Stephen, N 2009, *Cold chain assessment for Iraq*, United States Agency for International Development, USA.

Store It Cold Limited 2016, *Save money with CoolBot controller*, Store It Cold Limited, Viewed 23 July 2017, <https://www.storeitcold.com/economic-advantages/>.

Subin, R 2011, *Country: India's cold chain industry*, Indo-American Chamber of Commerce (IACC), India.

Sumari, S, Ibrahim, R, Zakaria, NH & Ab Hamid, AH 2013, 'Comparing three simulation model using taxonomy: System dynamic simulation, discrete event simulation and agent based simulation', *International Journal of Management Excellence*, vol. 1, no. 3, pp. 54-9.

Tako, AA & Robinson, S 2012, 'The application of discrete event simulation and system dynamics in the logistics and supply chain context', *Decision Support Systems*, vol. 52, no. 4, pp. 802-15.

Tamimi, M, Sundarakani, B & Vel, P 2010, 'Study of cold chain logistics implementation strategies: Insights from UAE industry', paper presented to Production and Operations Management Society Conference, Production and Operation Management Society, Miami, USA, 7-10 May, 2010.

Tang, J, Liu, K & Chen, Q 2013, 'Study on cold chain logistics of vehicle routing problem for agricultural products', paper presented to 2013 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), Dongguan, China, 28-30 July, 2013.

Teimoury, E, Nedaei, H, Ansari, S & Sabbaghi, M 2013, 'A multi-objective analysis for import quota policy making in a perishable fruit and vegetable supply chain: A system dynamics approach', *Computers and Electronics in Agriculture*, vol. 93, pp. 37-45.

Thakur, M & Forås, E 2015, 'EPCIS based online temperature monitoring and traceability in a cold meat chain', *Computers and Electronics in Agriculture*, vol. 117, pp. 22-30.

Thomassey, S 2014, 'A simulation based comparison: Manual and automatic distribution setup in a textile yarn rewinding unit of a yarn dyeing factory', *Simulation Modelling Practice and Theory*, vol. 45, pp. 80-90.

Thompson, J, Mejia, D & Singh, R 2010, 'Energy use of commercial forced-air coolers for fruit', *Applied Engineering in Agriculture*, vol. 26, no. 5, pp. 919-24.

Thorelli, HB 1986, 'Networks: Between markets and hierarchies', *Strategic Management Journal*, vol. 7, no. 1, pp. 37-51.

Thron, T, Nagy, G & Wassan, N 2007, 'Evaluating alternative supply chain structures for perishable products', *International Journal of Logistics Management*, vol. 18, no. 3, pp. 364-84.

Tian, F, Taudes, A, Yang, C & Deng, A 2015, 'Evaluation research on performance of Chinese agri-food cold-chain logistics company', paper presented to 2015 12th International

Conference on Service Systems and Service Management (ICSSSM), Guangzhou, China, 22-24 June, 2015.

Tiwong, S, Sopadang, A, Banomyong, R & Ramingwong, S 2013, 'Thai Mango Supply Chain Comparison and Analysis to Japanese Market', *室蘭工業大学紀要*, pp. 15-19.

Tongco, MDC 2007, 'Purposive sampling as a tool for informant selection', *Ethnobotany Research and Applications*, vol. 5, pp. 147-58.

Tsironi, T, Dermesonlouoglou, E, Giannakourou, M & Taoukis, P 2009, 'Shelf life modelling of frozen shrimp at variable temperature conditions', *LWT-Food Science and Technology*, vol. 42, no. 2, pp. 664-71.

Umble, M, Umble, E. and von Deylen, L. 2001, 'Integrating enterprise resources planning and theory of constraints: A case study', *Production and Inventory Management*, vol. 42, no. 3, pp. 43-8.

Umeda, S & Zhang, F 2006, 'Supply chain simulation: Generic models and application examples', *Production Planning & Control*, vol. 17, no. 2, pp. 155-66.

Urdan, TC 2016, *Statistics in plain English*, Taylor & Francis, New York.

van der Hulst, J 2004, 'Cool chain management for cut flowers', *Flower Tech*, vol. 7, no. 6, pp. 49-51.

van der Vorst, JGAJ, Beulens, AJ & van Beek, P 2000, 'Modelling and simulating multi-echelon food systems', *European Journal of Operational Research*, vol. 122, no. 2, pp. 354-66.

van der Vorst, JGAJ, Beulens, AJ, Wit, Wd & Beek, Pv 1998, 'Supply chain management in food chains: Improving performance by reducing uncertainty', *International Transactions in Operational Research*, vol. 5, no. 6, pp. 487-99.

van der Vorst, JGAJ, Tromp, S-O & van der Zee, D-J 2005, 'A simulation environment for the redesign of food supply chain networks: Modeling quality controlled logistics', paper presented to 37th conference on Winter simulation, Orlando, Florida, 4-7 December, 2005.

van der Vorst, JGAJ, Tromp, S-O & van der Zee, D-J 2009, 'Simulation modelling for food supply chain redesign; integrated decision making on product quality, sustainability and logistics', *International Journal of Production Research*, vol. 47, no. 23, pp. 6611-31.

van der Zee, D-J & van der Vorst, JGAJ 2005, 'A modeling framework for supply chain simulation: Opportunities for improved decision making', *Decision Sciences*, vol. 36, no. 1, pp. 65-95.

Van Rooyen, Z 2006, 'Factors affecting mesocarp discolouration severity in 'Pinkerton' avocados', *Horticultural Science. University of KwaZulu-Natal, Pietermaritzburg*.

Vellema, S, Admiraal, L, Naewbanij, J & Buurma, J 2005, 'Cooperation and strategic fit in the supply chain of Thai Fruit', *Acta Hort. (ISHS)*, pp. 477-86.

Verdouw, CN, Beulens, AJM, Trienekens, JH & Wolfert, J 2010, 'Process modelling in demand-driven supply chains: A reference model for the fruit industry', *Computers and Electronics in Agriculture*, vol. 73, no. 2, pp. 174-87.

Viswanadham, N 2005, *Cold chain management: India-Singapore initiative*, Institute of South Asian Studies, Singapore.

Viswanadham, N 2006, *Achieving rural & global supply chain excellence the Indian way*, Indian School of Business, Gachibowli, Hyderabad.

Wang, L & Zhang, ZY 2008, 'A research on related questions of Chinese food cold chain development', paper presented to 2008 International Conference on Management of e-Commerce and e-Government, Jiangxi, China, 17-19 October, 2008.

Wang, M & Luo, X 2012, 'Cold Chain Logistics in China: A case study of a Chinese Food Manufacturer', Master thesis, University of Gävle, Sweden.

Wang, X 2016, 'Keep the products fresh: A QFD approach to improve the logistics service quality of cold chain', paper presented to 2016 International Conference on Logistics, Informatics and Service Sciences (LISS), Sydney, Australia, 24-24 July, 2016.

Wang, X & Li, D 2012, 'A dynamic product quality evaluation based pricing model for perishable food supply chains', *Omega*, vol. 40, no. 6, pp. 906-17.

Wang, Y, Yi, J, Zhu, X, Luo, J & Ji, B 2015, 'Developing an ontology-based cold chain logistics monitoring and decision system', *Journal of Sensors*, vol. 2015.

Wangsinthaweekhun, N 2007, 'Supply chain of mango cv. Nam Dok Mai for Export to Japan in Chachoengsao province', Master thesis, Kasetsart University, Bangkok.

Wardlaw, C 1939, 'Cold Storage and Transport of Tropical Fruits', *Journal of the Royal Society of Arts*, vol. 88, no. 4539, pp. 22-33.

Wijewickrama, A & Takakuwa, S 2005, 'Simulation analysis of appointment scheduling in an outpatient department of internal medicine', paper presented to Proceedings of the 2005 conference on Winter simulation Orlando, USA, 4 December, 2005.

Wilson, N 1996, 'The supply chains of perishable products in northern Europe', *British Food Journal*, vol. 98, no. 6, pp. 9-15.

Winkworth-Smith, CG, Foster, TJ & Morgan, W 2015, *The impact of reducing food loss in the global cold chain*, University of Nottingham, UK.

Winrock International 2009, *Empowering Agriculture energy options for horticulture*, United States Agency for International Development, USA.

Worasatit, N, Atichart, S, Ek-un, K, Srisawangwong, S, Praprom, S, Sangsoda, P, Srisamran, J, Soonpum, P, Kaimook, N, Srisathit, R, Skunareewattana, P, Prasatsuwan, S, Puttiwong, S & Hintao, A 2017, *Analysis of climate change, adaptation and impact on crop production systems in the northeast*, Thailand Department of Agriculture, Bangkok.

World Health Organization 2003, *Fruit and vegetable promotion initative - report of the meeting*, World Health Organization, Geneva.

Xiaosheng, Y 2011, 'A research about the tracing technology and system designing of food-cold chain', paper presented to 2011 2nd International Conference on Artificial Intelligence, Management Science and Electronic Commerce (AIMSEC), Dengleng, China, 8-10 August, 2011.

Xie, T & Zhao, M 2016, 'Research on cold chain logistics joint distribution model based on cloud logistics', paper presented to 2016 IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC), Xi'an, China, 3-5 October, 2016.

Xu, X, Lan, H & Ruijiang, W 2010, 'Identification of critical control points of the food cold chain logistic process', paper presented to 2010 International Conference on Logistics Systems and Intelligent Management (ICLSIM), Harbin, China, 9-10 January, 2010.

Yachao, W 2013, 'The optimization analysis of cold chain logistics distribution route based on Particle Swarm Optimization (PSO) algorithm', *Advances in Information Sciences and Service Sciences*, vol. 5, no. 2, p. 801.

Yahia, E & Smolak, J 2014, *Developing the cold chain for agriculture in the near east and north Africa (NENA)*, Food and Agriculture Organization, USA.

Yahia, EHM 1999, *Postharvest handling of mango*, ATUT/RONCO technical staff, Egypt.

Yahia, EM 2009, 'Cold chain development and challenges in the developing world', *Acta Hort. (ISHS)*, pp. 127-32.

Yang, S, Lu, H, Lu, E, Guo, J & Xu, J 2012, 'Strategies on fruits and vegetables cold chain logistics in China', paper presented to World Automation Congress (WAC), Puerto Vallarta, Mexico, 4 December, 2012.

Yifeng, Z & Ruhe, X 2013, 'Application of cold chain logistics safety reliability in fresh food distribution optimization', *Advance Journal of Food Science and Technology*, vol. 5, pp. 356-60.

Ying, W & Xi, C 2010, 'Research on vehicle routing problem of cold chain logistics', paper presented to 2010 International Conference on Multimedia Information Networking and Security (MINES), Nanjing, China, 4-6 November, 2010.

Yu, B & Yan, WB 2010, 'How to Locate the Cold Chain Logistics Distribution Center Based on the Gray Comprehensive Evaluation', paper presented to 2010 International Conference on E-Product E-Service and E-Entertainment, Henan, China, 7-9 November, 2010.

Zanoni, S & Zavanella, L 2012, 'Chilled or frozen? Decision strategies for sustainable food supply chains', *International Journal of Production Economics*, vol. 140, no. 2, pp. 731-36.

Zeng, Q & Yu, X 2011, 'An empirical research about cold-chain of the food in Henan province', paper presented to 2011 International Conference on Computer Science and Service System (CSSS), Nanjing, China, 27-29 June, 2011.

Zhang, DZ, Anosike, AI, Lim, MK & Akanle, OM 2006, 'An agent-based approach for e-manufacturing and supply chain integration', *Computers & Industrial Engineering*, vol. 51, no. 2, pp. 343-60.

Zhang, P, Hou, H, Yang, J & Zhang, D 2016, 'Study on appreciation strategy of meat cold chain in China', paper presented to 2016 International Conference on Logistics, Informatics and Service Sciences (LISS), Sydney, Australia, 24-27 July, 2016.

Zhang, Y, Dube, M, McLean, D & Kates, M 2003, 'Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis', *Bioresource Technology*, vol. 90, no. 3, pp. 229-40.

Zhang, Y, Wang, Y & Wu, L 2012, 'Research on demand-driven leagile supply chain operation model: A simulation based on AnyLogic in system engineering', *Systems Engineering Procedia*, vol. 3, pp. 249-58.

Zheng, L 2015, 'Research on the performance evaluation method for cold chain logistics of agriculture products based on BP Neural Network mode', *Open Cybernetics & Systemics Journal*, vol. 9, pp. 2168-72.

Zhu, X, Zhang, R, Chu, F, He, Z & Li, J 2014, 'A flexsim-based optimization for the operation process of cold-chain logistics distribution centre', *Journal of Applied Research and Technology*, vol. 12, no. 2, pp. 270-78.

Zubeldia, BB, Jiménez, MN, Claros, MTV, Andrés, JLM & Martin-Olmedo, P 2016, 'Effectiveness of the cold chain control procedure in the retail sector in Southern Spain', *Food Control*, vol. 59, pp. 614-18.

Zwierzycki, W, Bieńczak, K, Bieńczak, M, Stachowiak, A, Tyczewski, P & Rochatka, T 2011, 'Thermal damage to the load in cold chain transport', *Procedia-Social and Behavioral Sciences*, vol. 20, pp. 761-66.

APPENDIX A

Cold Chain Technologies

The cold chain infrastructure comprises pre-cooling technology, a cold room, and refrigerated transport (Sharma & Pai 2015). As revealed from the literature, there are two options for cold chain technology for food handling, processing, storing and transportation. The first group is simple and low-cost, which is more suitable for developing countries; while the other group is intended to reach the same results but is more complex and expensive (Kitinoja 2013). Table A1 shows the mechanical technologies available for refrigeration.

Table A.1 – Mechanical technologies available for refrigeration

Cold chain stage	Small-scale	Large-scale
Pre-cooling	Portable forced air cooling systems, Icing, Room cooling	Vacuum cooling, Forced air cooling, Hydro-cooling
Cold storage	Walk- in cold room, CoolBot^{TM}- equipped cold room	Mechanical refrigeration
Refrigerated transport	USDA Porta-cooler	Cold trucks, Refrigerated marine containers

Source: Adapted from Kitinoja (2013), Kitinoja and Thompson (2010) and Thompson and Spinoglio (1988)

Pre-cooling

It is important to do a pre-cooling as near to the harvest area as possible (Stephen 2009). Cooling is vital to preserve the quality of perishable products. Even a small delay before commencement of pre- cooling can lead to produce quality loss and food deterioration (Intelligent Supply Chain Solutions 2015; Wardlaw 1939). According to Picha (2001), every hour that the produce stays at field temperature after harvesting leads to a reduction in shelf life of ten hours. There are several types of pre- cooling techniques for perishable produce. Therefore, it is very significant to select the suitable pre-cooling method, which depends on several factors (Bledsoe 2009; Brosnan & Sun 2001; Quaye 2011) including: (1) the nature of the product (*i.e.*, some products can be badly affected by wetting, hydro cooling or icing, which thus may not be appropriate for fruits such as tomatoes); (2) product packaging requirements (*i.e.*, the dominant selection of cooling method depends on the product being in a bag, box or bin, because this can affect the rate of cooling); (3) product flow capacity (*i.e.*, some cooling methods are quicker than others); and (4) economic constraints (*i.e.*, operation and building costs differ amongst cooling approaches). Common methods used for the first cooling are icing, forced-air cooling, room cooling, hydro cooling, and vacuum cooling.

- **Icing**

There are several types of approach that use ice to cool a commodity. They may include simply adding ice packs to the product (either placed directly in touch with the produce, or by passing cooled air over the produce) (Kitinoja & Kader 2015). Icing can be used on a range of produce. In the package icing process, it can be applied directly as a slurry in water, which is injected into commodity packages over handholds or openings, often without the necessity for removing their tops or depalletising (Bledsoe 2009). The particles of ice are forced into all available room in the container, thus accomplishing better contact with the product (Regional Office for Asia and Pacific Division 2012). For the top icing procedure, crushed or flaked ice is added by machine or hand to the container above the upper part of goods (Bledsoe 2009). There are several disadvantages of using ice as a cooling method: for example, the melting ice damps the produce; it leads to more susceptibility to disease of the produce because the produce is in direct contact with ice; and it also adds weight to the box (Regional Office for Asia and Pacific Division 2012). Therefore, this method works well with water-tolerant packaging (plastic, fibreboard, or wood), and with water-tolerant and non-chilling-sensitive goods such as carrots, sweet corn, broccoli, green onions, and lettuce (Kitinoja & Kader 2015; Kitinoja & Thompson 2010).

- **Forced-air cooling**

According to the Kitinoja and Thompson (2010) and Regional Office for Asia and Pacific Division (2012), this cooling technique forces cool air to be transferred over containers of goods. This approach can be effective for most packaging of produce, and it is extremely energy efficient. This technique is generally 75% to 90% faster than room cooling, although the cooling level depends on the rate of air flow and the temperature target (Bledsoe 2009). It requires an energy cost of 35 kWh/MT and two to four hours for cooling time to maintain 13 degrees Celsius (Brecht *et al.* 2010; Winrock International 2009). Forced-air cooling is where goods are cooled by placing the products into a cold room and organising the air-flow pattern by adding fans to raise the cooling speed (Quaye 2011). There are diverse styles of forced-air cooling designs in usage; while the most commonly used in developed countries is termed tunnel cooling (Regional Office for Asia and Pacific Division 2012). However, a forced-air cooling which is particularly suitable for small-scale business, especially in developing countries, is portable forced-air cooling (Bhawna 2016; Kitinoja & Thompson 2010; Winrock International 2009). This cooling method is useful for fruits that need to be cooled quickly after harvesting such as mangos and strawberries (Quaye 2011).

- **Room cooling**

This technique basically involves placing goods in an insulated room provided with cooling units, and cooling air is disseminated everywhere, to the bins, sacks or cartons (Bledsoe 2009; Kitinoja & Thompson 2010). However, while this technique is a relatively energy efficient and appropriate one for produce that is marketed rapidly after harvest, it provides the slowest refrigeration rate, extreme water loss according to the slow rate of cooling, and is inappropriate for packed produce (Bhawna 2016). It is suitable only for products that have a long shelf life such as onions, sweet potato and tomatoes, because more highly perishable products will spoil before being sufficiently cooled (Kitinoja & Kader 2015; Kitinoja & Thompson 2010; Regional Office for Asia and Pacific Division 2012).

- **Hydro-cooling**

Hydro-cooling can be used only on products that are not too delicate for wetting, which frequently encourages the growth of microorganisms, because it will increase deterioration through these organisms (Bledsoe 2009; Kitinoja & Thompson 2010). The standard style of hydro-cooling is using a cistern of cold water in which goods are immersed or drenched, and therefore cold water moves over the goods to remove heat (Kader 2002; Kitinoja & Kader 2002). According to Bledsoe (2009) and Kitinoja and Kader (2015), air removes heat approximately 15 times more slowly than water, the latter which thus provides faster cooling to the product. Nevertheless, hydro-cooling is only 20% to 40% energy efficient, as compared to 70% to 80% for forced-air cooling and room cooling; and, in addition, it is more suitable for large-scale business than small-scale industry, because it requires high capital investment (Bledsoe 2009; Brosnan & Sun 2001). There is some produce that responds well to hydro-cooling, especially products that have a large surface area such as peaches and sweet corn (Bledsoe 2009).

- **Vacuum cooling**

This cooling method works well with goods that have a large surface area such as lettuce and leafy greens, which might be extremely hard to cool with hydro-cooling or forced air cooling (Bhawna 2016; Bledsoe 2009). The product is located inside a metal cylinder, where the atmospheric pressure is decreased. The low pressure also results in the water in the produce boiling, as the produce is refrigerated (Quaye 2011; Regional Office for Asia and Pacific Division 2012). However, there are several adverse effects for vacuum cooling, such as that it leads to a water loss in the product if overdone, and that the equipment is extremely costly to operate and to purchase (Bledsoe 2009).

Cool storage

Cold storage can have a very high energy demand; however, the cold storage costs are usually more than counterbalanced by cost saving from decreased produce loss and improved quality. Appropriate selection of cold storage for a proposed use will increase energy effectiveness of the cold chain (Winrock International 2009). However, there is a diverse range of choices in cold storage type, from small, walk-in cold rooms to large-scale refrigerated warehouses.

- **Walk-in cold rooms, CoolBot™-equipped**

Small-scale cold rooms can be considered using a recent development in cooling technology, namely the low-cost, CoolBot™-equipped air conditioner-based systems, which were developed by Boyette and Rohrbach in 1993 (Kitinoja 2013). According to CDH Energy Corp (2009) and Store It Cold Limited (2016), CoolBot™ can help to save up to 42% of the energy use of a mechanical refrigeration system; and a Coolbot™ system with a room air conditioner costs approximately 90% less than an equal-sized commercial refrigeration method (Kitinoja & Thompson 2010). The CoolBot™ is a controller for a normal air conditioner which works by operating the air conditioner to refrigerate the storing room. The air conditioner is changed to function so as to drop the temperature without creating ice on the evaporator despite being at an extremely low temperature (Karithi 2016; Kitinoja & Thompson 2010).

- **Mechanical refrigeration**

Although mechanical refrigeration is the considered the most effective technology for transportation systems and cold rooms, mechanical refrigeration is practically infeasible for the limited resources of small-scale business (Dubey 2011). These systems have higher working costs than CoolBot™, because they consume more electricity to cool a space (Robert, Andrew & John 2016). The energy use for a cold room of mechanical refrigeration costs 30 kWh/MT for 12 degrees Celsius of cooling (Winrock International 2009). Cold rooms can be bought new or used, as pre-assembled units such as prefabricated cold rooms, highway vans, marine containers, or owner-built cold rooms (Thompson & Spinoglio 1988). However, some researchers suggest that the owner-built cold room and used, prefabricated cold room are the cheapest choices among the range of mechanical refrigeration (Thompson & Spinoglio 1988; Winrock International 2009). However, used cooled highway vans and marine containers have the benefit that the cold room is portable, and thus can be relocated to the new site; but they are the most costly among this group in some regions (Thompson & Spinoglio 1988; Winrock International 2009).

- **Refrigerated transport**

Transportation happens several times in the agricultural supply chain, which is a significant part of the cold supply chain in terms of transporting produce at a particular temperature (Zhang, Chen & Lu 2011). Vehicles are an essential component of the cold chain to transport produce from the farm to the packinghouse, and from the packinghouse to the wholesale or retail market (Winrock International 2009). Transportation of perishable produce from the farm to the consumer has an aspect of time and might lead to significant losses if there are postponements at any stage in the supply chain (Karithi 2016). There are a number of technologies for transportation, such as USDA Porta-cooler, Cold truck, and Marine container. Therefore, efficiency, productivity and cost are factors that of necessity are to be considered in the selection of refrigerated transportation (Quaye 2011).

- **USDA Porta-cooler**

USDA porta-coolers can be transported on traditional small-scale transport such as pick-up trucks, either set into a pick-up truck bed or pulled as a trailer (Kitinoja 2013; Winrock International 2009). This method is suitable for small farmers that have to sort and grade crops in the field, directly cool the harvest to take away field heat, pack the produce appropriately for the marketplace, and transport straight to the market (Kitinoja & Kader 2015). The USDA Porta-cooler uses a room-size air conditioner to refrigerate air in a small insulated box. The refrigerated air in the front of the insulated box is enforced through the produce by a pressure fan inside an insulated box (Global Cold Chain Alliance 2016; Kitinoja & Kader 2015).

- **Cold trucks**

Fruit and vegetables should be transported in fully covered trucks, if possible in refrigerated trucks (Agricultural & Processed Food Products Export Development Authority 2009), which are also termed 'reefer' trucks. There are several sizes of cold trucks. The most common cold trucks are 12 feet and 20 feet in size, which normally can carry approximately six to ten pallets of produce. Due to the cooling system fitted on a reefer truck being quite small compared with the dimensions of the truck, a cold truck would require five to ten percent more energy than a normal truck to transport the equivalent load over the same length (Winrock International 2009).

- **Refrigerated marine containers**

A reefer, or refrigerated container, is a container in intermodal transportation that is cooled for sensitive produce at a target temperature during delivery (Bledsoe 2009). It can be used to transport anything, such as fruit, vegetables, meat, and pharmaceuticals. Refrigerated marine containers are usually either 20 or 40 feet (NPCS Board of Consultants & Engineer 2015). The refrigerated container is suitable for use in developing countries such as India (Maheshwar & Chanakwa 2006).

APPENDIX B

Base Model Development

Table B.1 – Distributions and input parameters for the module representing farms A, B and C

Process	Statistical distributions	Units of time	*P*-value	Mean Square Error
Process harvesting	2 + 7 * BETA (1.29, 1.51)	Seconds/Mango	0.62	0.005249
Process move to inspection Yard	NORM (14.7, 2.08)	Seconds/Basket	>0.75	0.002313
Process cover release	TRIA (2, 4.18, 10)	Seconds/Mango	0.62	0.009047
Process inspection and cutting	2 + 8.93 * BETA (2.14, 2.39)	Seconds/Mango	0.47	0.007623
Process put into basket	2.02 + GAMM (0.0605, 6.66)	Minutes/Basket	>0.15	0.009933
Process truck loading	23.4 + 1.96 * BETA (0.585, 0.526)	Minutes/Truck	>0.15	0.039651
Travel to processor A	TRIA (55, 60 , 65)	Minutes/1 time	-	-

Table B.2 – Distributions and input parameters for the module representing farms D and E

Process	Statistical distributions	Units of time	*P*-value	Mean Square Error
Process harvesting	3 + 4.9 * BETA (1.83, 1.84)	Seconds/Mango	>0.75	0.005127
Process truck loading	7.18 + 3.24 * BETA (1.04, 0.995)	Minutes/Truck	>0.15	0.006314
Travel to processor B or C	4 + GAMM (0.506, 1.15)	Minutes/ 1 time	>0.15	0.022706

Table B.3 – Distributions and input parameters for the module representing processor A

Process	Statistical distributions	Units of time	*P*-value	Mean Square Error
Process truck unloading	14 + GAMM (0.579, 3.14)	Seconds/3 Baskets	0.15	0.019209
Process weighing 1	1.64 + LOGN (0.711, 0.375)	Seconds/ 3 Baskets	0.56	0.001258
Process move to yard	3.61 + ERLA (0.285, 3)	Seconds/3 Baskets	0.21	0.006876
Process lay down mangoes to yard	6 + 5.62 * BETA (1.85, 1.64)	Seconds/3 Baskets	0.61	0.005664
Process decide grading	1.53 + LOGN (1.11, 0.469)	Seconds/3 Mangoes	0.07	0.016672
Process packing	12 + GAMM (0.447, 3.32)	Seconds/Box	0.49	0.005650
Process move to weighing	TRIA (3.15, 5.67, 8)	Seconds/Box	0.34	0.011043
Process weighing 2	NORM (2.68, 0.374)	Seconds/Box	>0.15	0.01.781
Process weight adjustment	10 + 4.65 * BETA (1.61, 1.6)	Seconds/Box	0.06	0.017092
Process move to box cover yard	1.75 + 2.59 * BETA (2.44, 3.69)	Seconds/Box	>0.15	0.004931
Process box cover and stamp	NORM (5.08, 0.982)	Seconds/Box	0.21	0.007023
Process move to box wrap	TRIA (1.12, 2.31, 2.63)	Seconds/Box	0.47	0.008205
Process wrap box	5 + ERLA (0.373, 4)	Seconds/Box	0.19	0.007414
Process move to transportation preparing yard	7 + 5 * BETA (1.68, 1.75)	Seconds/Box	0.35	0.007732

Table B.4 – Distributions and input parameters for the module representing processors B and C

Process	Statistical distributions	Units of time	*P*-value	Mean Square Error
Process truck unloading	4.34 + 6.53 * BETA (2.54, 1.77)	Seconds/Basket	0.34	0.005947
Process cover release	1.03 + LOGN (3.59, 1.8)	Seconds/Mango	0.24	0.007323
Process inspection and cutting	4 + GAMM (1.32, 1.44)	Seconds/Mango	0.66	0.000637
Process put into basket	15 + 6.95 * BETA (1.06, 1.56)	Seconds/Basket	0.23	0.010662
Process put into trolley	2.16 + 3.84 * BETA (1.99, 2.14)	Seconds/ 3 Baskets	0.20	0.012749
Process move to grading yard	NORM (16.3, 2.31)	Seconds/1 time	>0.15	0.008150
Process lay down mango to yard	TRIA (3, 4.5, 6)	Seconds/3 baskets	0.66	0.003468
Process decide grading	1.07 + WEIB (2.02, 3.76)	Seconds/Mango	0.38	0.003636
Process put plastic bubble	1.21 + 2.31 * BETA (2.09, 2.05)	Seconds/Mango	>0.75	0.004228
Process packing	NORM (43.5, 4.48)	Seconds/Box	0.18	0.007058
Process move to weighing	2 + WEIB (3.44, 2.64)	Seconds/Box	0.57	0.002882
Process weighing 2	2.41 + 2.59 * BETA (2.08, 1.55)	Seconds/Box	>0.75	0.001650
Process weight adjustment	NORM (9.62, 1.18)	Seconds/Box	0.49	0.005761
Process box cover and stamp	4 + 8.97 * BETA (1.82, 2.5)	Seconds/Box	0.40	0.010487
Process move to box wrap	4 + GAMM (1.04, 3.79)	Seconds/Box	0.41	0.005050
Process wrap box	5.03 + 4.97 * BETA (2.86, 3.21)	Seconds/Box	0.07	0.019714
Process move to transportation preparing yard	TRIA (2, 4.63, 9)	Seconds/Box	0.40	0.011424

Table B.5 – Distributions and input parameters for the module representing transporter

Process	Statistical distributions	Units of time	*P*-value	Mean Square Error
Travel to processor B	TRIA (35, 40, 45)	Minutes	-	-
Process pick up boxes Pro B	24 + 8 * BETA (0.834, 0.703)	Minutes/1 Time	>0.15	0.047045
Travel to processor C	UNIF (15, 20)	Minutes	-	-
Process pick up boxes Pro C	24 + 8 * BETA (0.834, 0.703)	Minutes/1 Time	>0.15	0.047045
Travel to processor A	TRIA (30, 35, 40)	Minutes	-	-
Process pick up Boxes Pro A	34 + 11 * BETA (0.506, 0.756)	Minutes/1 Time	>0.15	0.027957
Travel to middleman firm	TRIA (13.5, 14, 14.5)	Hours	-	-

Table B.6 – Distributions and input parameters for the module representing middleman firm

Process	Statistical distributions	Units of time	*P*-value	Mean Square Error
Process truck unloading	2.43 + 5.02 * BETA (2.57, 2.68)	Seconds/Box	0.63	0.003770
Process truck unloading operation break down	TRIA (25, 30, 35)	Minutes	-	-
Process sorting	26 + GAMM (1.81, 3.99)	Seconds/Box	0.51	0.002222
Process stamp and labelling CA	2.6 + 3.91 * BETA (2.2, 2.58)	Seconds/Box	0.61	0.006271
Process stamp and labelling CB	1.49 + 1.19 * BETA (3.8, 1.61)	Minutes/Pallet	>0.15	0.013046
Process wrap	NORM (2.32, 0.291)	Minutes/Pallet	>0.15	0.140333
Process truck loading CA	30.4 + 6.42 * BETA (0.973, 0.924)	Minutes/1 Time	>0.15	0.047292
Process truck loading CB	12.4 + 1.9 * BETA (0.685, 0.911)	Minutes/1 Time	>0.15	0.104751
Travel to CA	TRIA (7.5, 8, 8.5)	Hours	-	-
Travel to CB	TRIA (13.5, 14, 14.5)	Hours	-	-

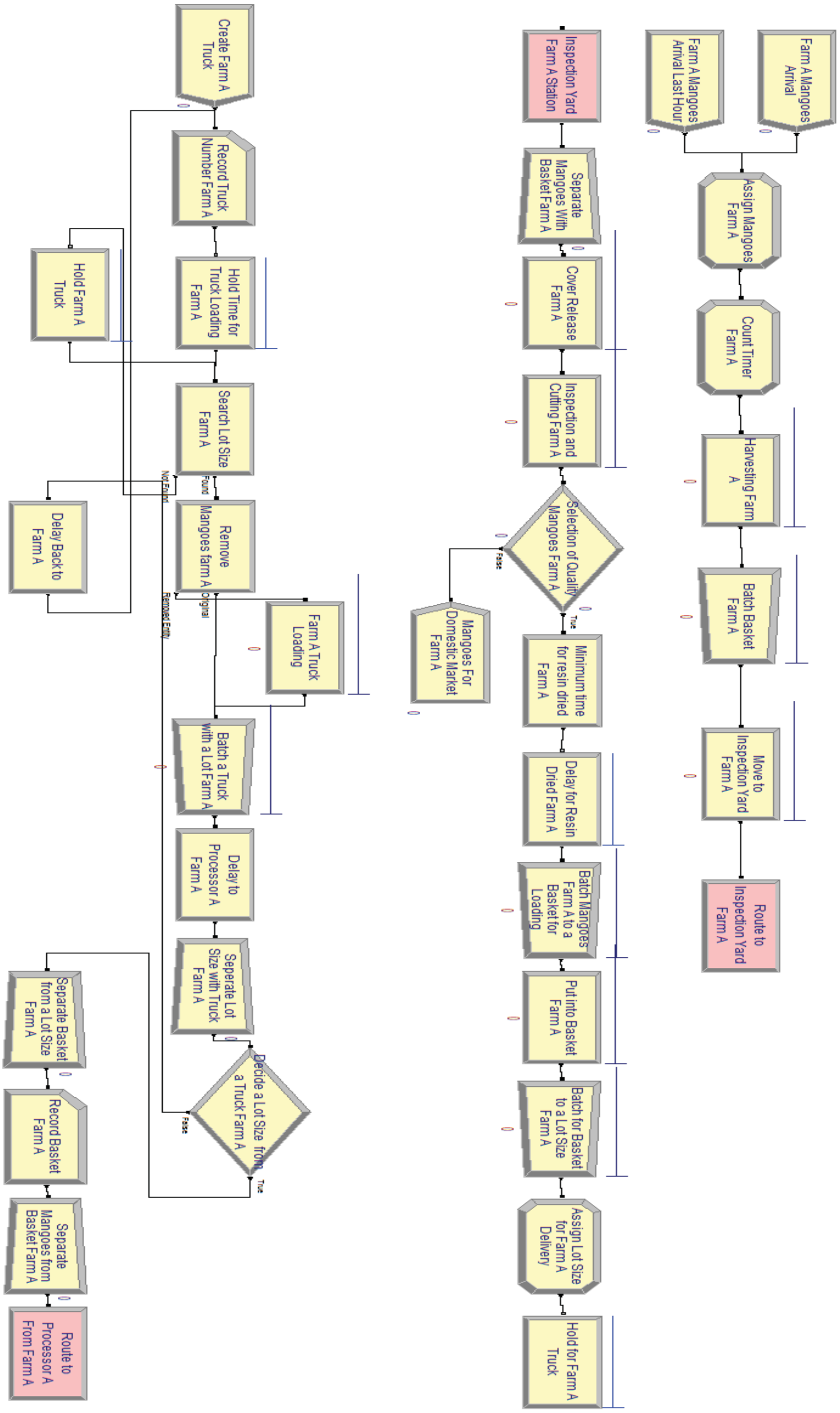


Figure B.1 – Screenshot for ARENA model for farm A

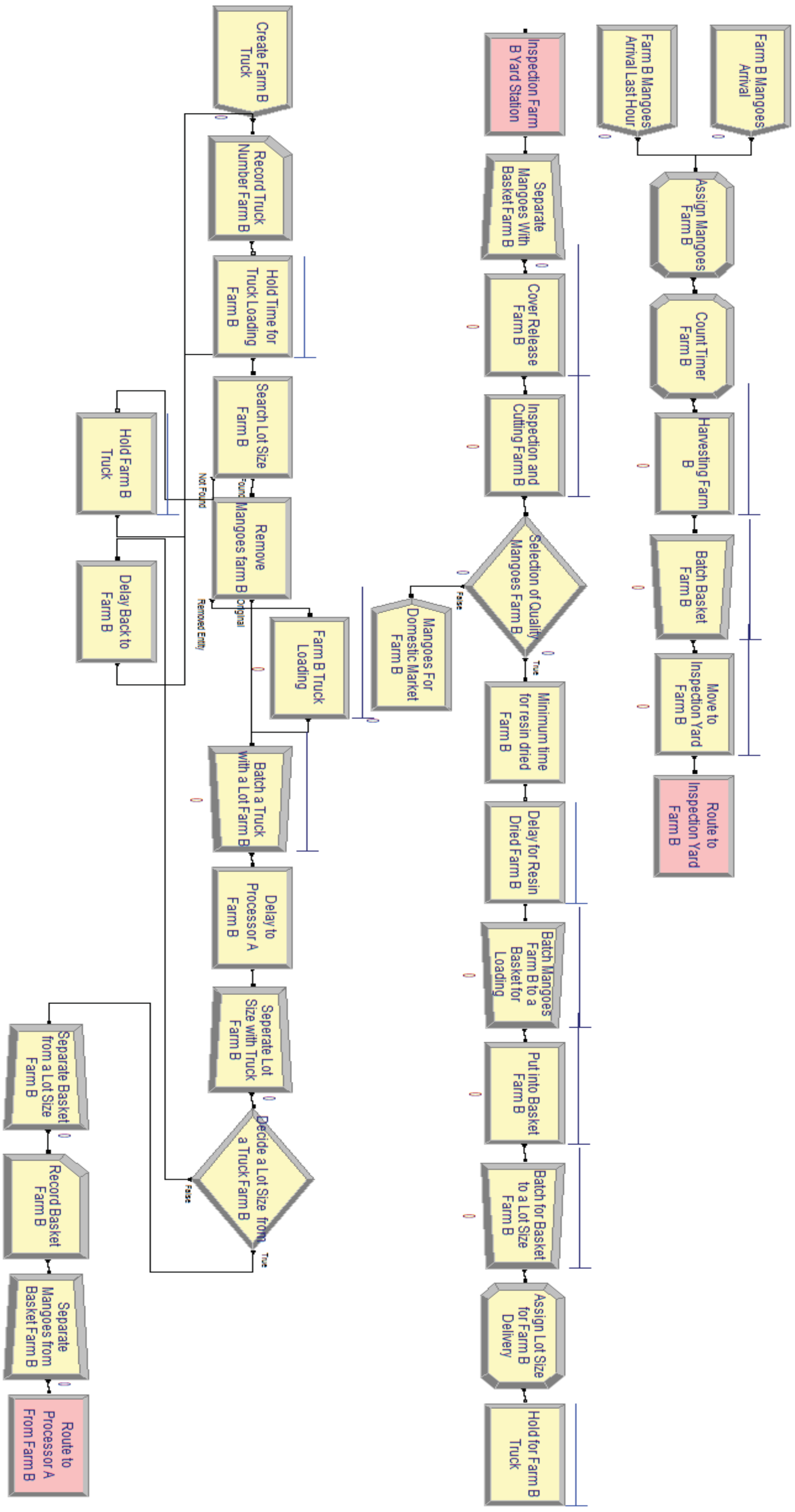


Figure B.2 – Screenshot for ARENA model for farm B

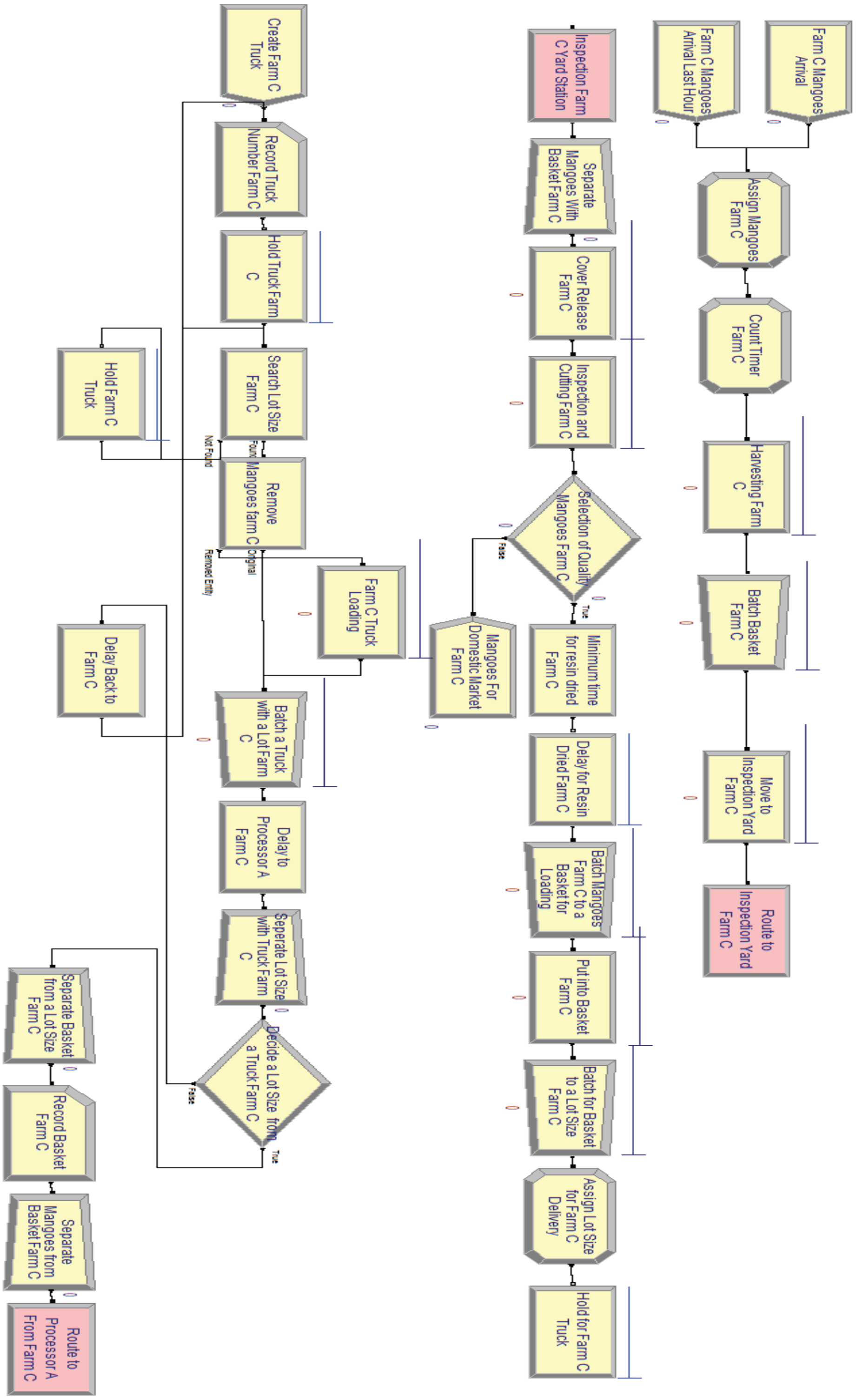


Figure B.3 – Screenshot for ARENA model for farm C

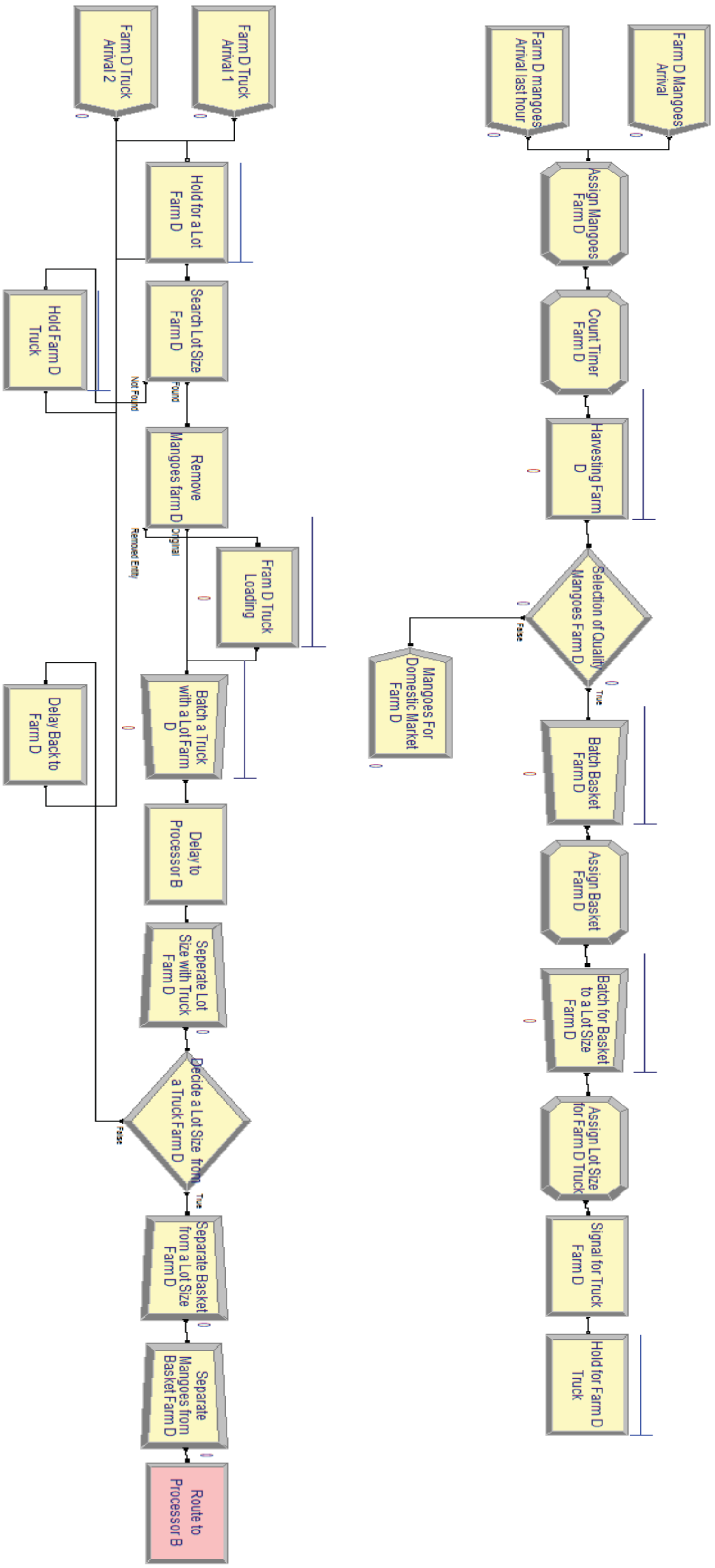


Figure B.4 – Screenshot for ARENA model for farm D

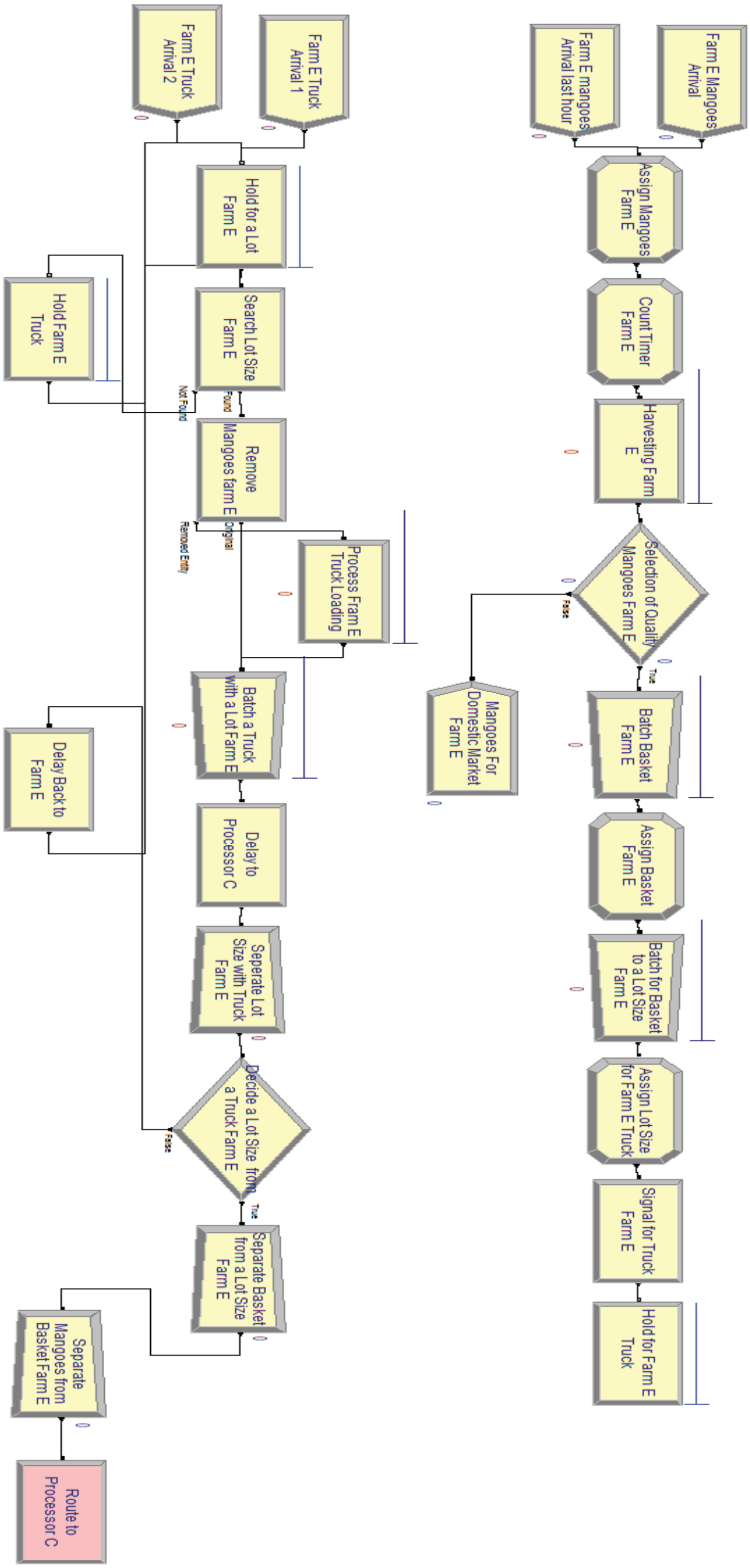


Figure B.5 – Screenshot for ARENA model for farm E

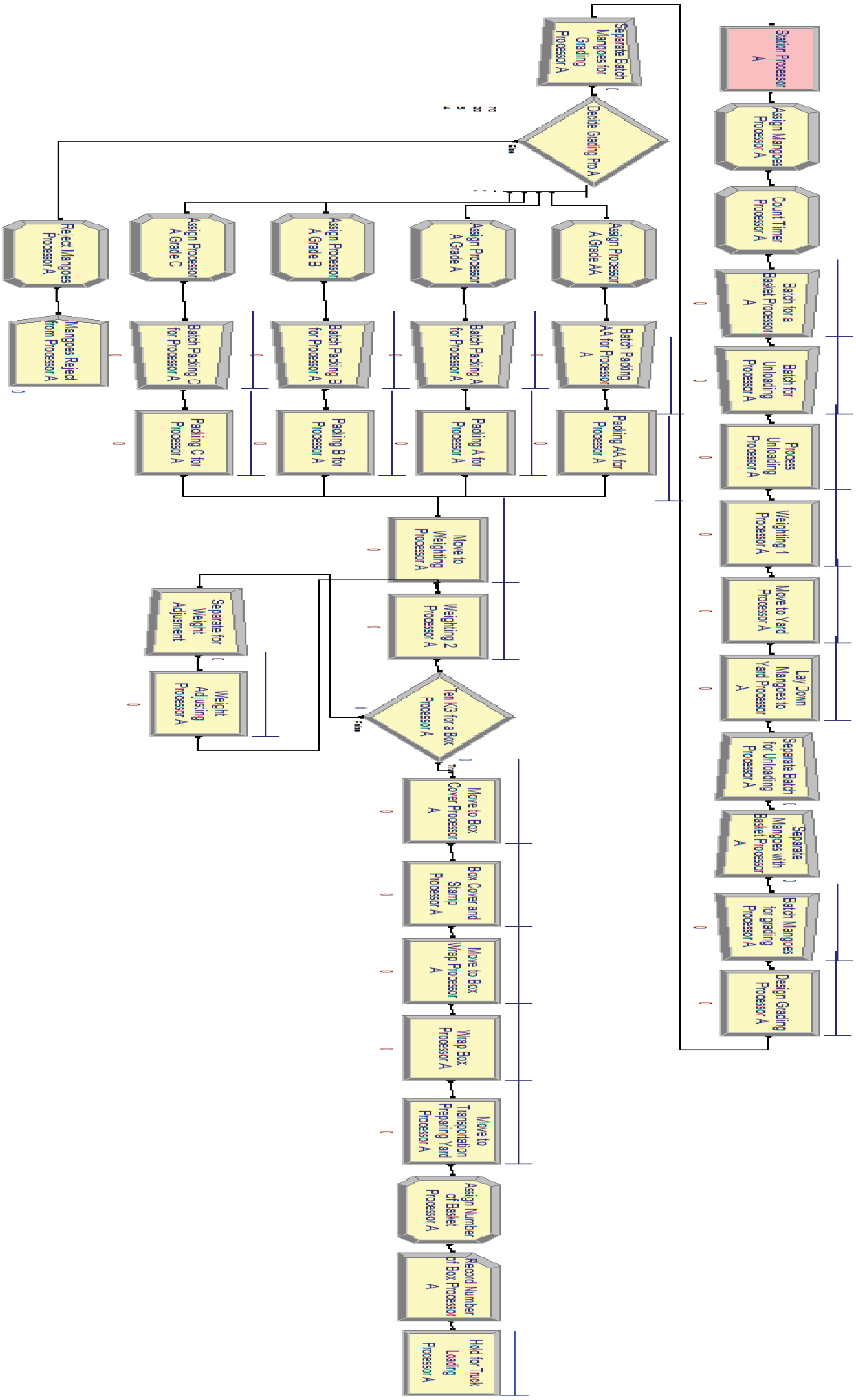


Figure B.6 – Screenshot for ARENA model for processor A

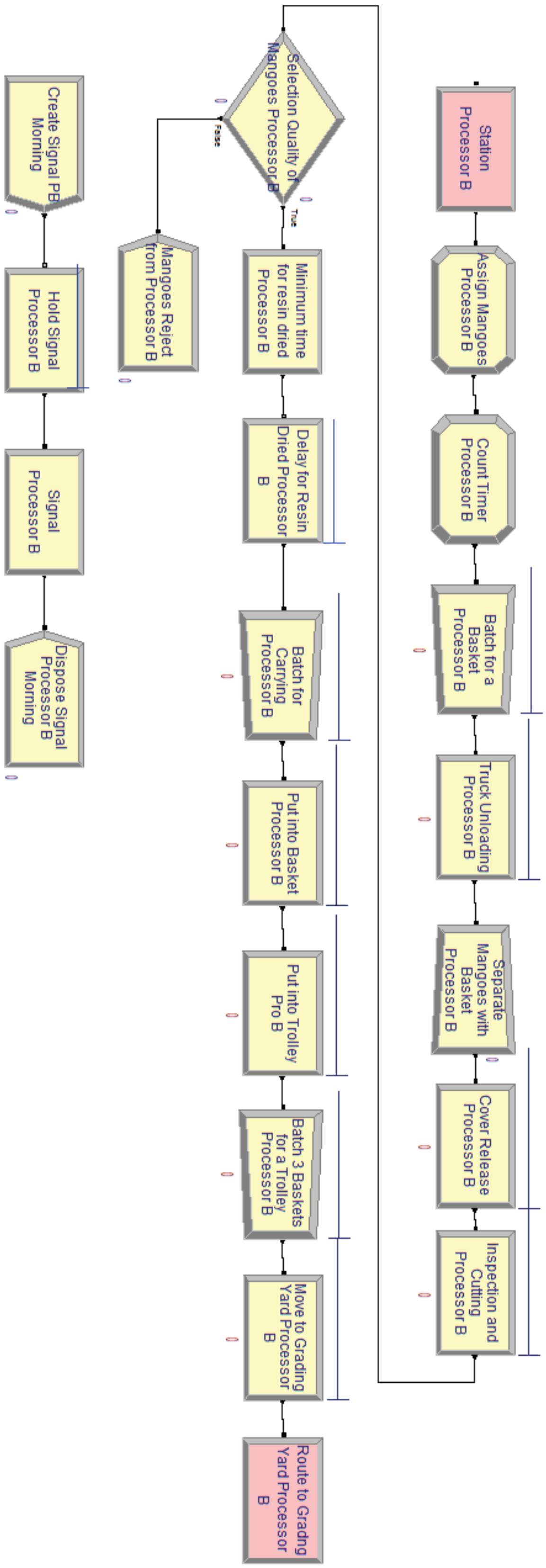


Figure B.7 – Screenshot for ARENA model for processor B

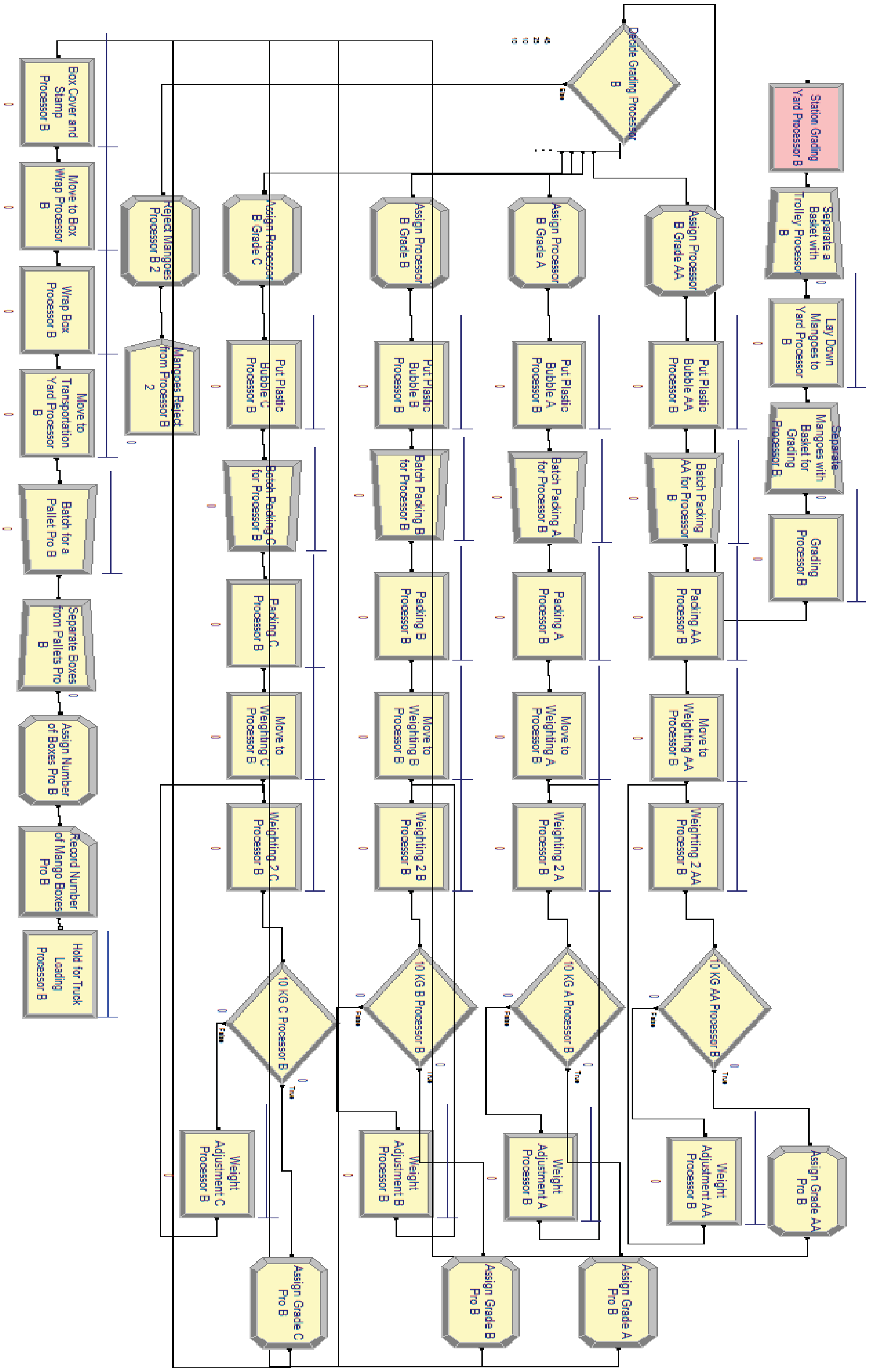


Figure B.7 – Screenshot for ARENA model for processor B (continued)

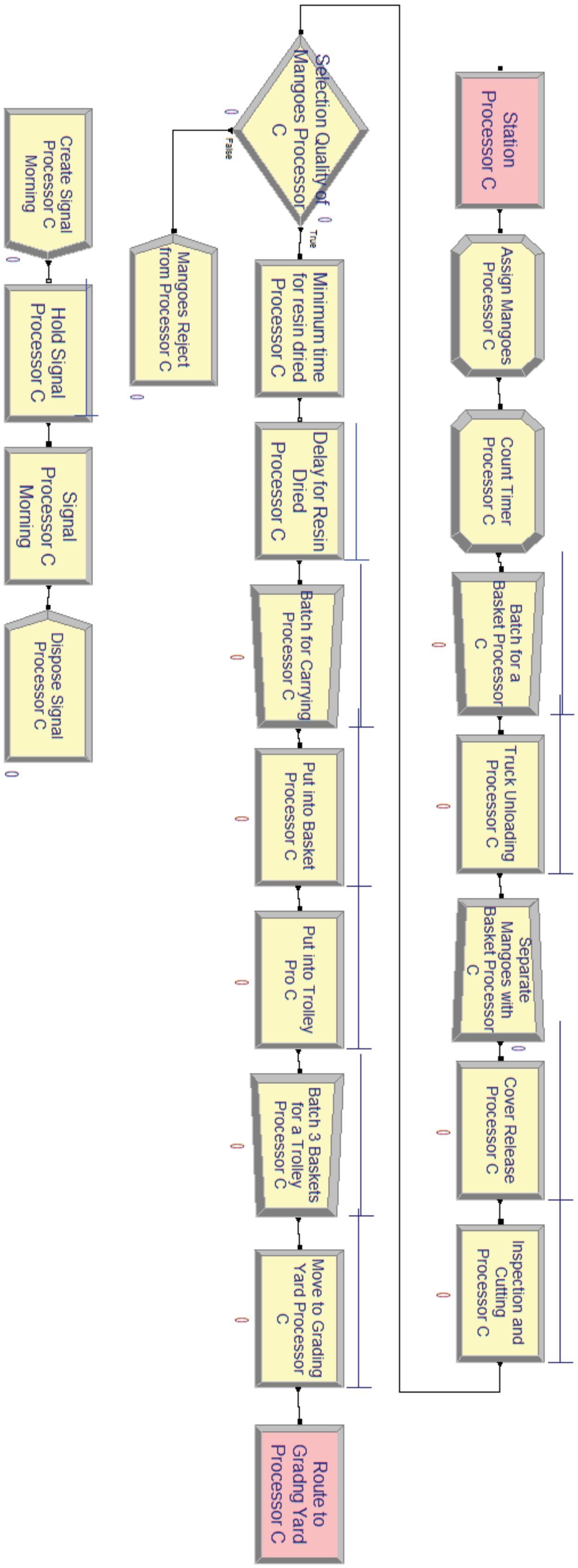


Figure B.8 – Screenshot for ARENA model for processor C

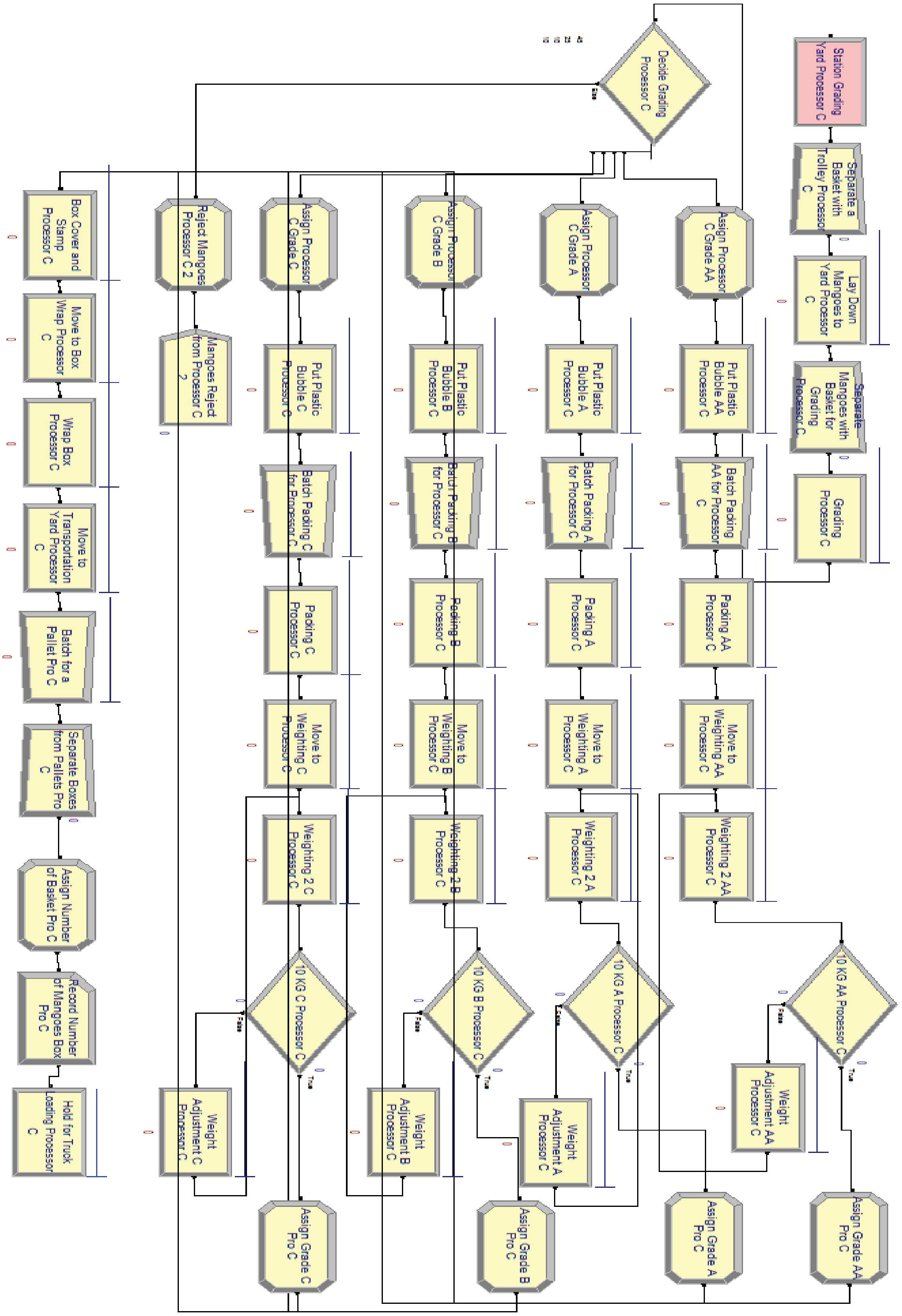


Figure B.8 – Screenshot for ARENA model for processor C (continued)

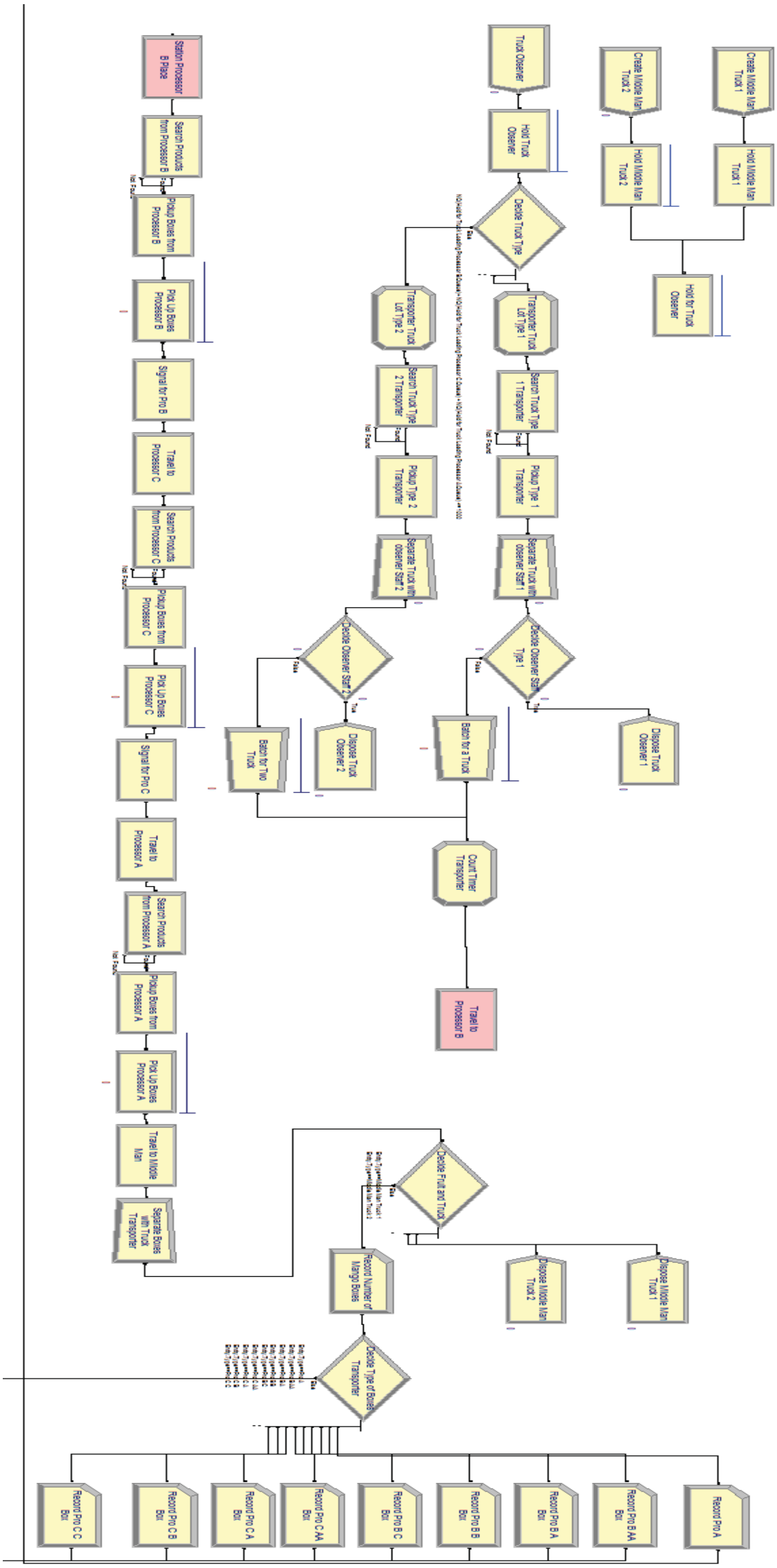


Figure B.9 – Screenshot for ARENA model for transporter

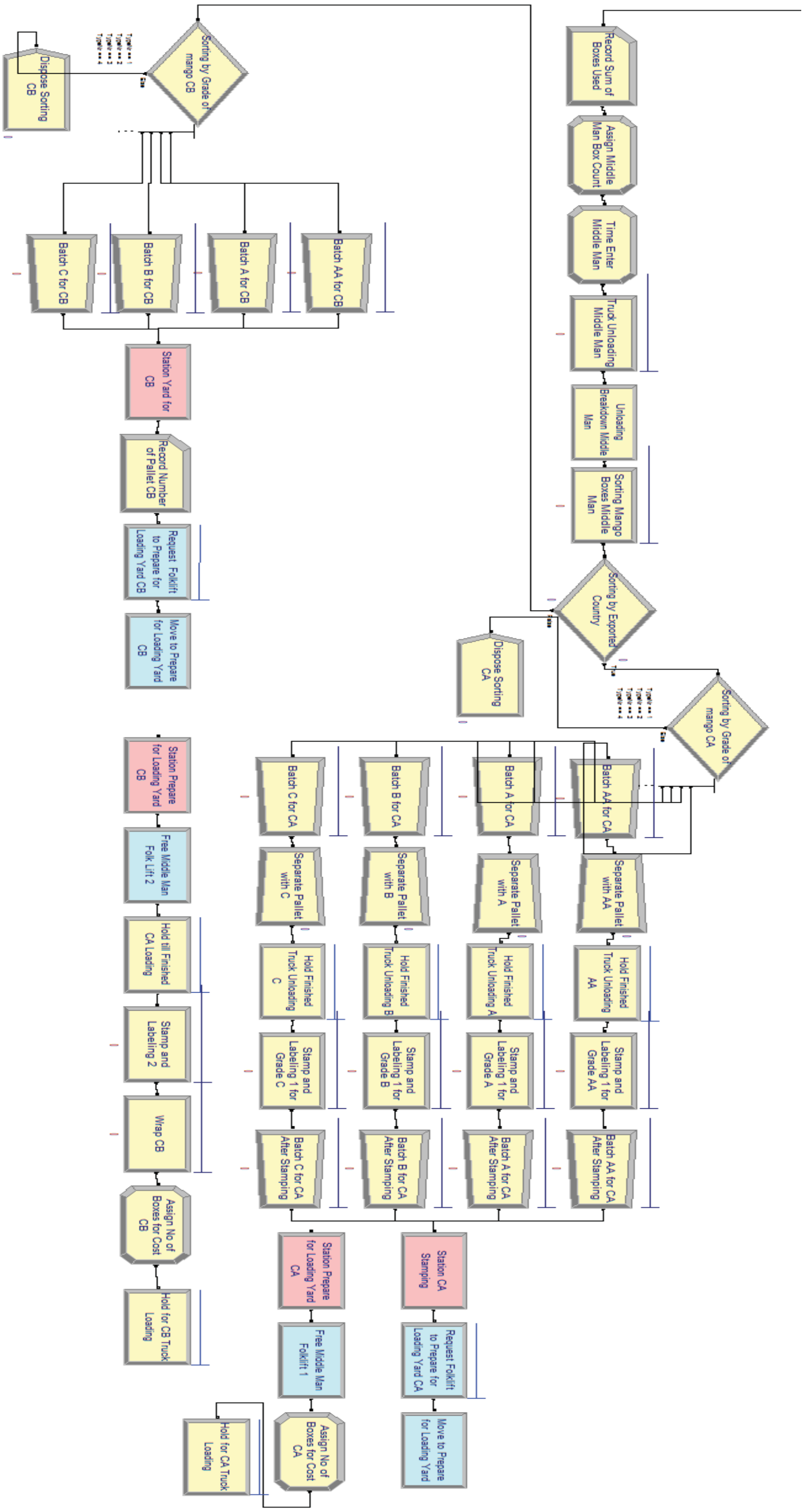


Figure B.10 – Screenshot for ARENA model for middleman firm

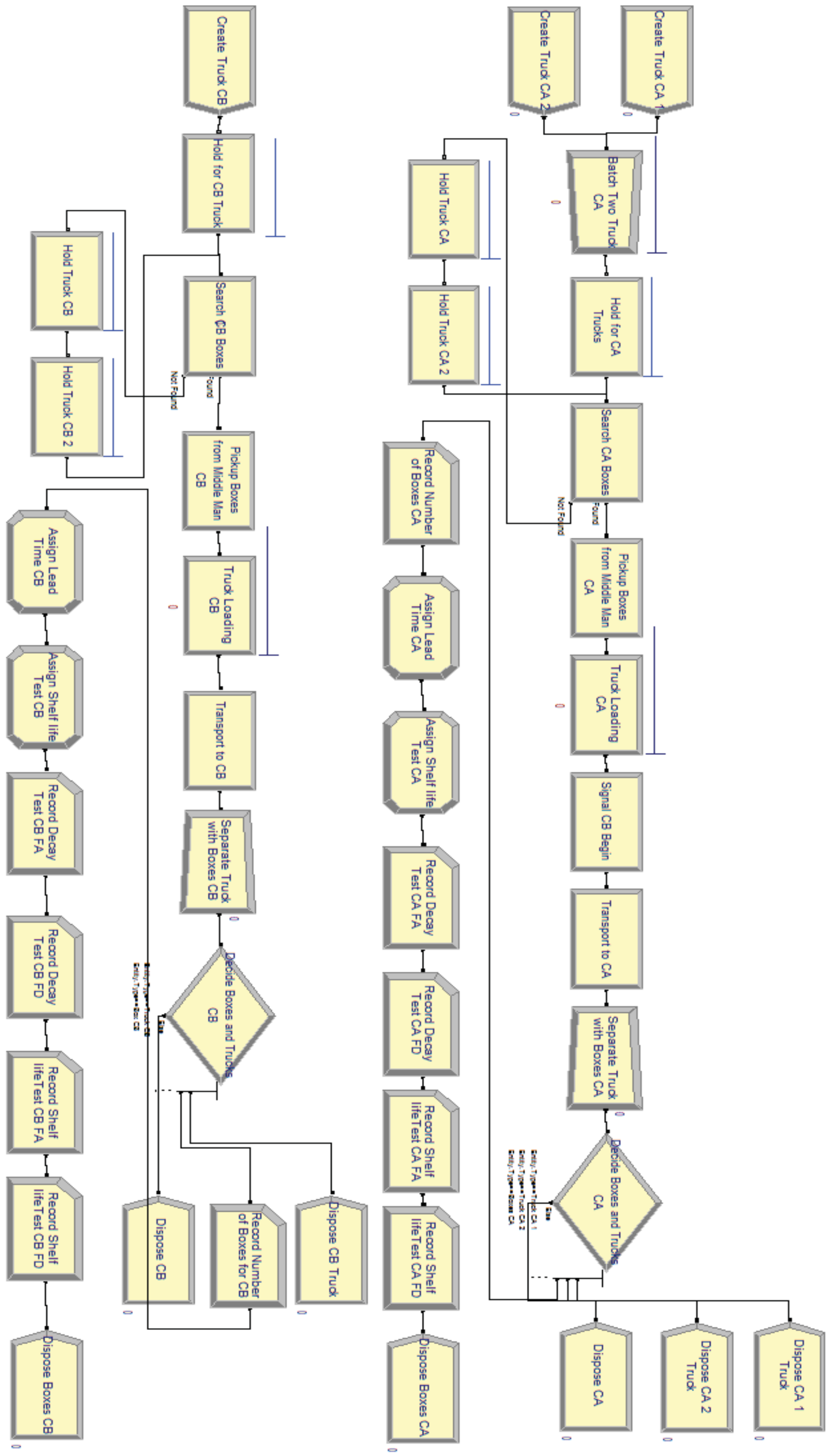


Figure B.10 – **Screenshot for ARENA model for middleman firm** (**continued**)

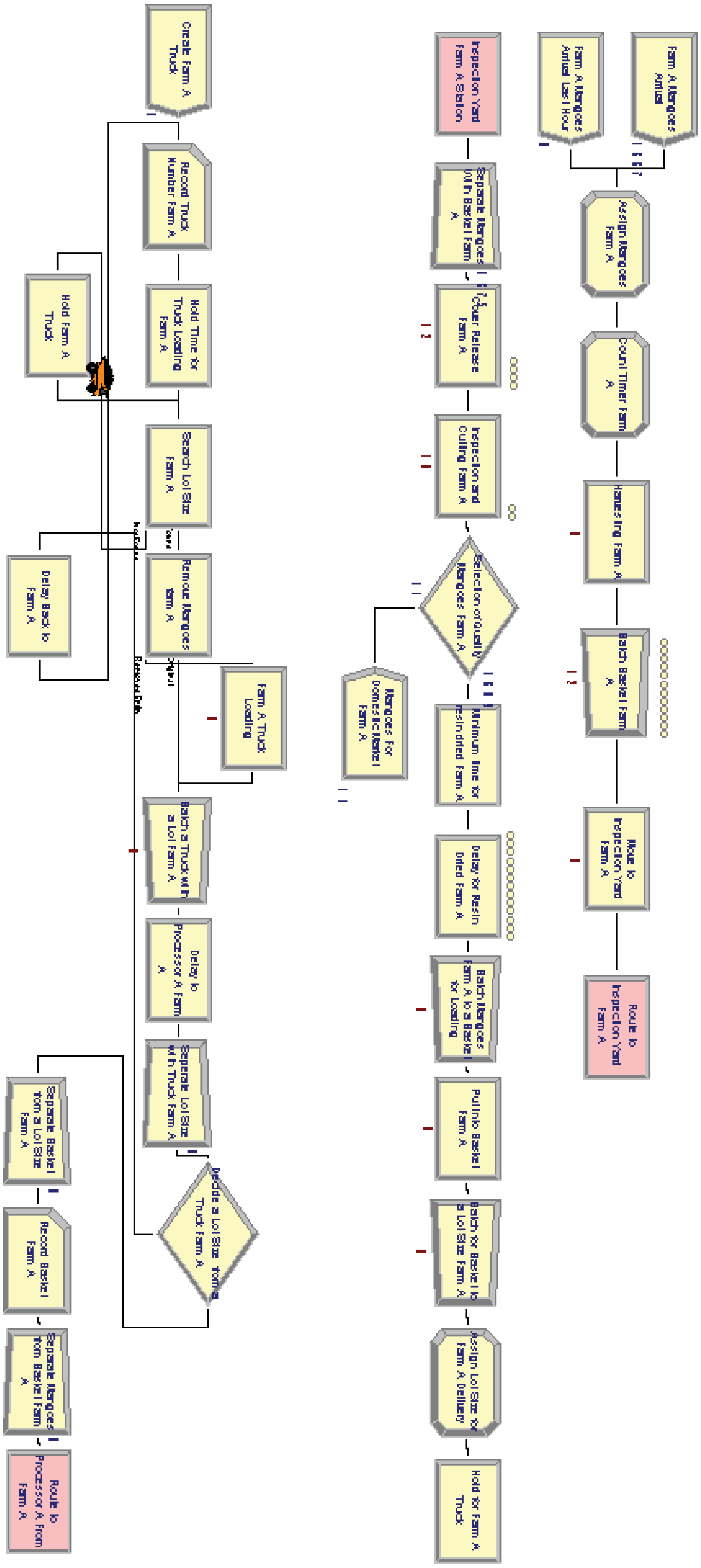


Figure B.11 – **Screenshot of the model animation for farm A**

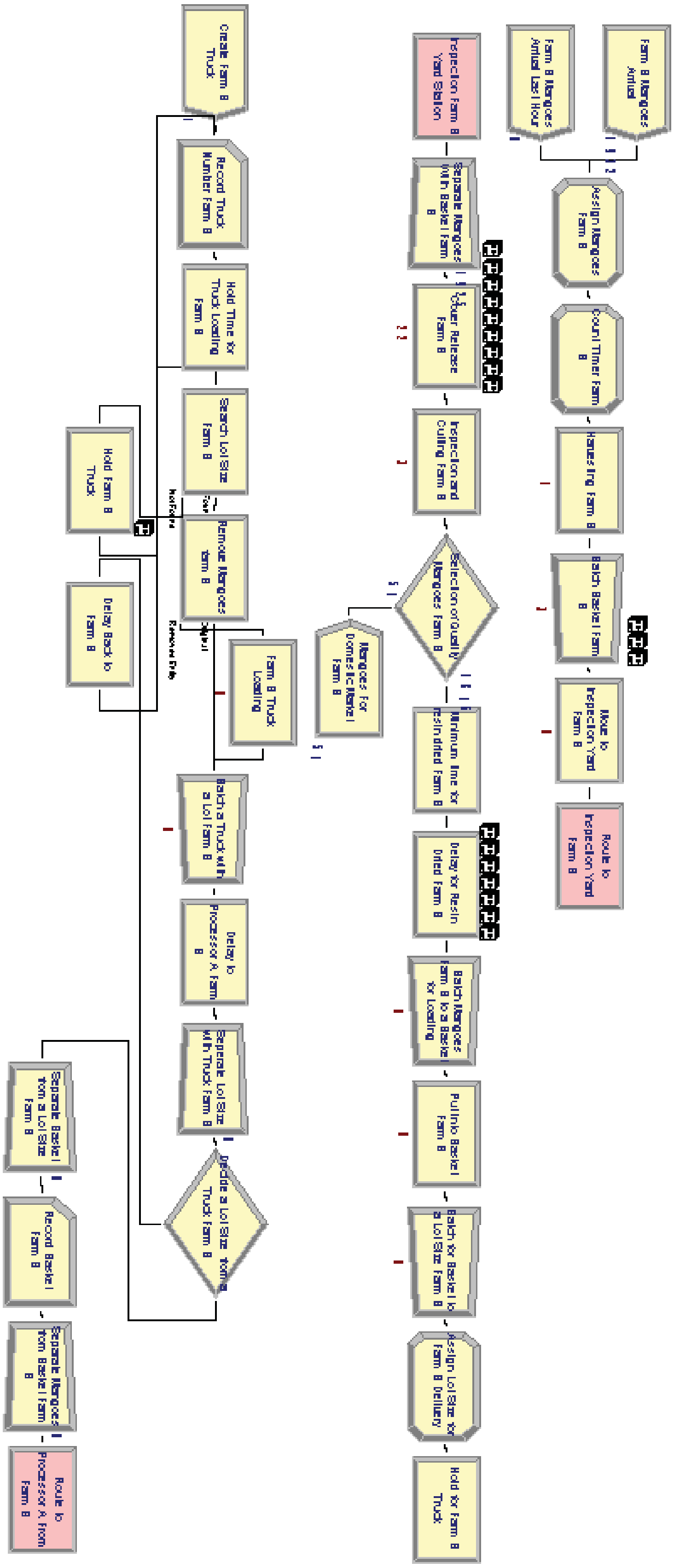


Figure B.12 – Screenshot of the model animation for farm B

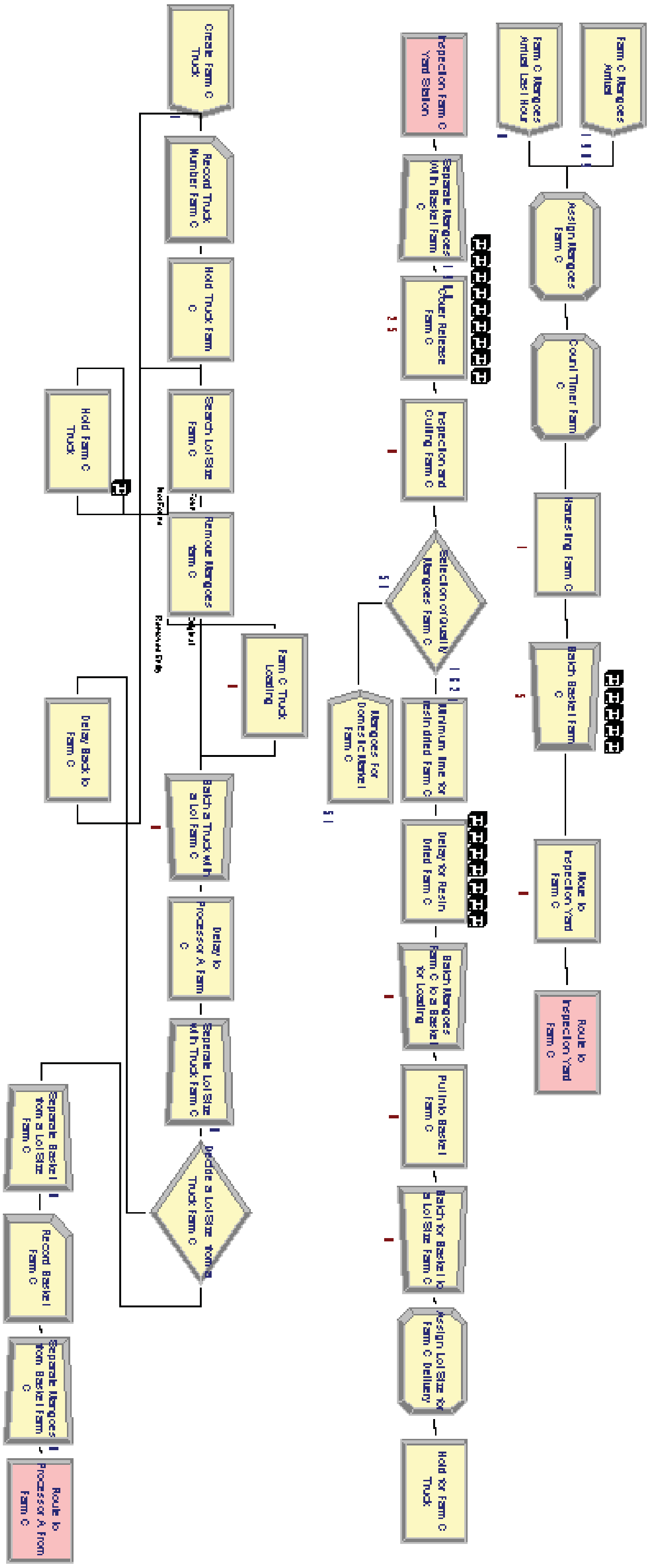


Figure B.13 – Screenshot of the model animation for farm C

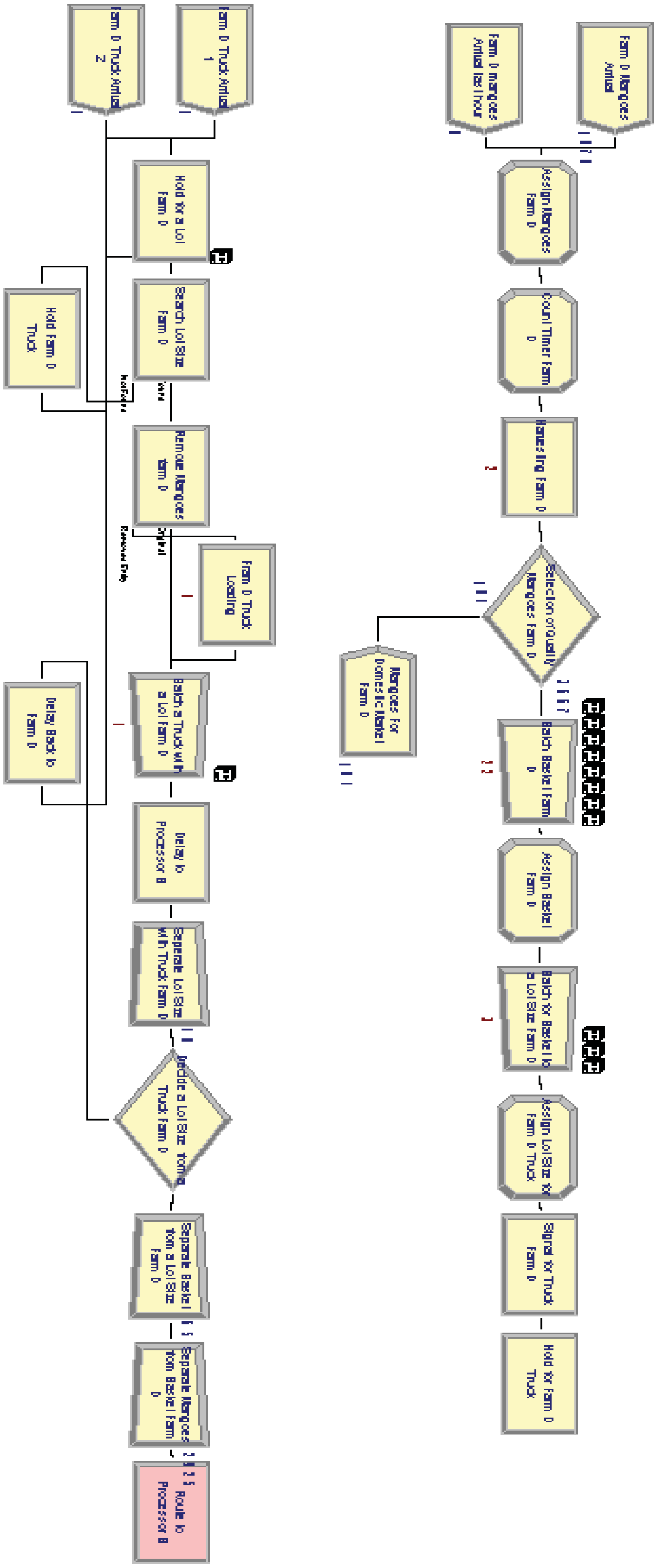


Figure B.14 – Screenshot of the model animation for farm D

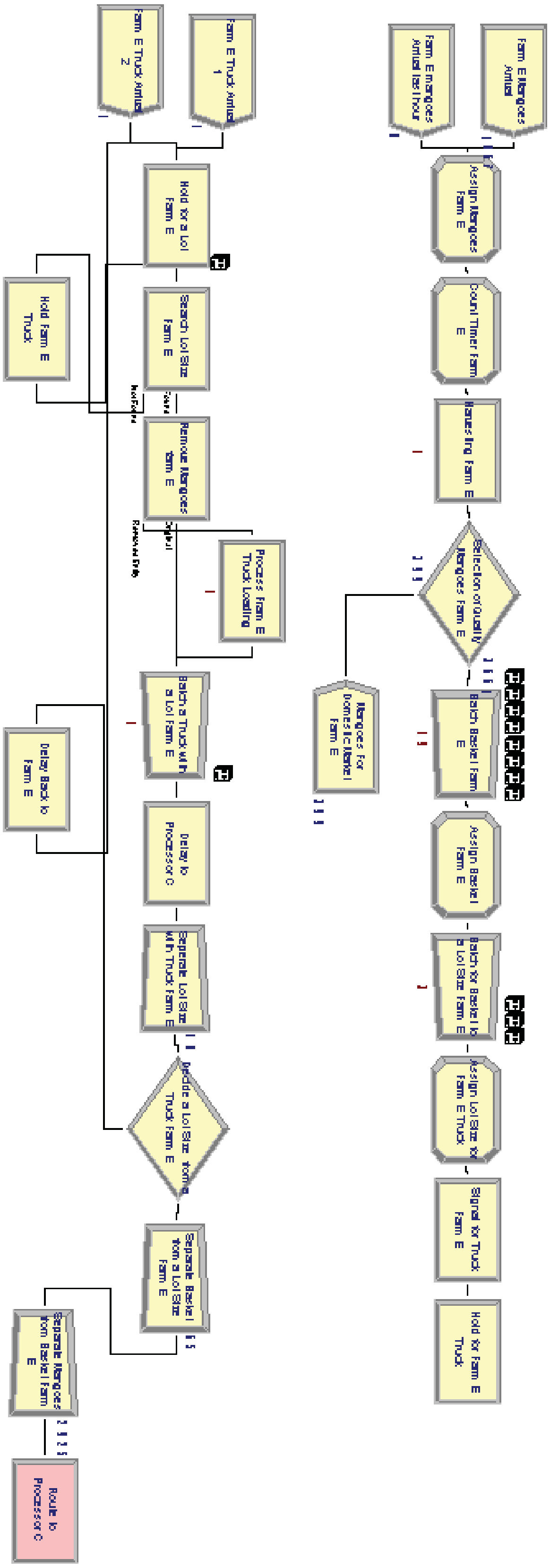


Figure B.15 – Screenshot of the model animation for farm E

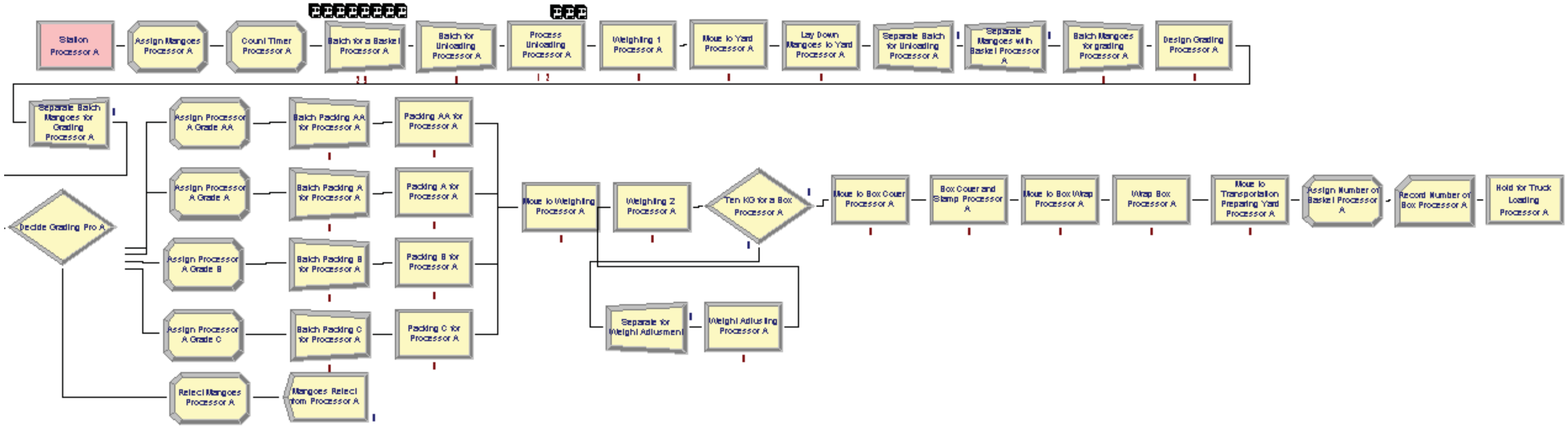


Figure B.16 – Screenshot of the model animation for processor A

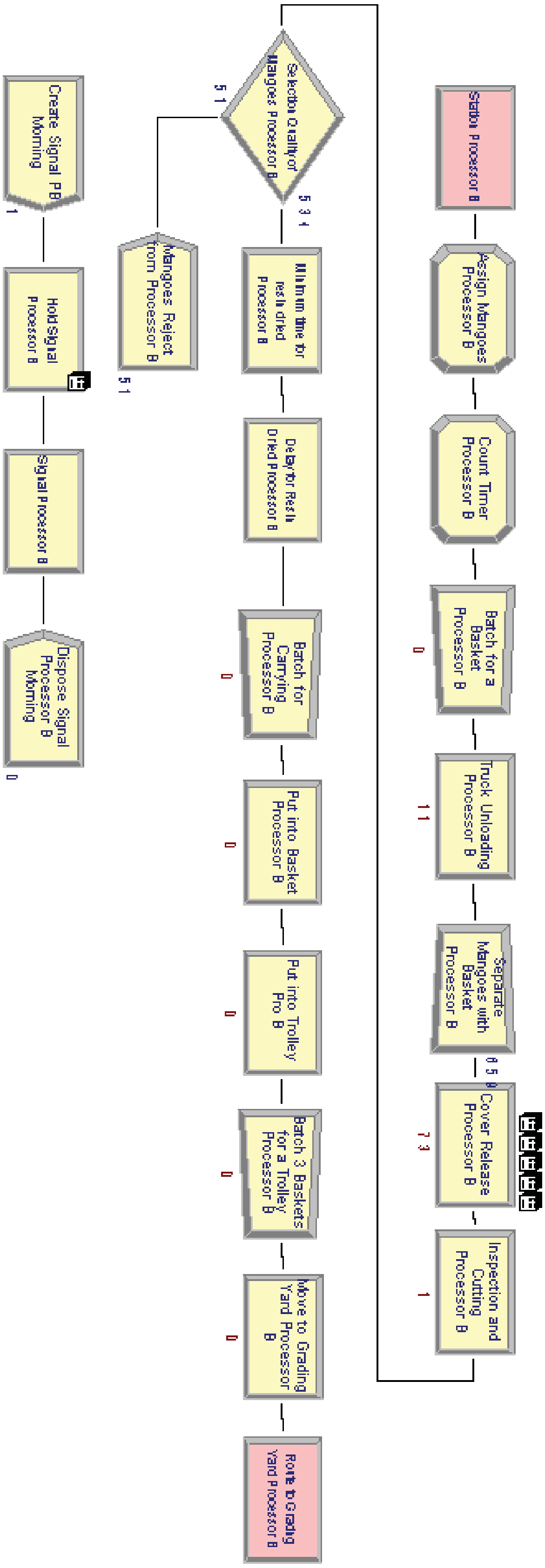


Figure B.17 – Screenshot of the model animation for processor B

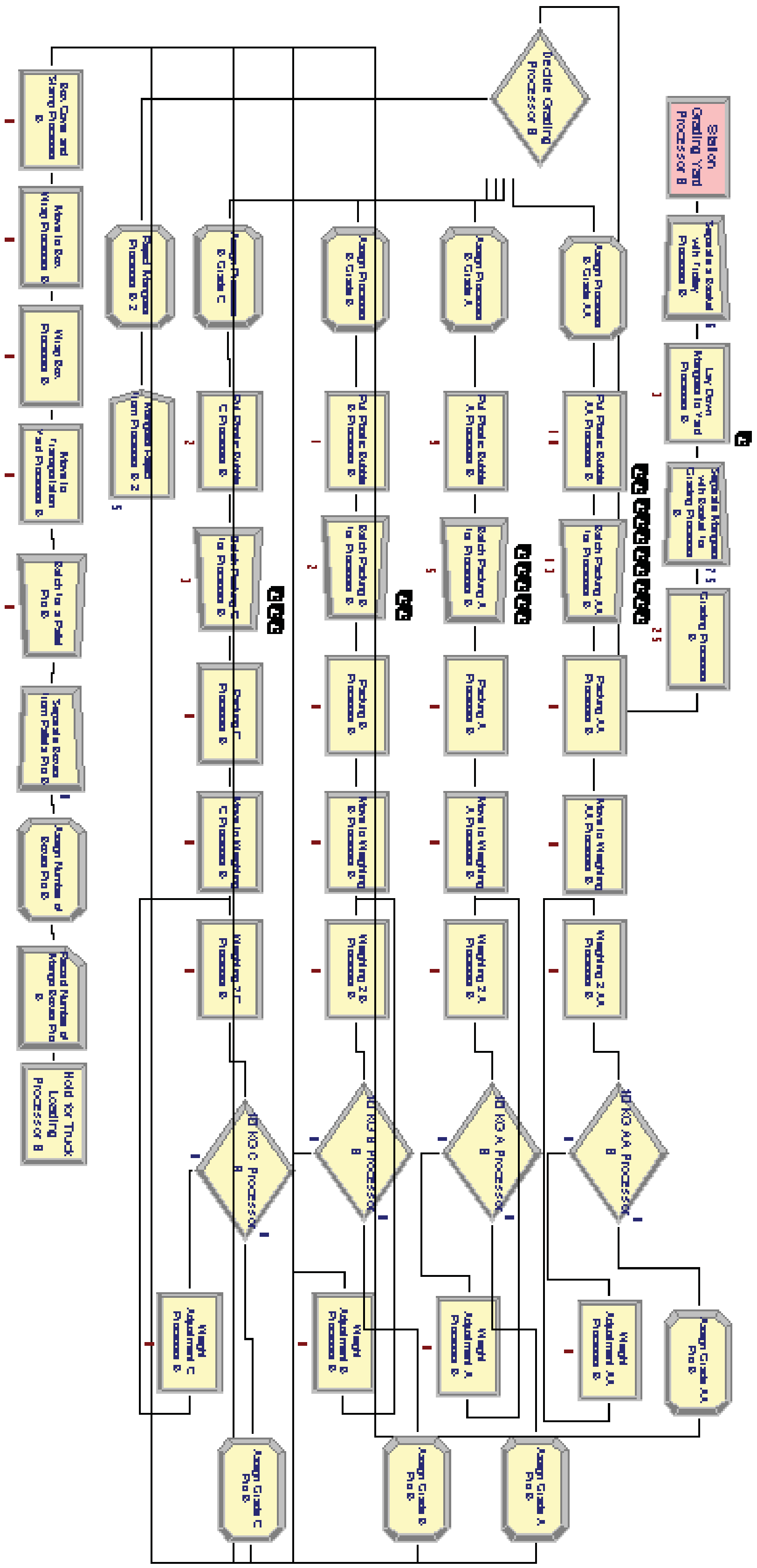


Figure B.17 – Screenshot of the model animation for processor B (continued)

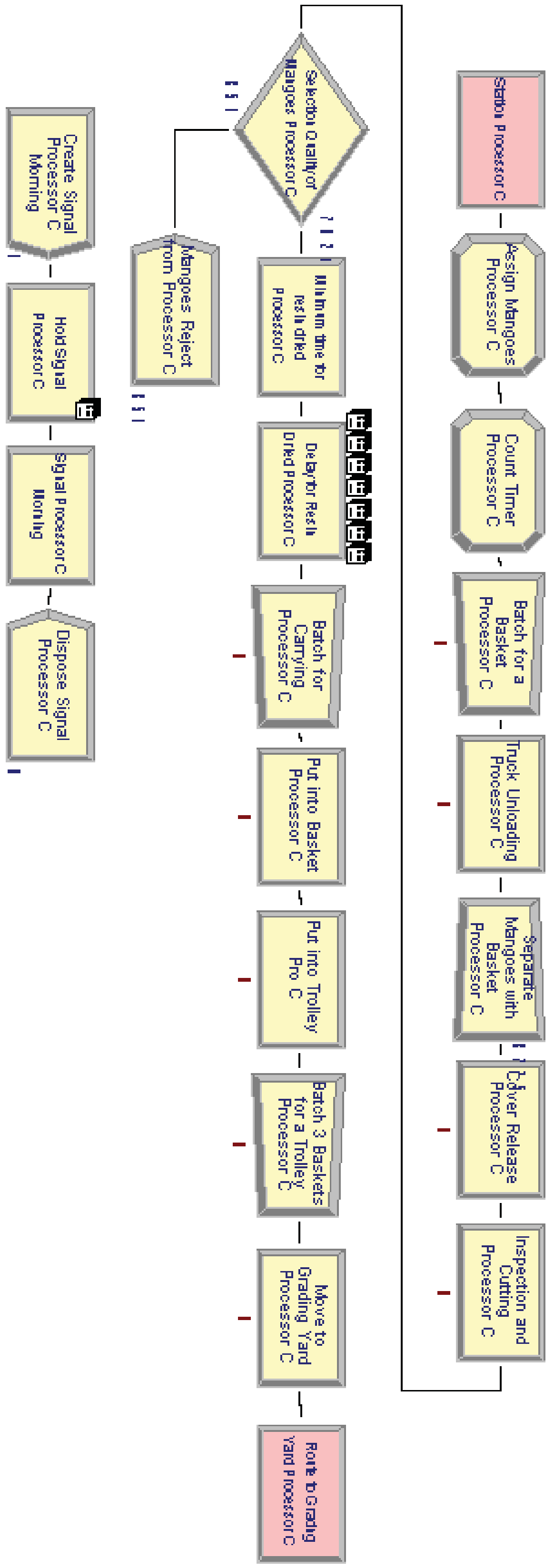


Figure B.18 – Screenshot of the model animation for processor C

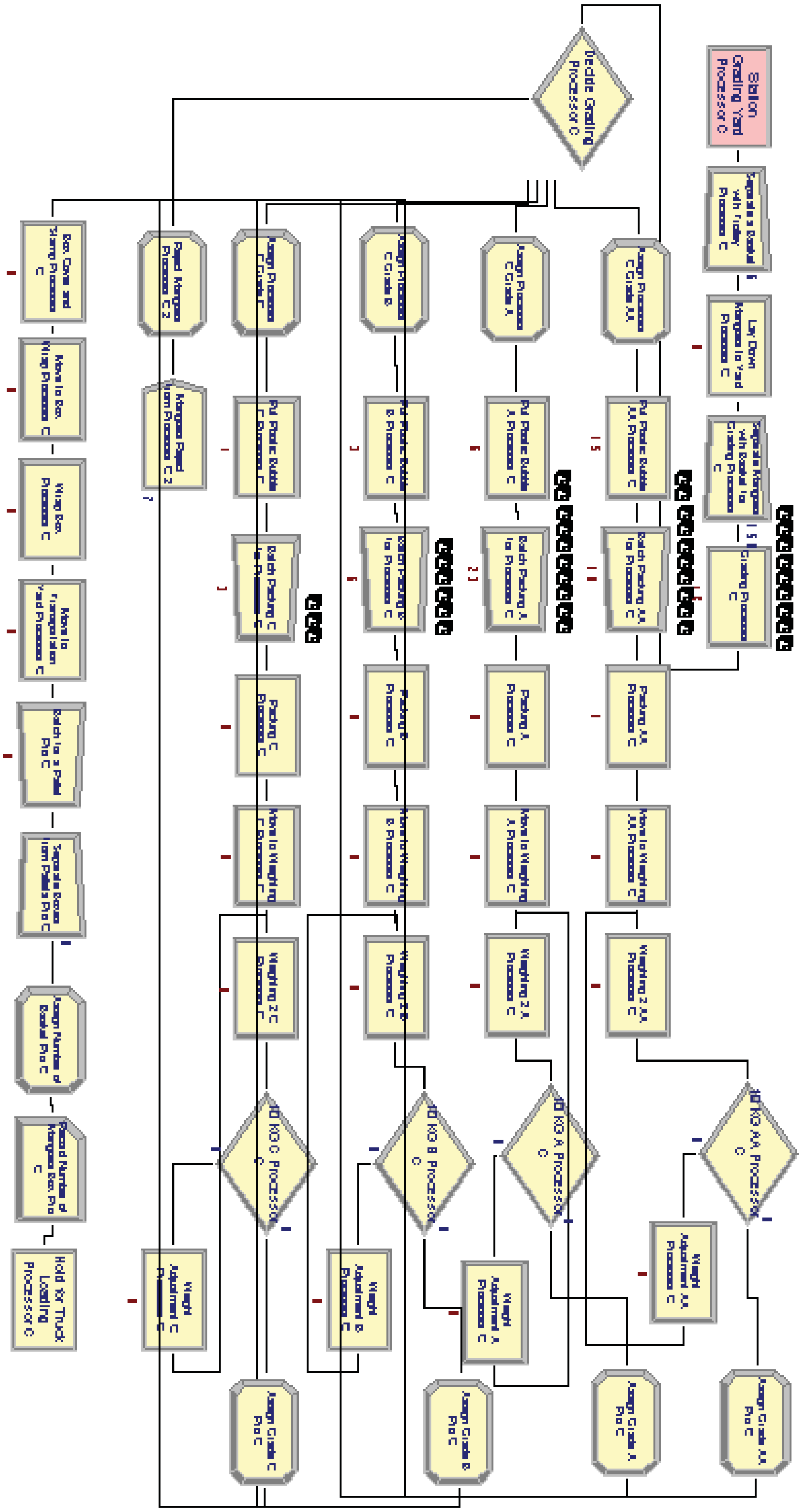


Figure B.18 – Screenshot of the model animation for processor C (continued)

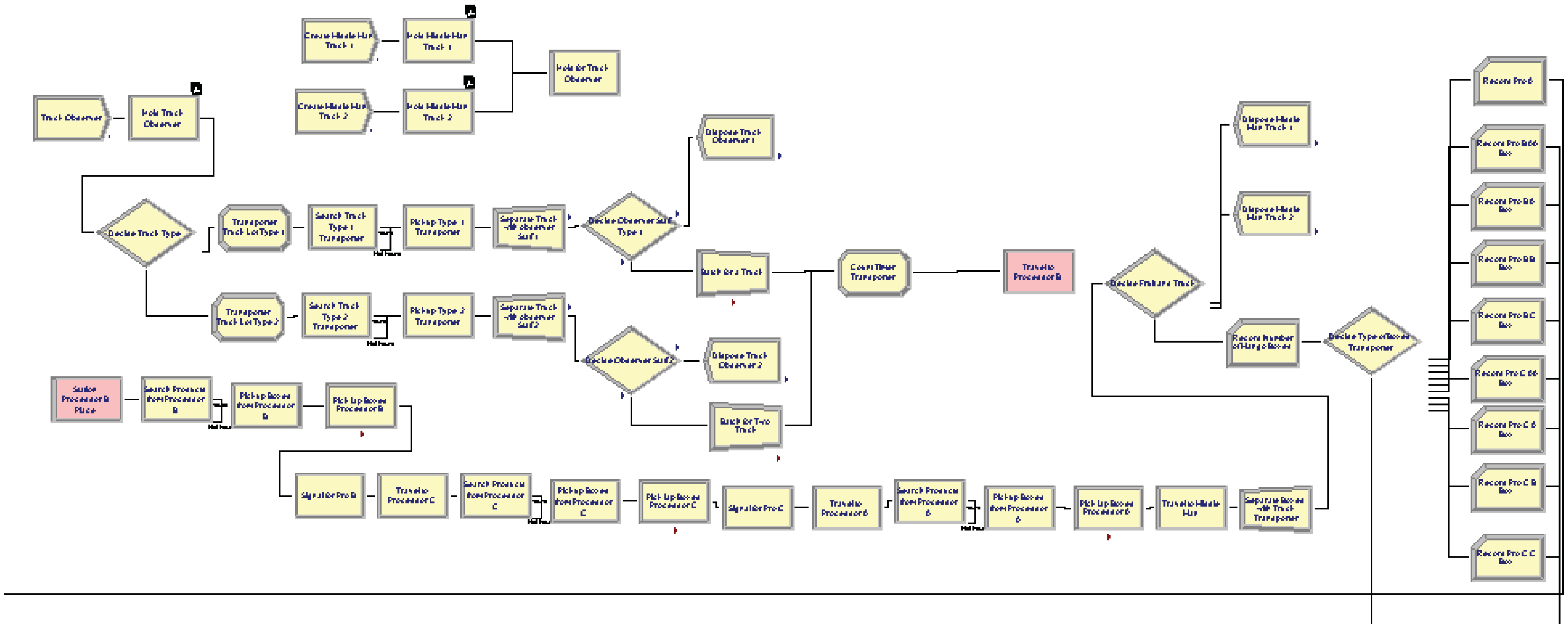


Figure B.19 – Screenshot of the model animation for transporter

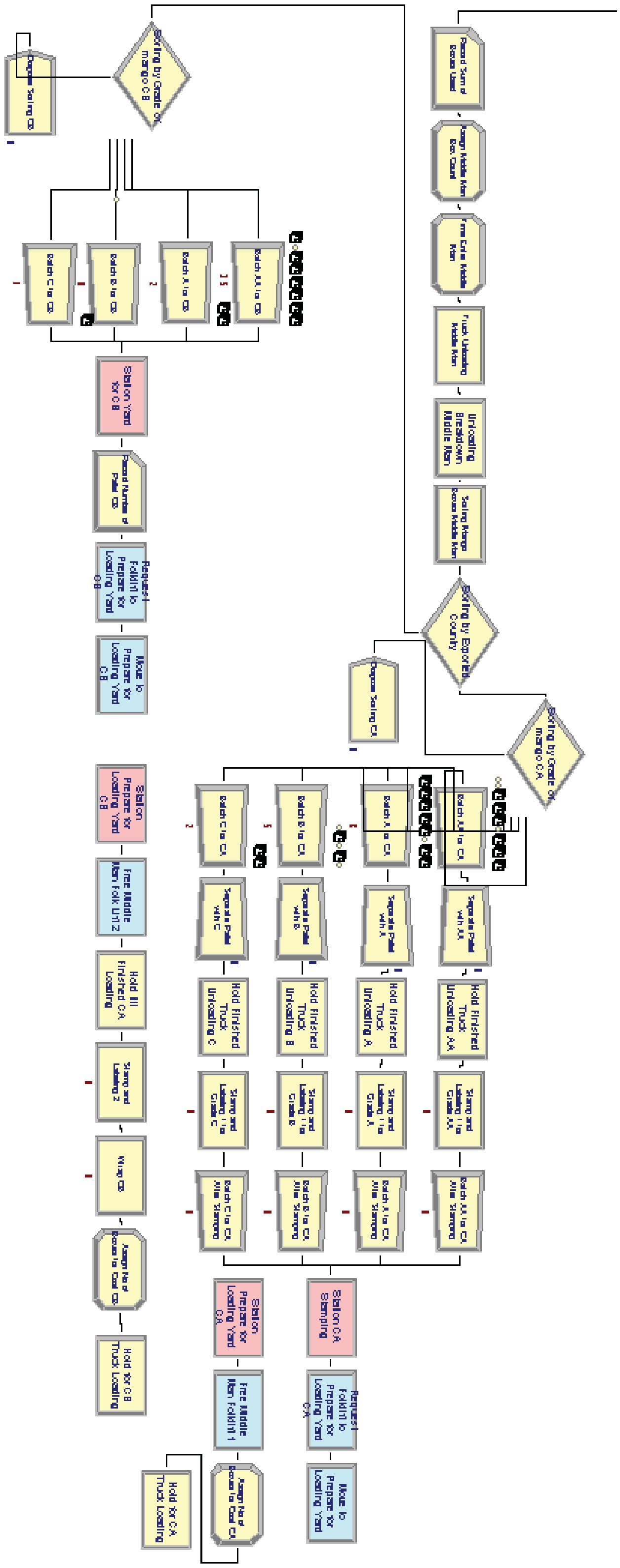


Figure B.20 – Screenshot for ARENA model for middleman firm

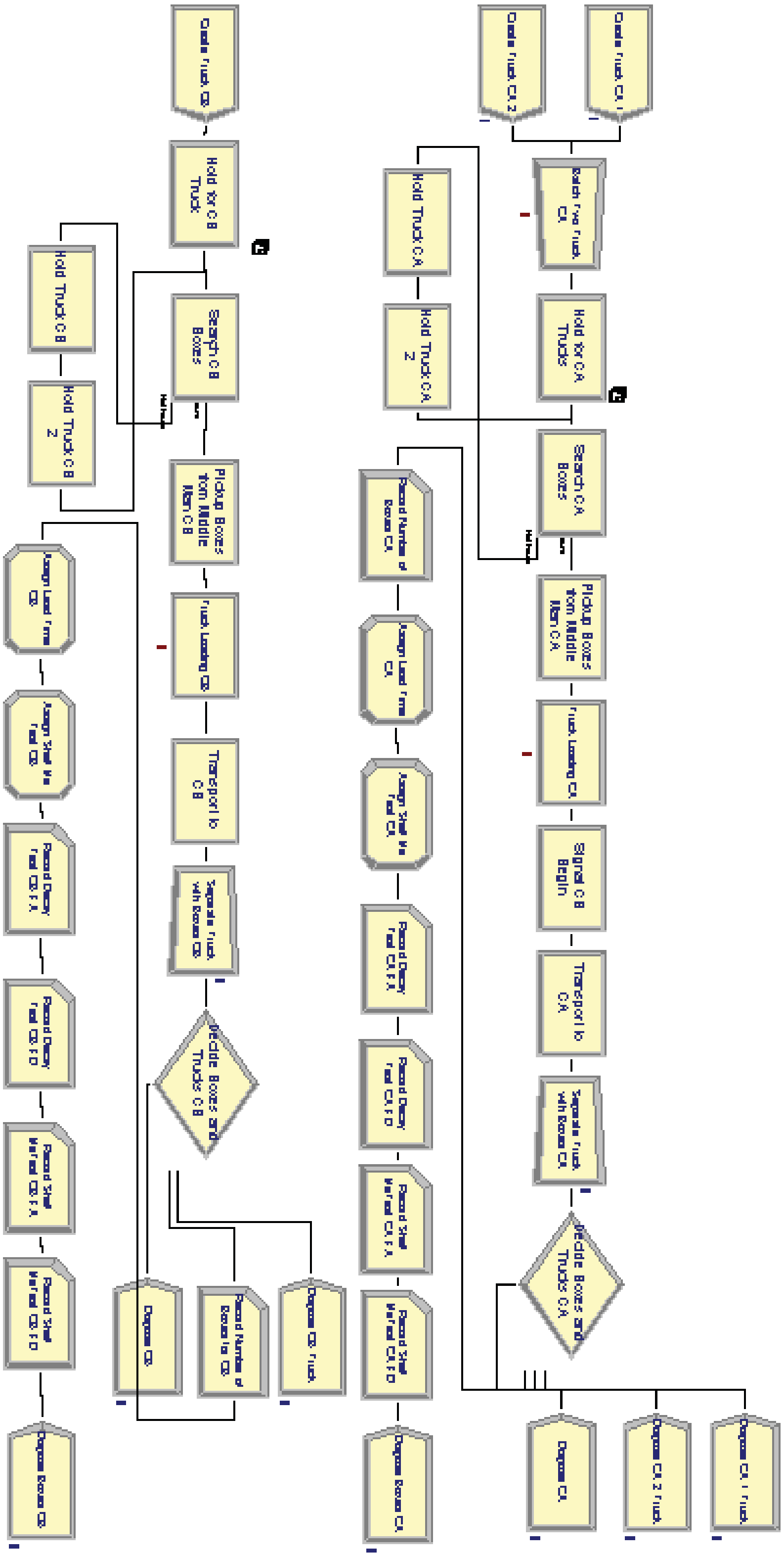


Figure B.20 – Screenshot for ARENA model for middleman firm (continued)

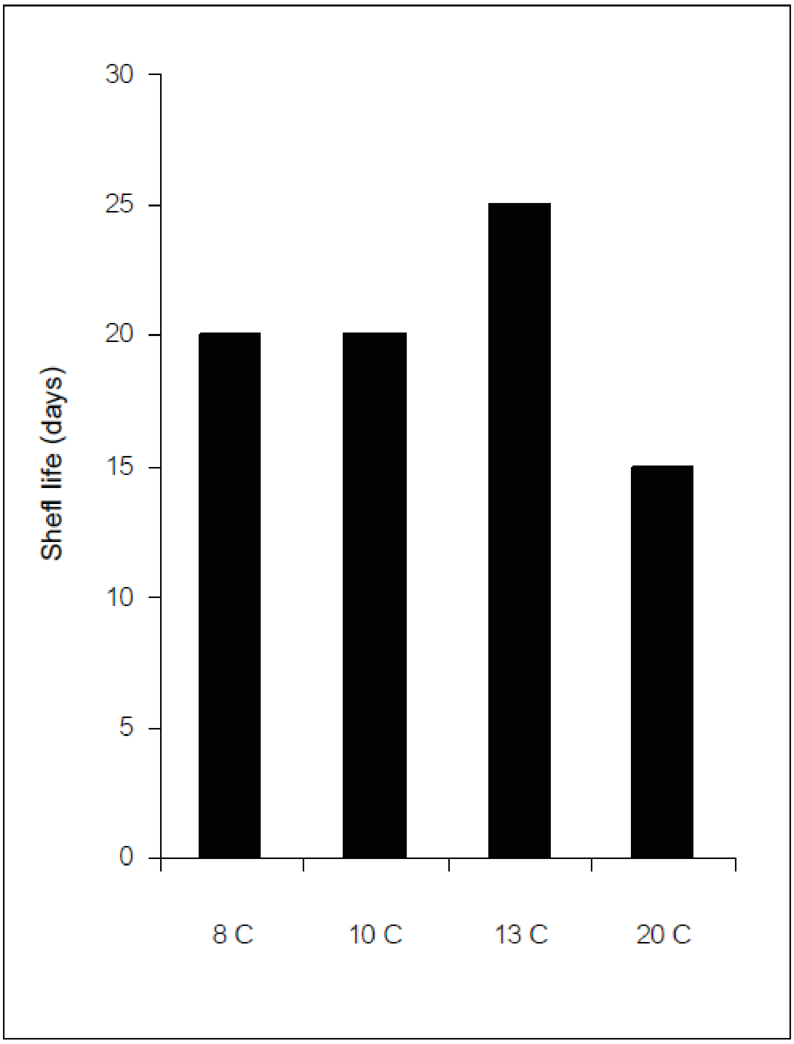
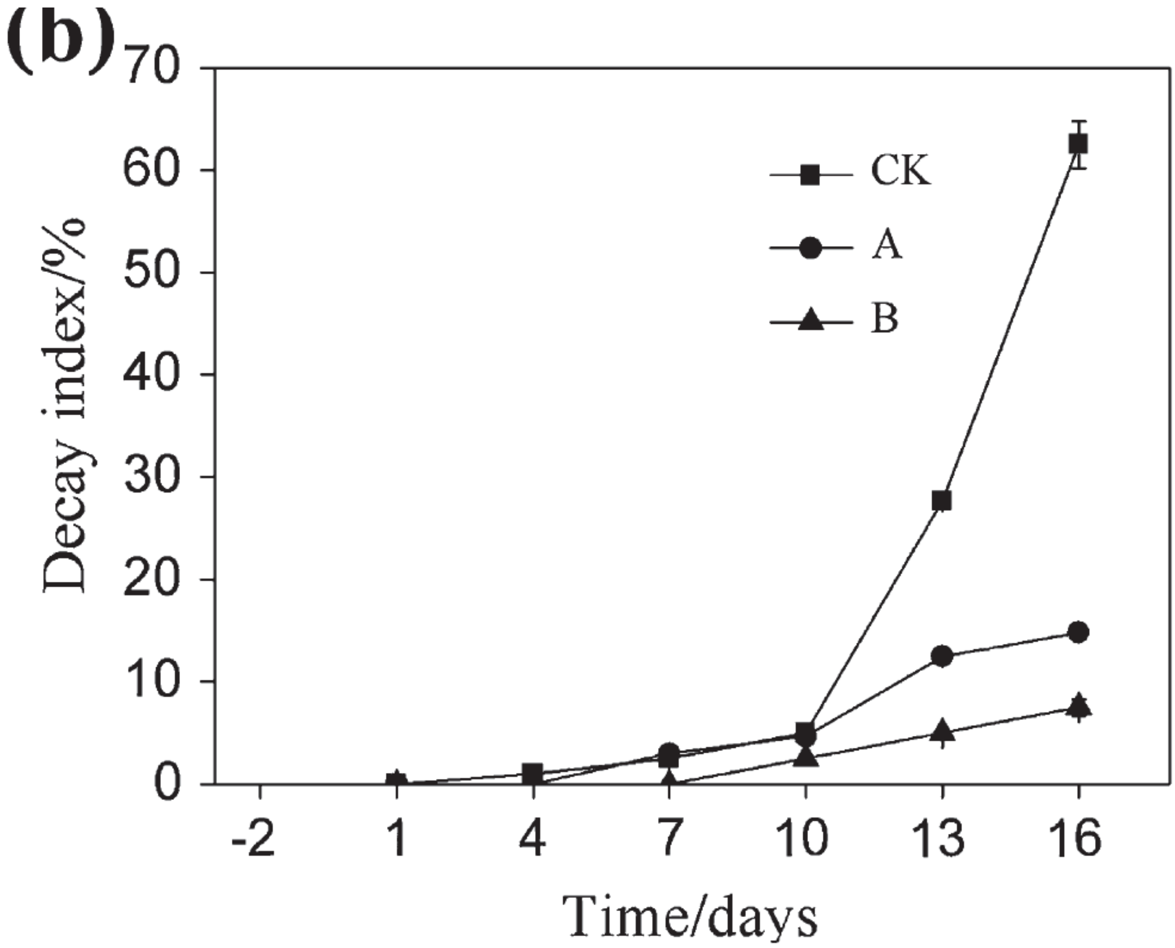


Figure B.21 – Mango shelf life with different temperature in degrees (Dongkhum & Kanlayanarat 2002).



CK = Control, A = Coated by bentonite (Deionizedwater:bentonite = 1:15), B= Coated by bentonite + potassium sorbate bentonite (Deionized water:bentonite = 1:15:0.07)

Figure B.22 – Mango decay index at room temperature (Liu, Wang & Young 2014)

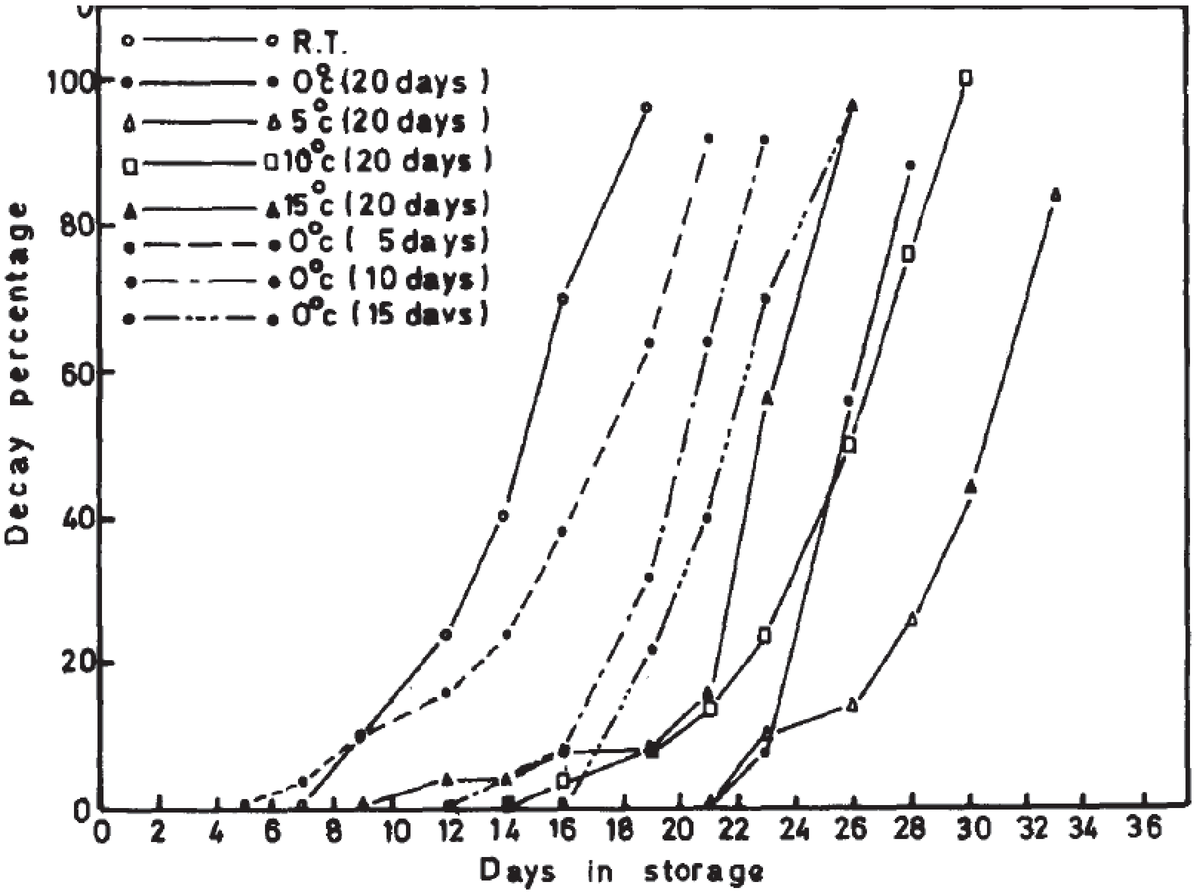
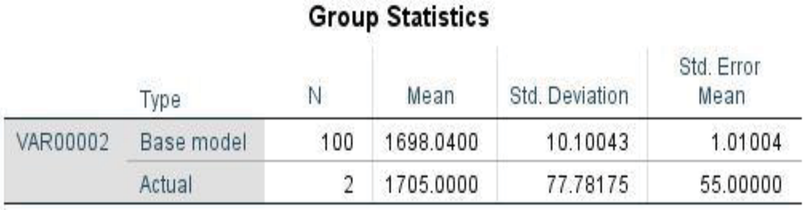


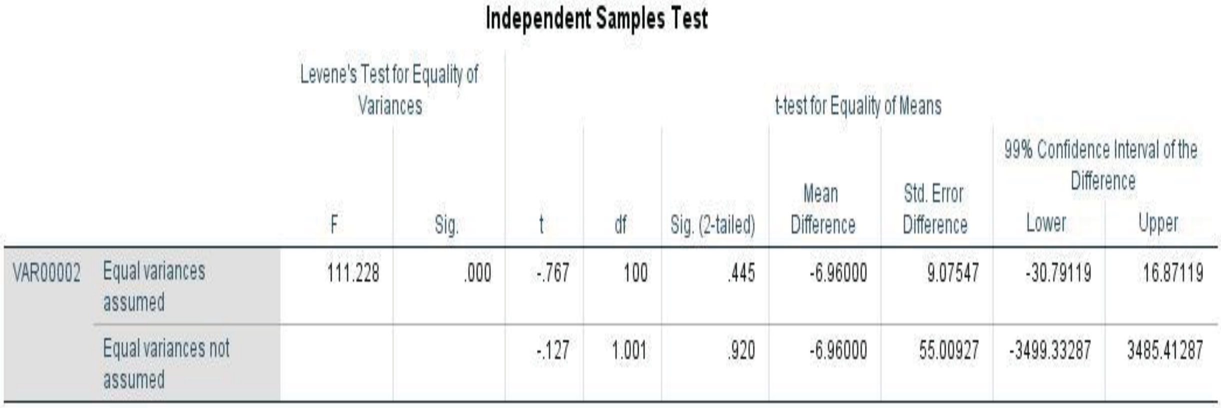
Figure B.23 – Mango decay percentage at 10-15 Degrees Celsius (Abou-Aziz et al. 1976)

Table B.7 – *t*-test results comparing base model and actual on Throughput of mango supply chain



Group Statistics

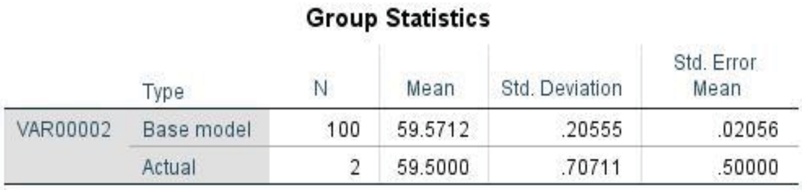
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	1698.0400	10.10043	1.01004
	Actual	2	1705.0000	77.78175	55.00000



Independent Samples Test

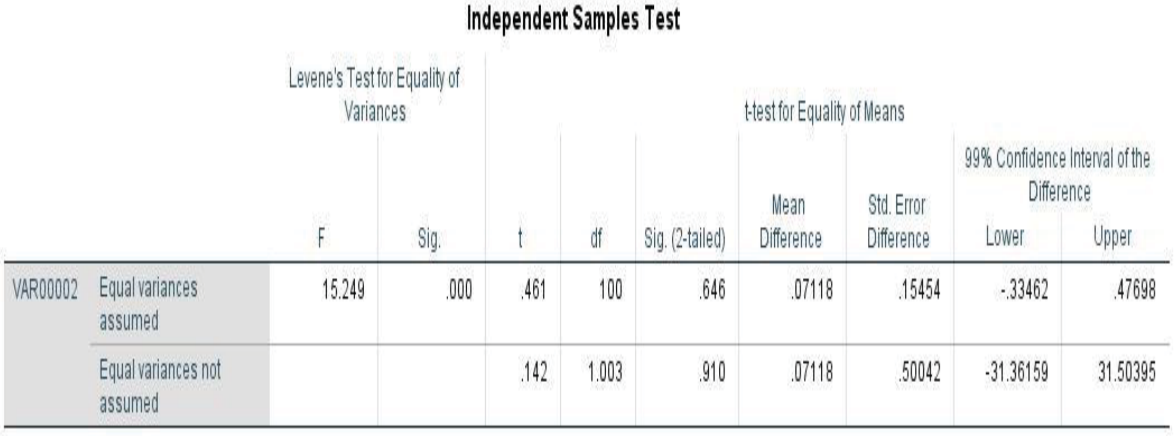
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	111.228	.000	-.767	100	.445	-6.96000	9.07547	-30.79119	16.87119
	Equal variances not assumed			-.127	1.001	.920	-6.96000	55.00927	-3499.33287	3485.41287

Table B.8 – *t*-test results comparing base model and actual on country A processing time of mango supply chain



Group Statistics

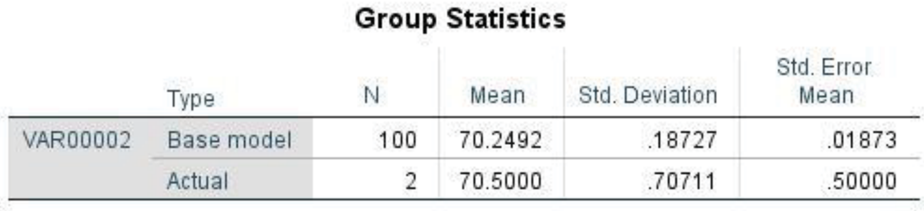
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	59.5712	.20555	.02056
	Actual	2	59.5000	.70711	.50000



Independent Samples Test

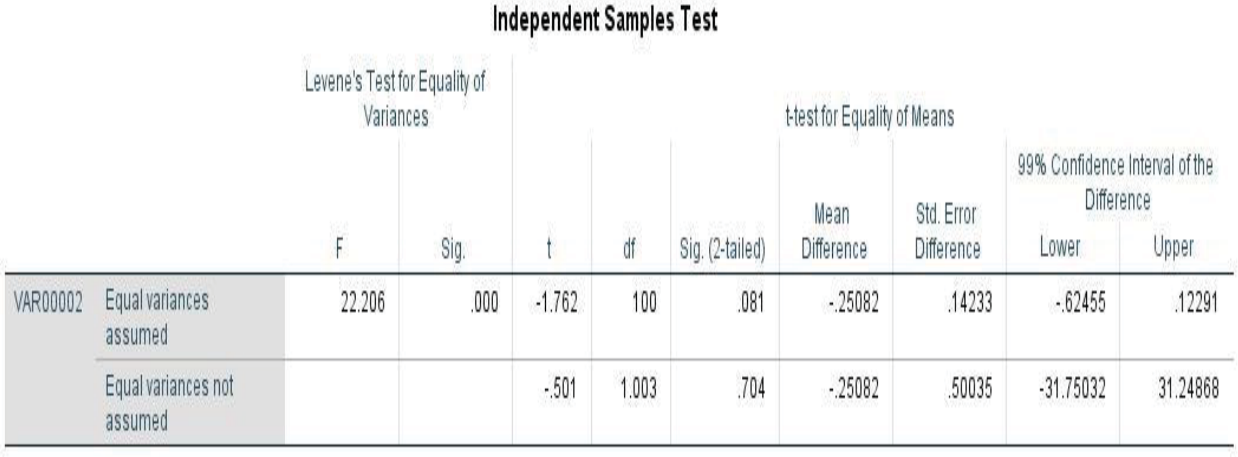
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	15.249	.000	.461	100	.646	.07118	.15454	-.33462	.47698
	Equal variances not assumed			.142	1.003	.910	.07118	.50042	-31.36159	31.50395

Table B.9 – *t*-test results comparing base model and actual on country B processing time of mango supply chain



Group Statistics

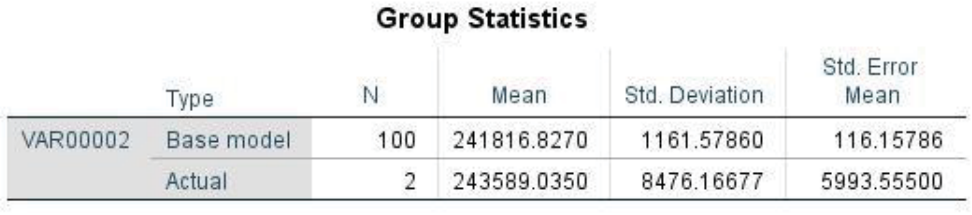
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	70.2492	.18727	.01873
	Actual	2	70.5000	.70711	.50000



Independent Samples Test

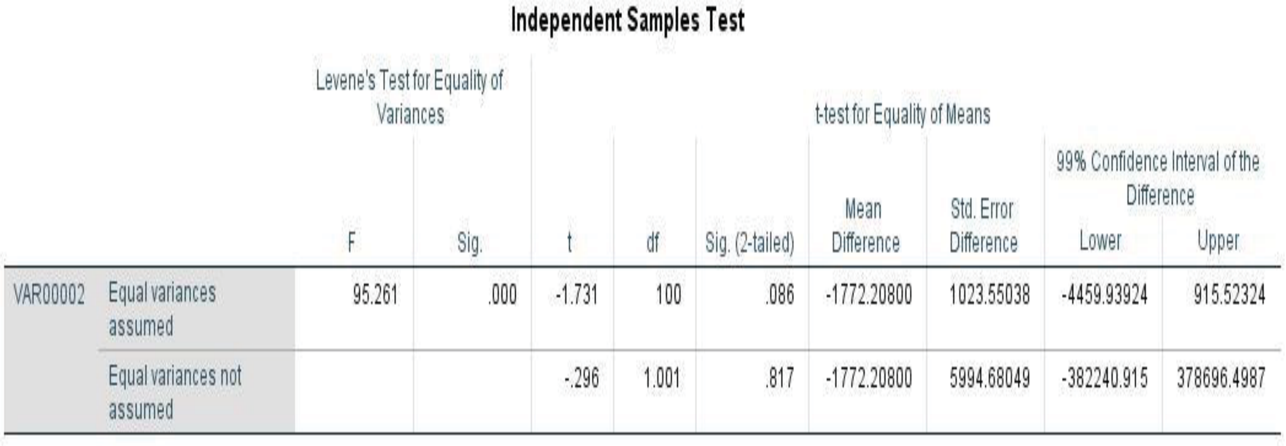
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	22.206	.000	-1.762	100	.081	-.25082	.14233	-.62455	.12291
	Equal variances not assumed			-.501	1.003	.704	-.25082	.50035	-31.75032	31.24868

Table B.10 – *t*-test results comparing base model and actual on operating cost of mango supply chain



Group Statistics

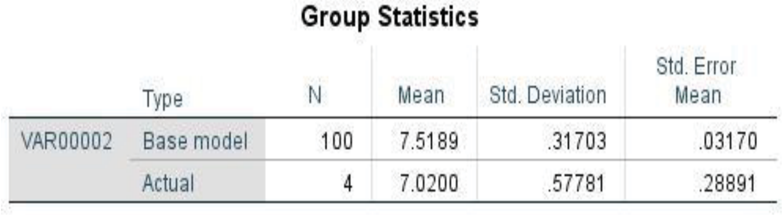
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	241816.8270	1161.57860	116.15786
	Actual	2	243589.0350	8476.16677	5993.55500



Independent Samples Test

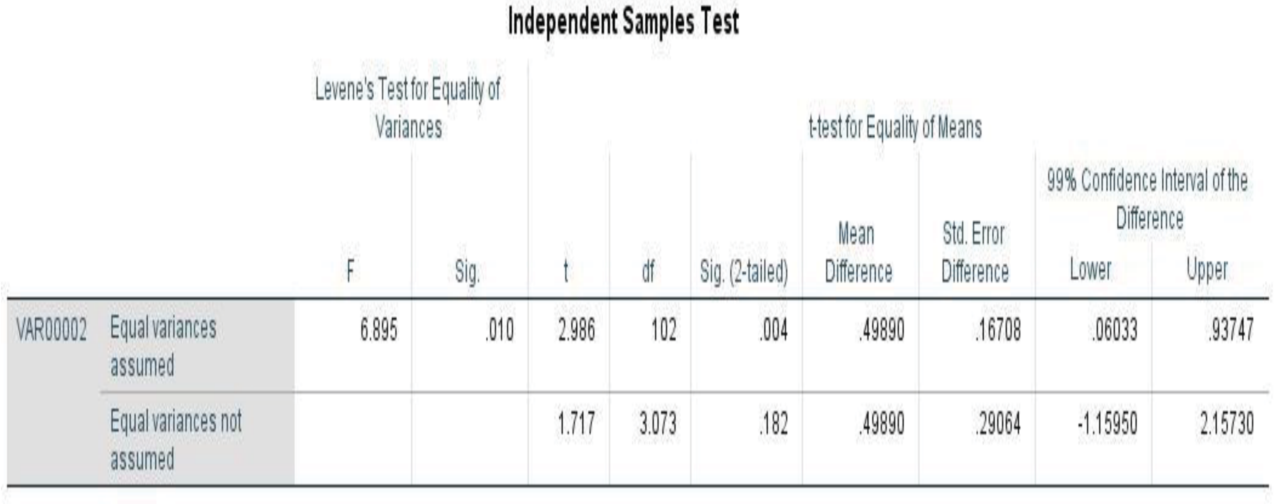
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	95.261	.000	-1.731	100	.086	-1772.20800	1023.55038	-4459.93924	915.52324
	Equal variances not assumed			-.296	1.001	.817	-1772.20800	5994.68049	-382240.915	378696.4987

Table B.11 – *t*-test results comparing base model and actual on farm group A to country A shelf life of mango supply chain



Group Statistics

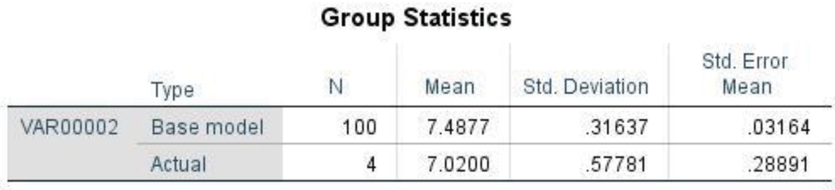
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	7.5189	.31703	.03170
	Actual	4	7.0200	.57781	.28891



Independent Samples Test

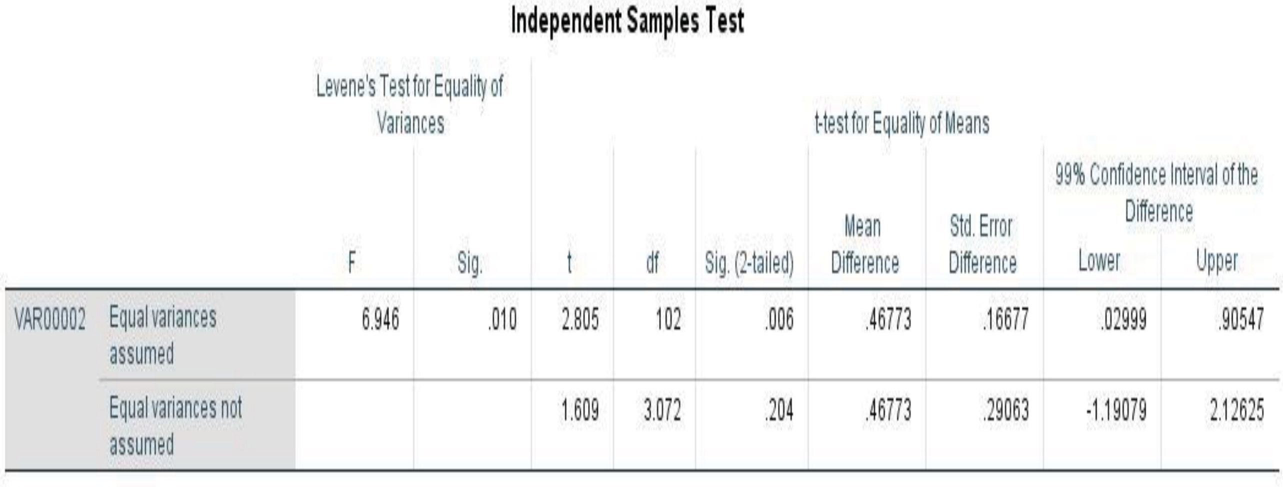
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	6.895	.010	2.986	102	.004	.49890	.16708	.06033	.93747
	Equal variances not assumed			1.717	3.073	.182	.49890	.29064	-1.15950	2.15730

Table B.12 – *t*-test results comparing base model and actual on farm group B to country A shelf life of mango supply chain



Group Statistics

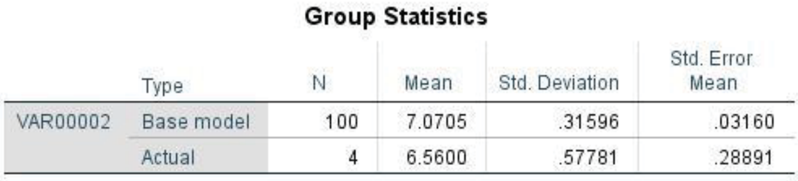
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	7.4877	.31637	.03164
	Actual	4	7.0200	.57781	.28891



Independent Samples Test

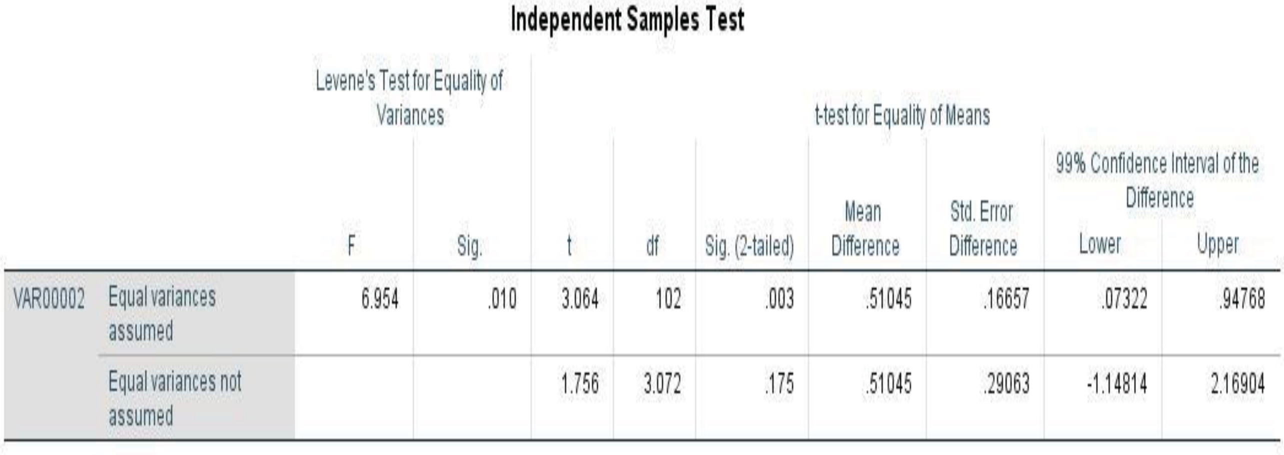
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	6.946	.010	2.805	102	.006	.46773	.16677	.02999	.90547
	Equal variances not assumed			1.609	3.072	.204	.46773	.29063	-1.19079	2.12625

Table B.13 – *t*-test results comparing base model and actual on farm group A to country B shelf life of mango supply chain



Group Statistics

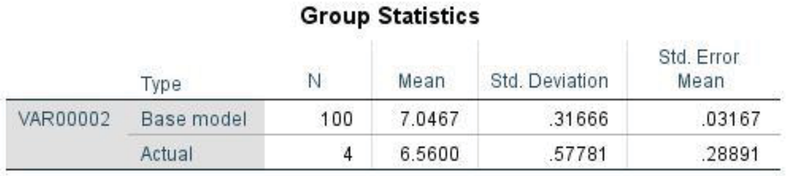
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	7.0705	.31596	.03160
	Actual	4	6.5600	.57781	.28891



Independent Samples Test

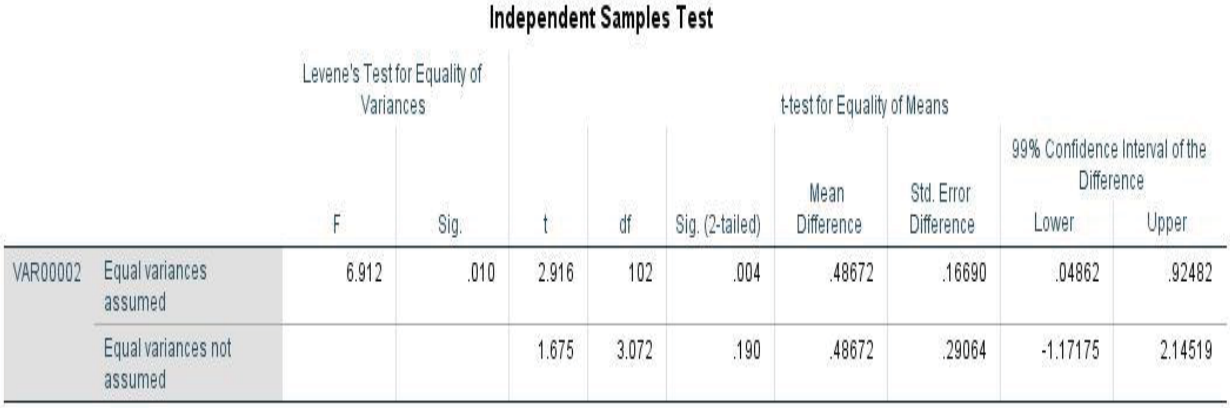
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	6.954	.010	3.064	102	.003	.51045	.16657	.07322	.94768
	Equal variances not assumed			1.756	3.072	.175	.51045	.29063	-1.14814	2.16904

Table B.14 – *t*-test results comparing base model and actual on farm group B to country B shelf life of mango supply chain



Group Statistics

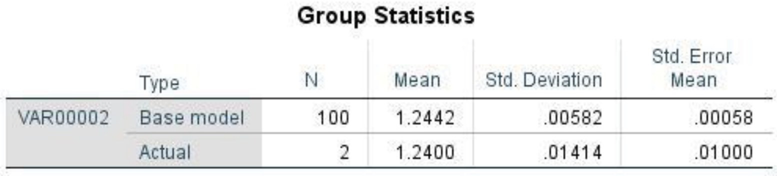
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	7.0467	.31666	.03167
	Actual	4	6.5600	.57781	.28891



Independent Samples Test

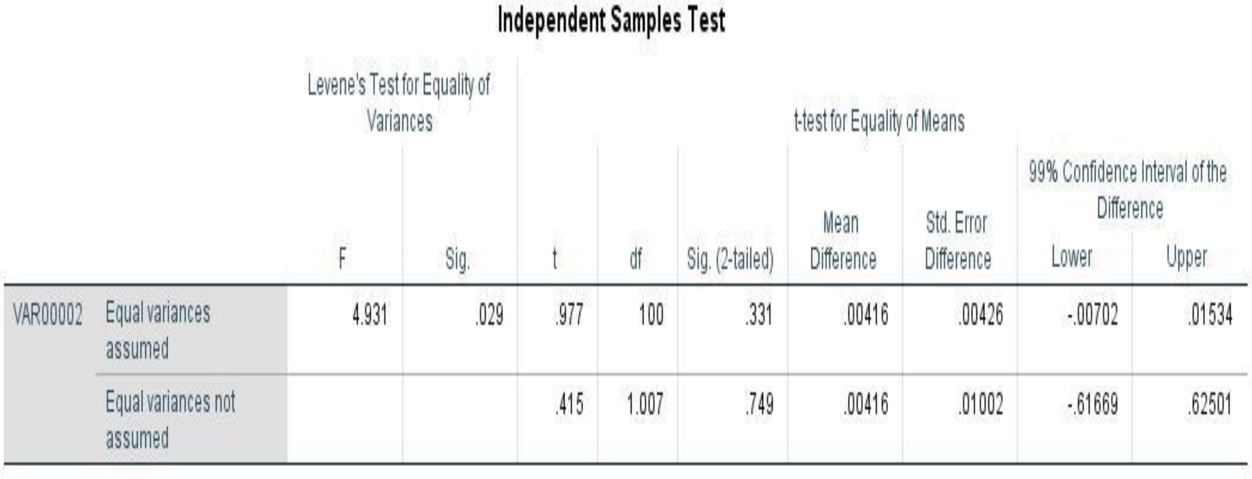
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	6.912	.010	2.916	102	.004	.48672	.16690	.04862	.92482
	Equal variances not assumed			1.675	3.072	.190	.48672	.29064	-1.17175	2.14519

Table B.15 – *t*-test results comparing base model and actual on farm group A to country A wastage of mango supply chain



Group Statistics

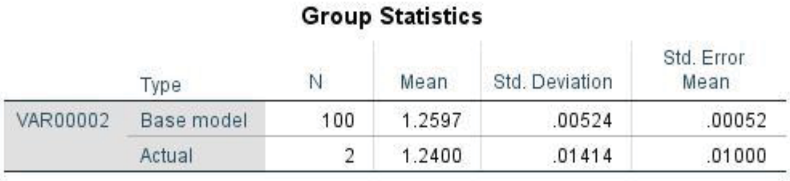
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	1.2442	.00582	.00058
	Actual	2	1.2400	.01414	.01000



Independent Samples Test

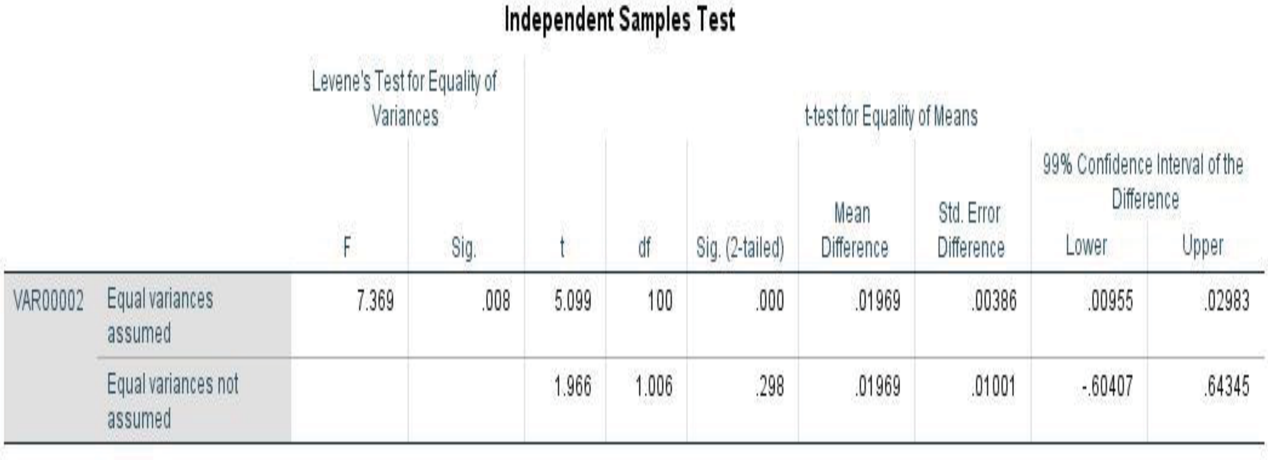
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	4.931	.029	.977	100	.331	.00416	.00426	-.00702	.01534
	Equal variances not assumed			.415	1.007	.749	.00416	.01002	-.61669	.62501

Table B.16 – *t*-test results comparing base model and actual on farm group B to country A wastage of mango supply chain



Group Statistics

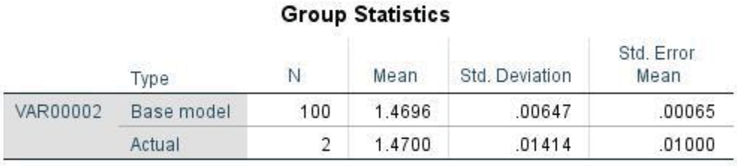
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	1.2597	.00524	.00052
	Actual	2	1.2400	.01414	.01000



Independent Samples Test

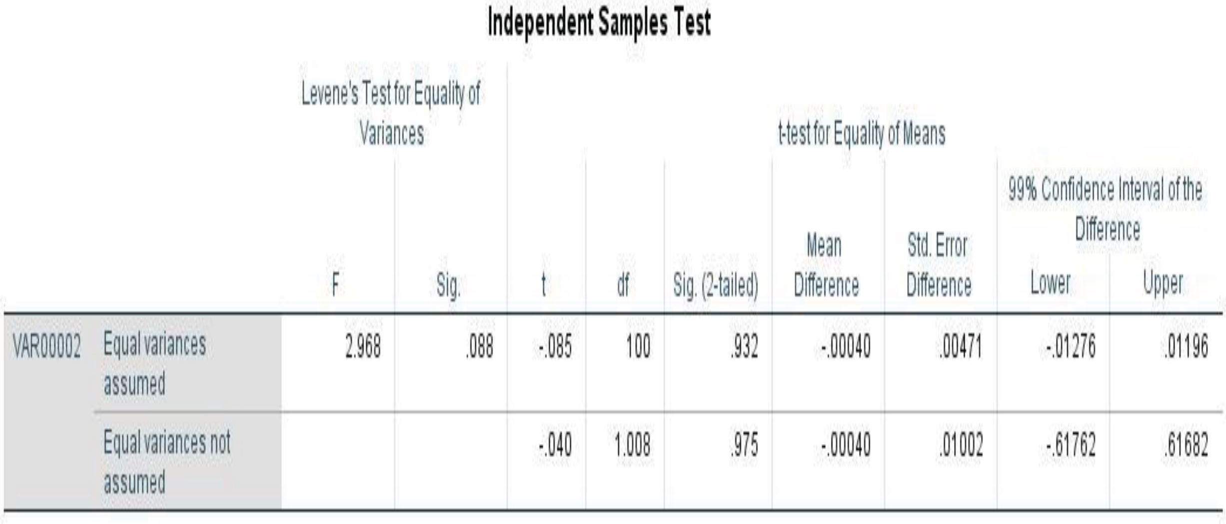
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	7.369	.008	5.099	100	.000	.01969	.00386	.00955	.02983
	Equal variances not assumed			1.966	1.006	.298	.01969	.01001	-.60407	.64345

Table B.17 – *t*-test results comparing base model and actual on farm group A to country B wastage of mango supply chain



Group Statistics

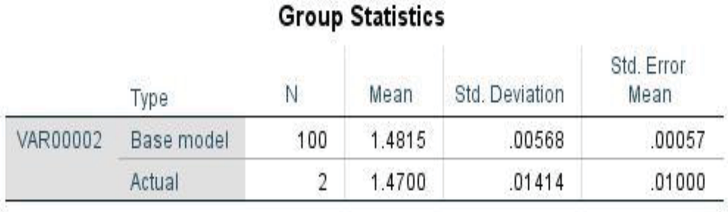
	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	1.4696	.00647	.00065
	Actual	2	1.4700	.01414	.01000



Independent Samples Test

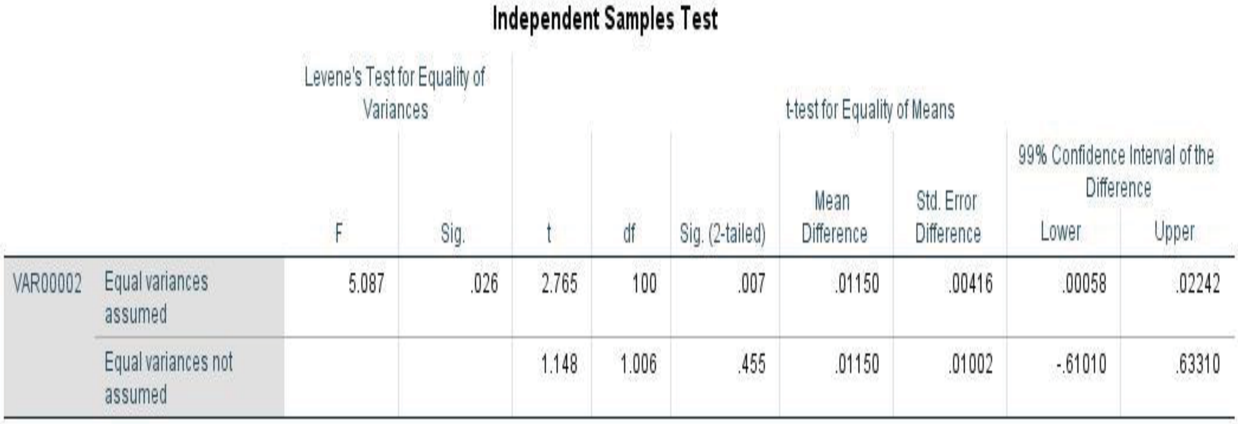
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	2.968	.088	-.085	100	.932	-.00040	.00471	-.01276	.01196
	Equal variances not assumed			-.040	1.008	.975	-.00040	.01002	-.61762	.61682

Table B.18 – *t*-test results comparing base model and actual on farm group B to country B wastage of mango supply chain



Group Statistics

	Type	N	Mean	Std. Deviation	Std. Error Mean
VAR00002	Base model	100	1.4815	.00568	.00057
	Actual	2	1.4700	.01414	.01000



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									99% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
VAR00002	Equal variances assumed	5.087	.026	2.765	100	.007	.01150	.00416	.00058	.02242
	Equal variances not assumed			1.148	1.006	.455	.01150	.01002	-.61010	.63310

Table B.19 – Model change of base model under different sensitivity analysis tests regarding statistical distribution for change in transportation delay

Change in truck loading/unloading time	Change made to base model
Increase 5%	TRIA (1.03, 1.05, 1.07) of the current transportation delay time
Increase 10%	TRIA (1.08, 1.10, 1.12) of the current transportation delay time
Increase 15%	TRIA (1.13, 1.15, 1.17) of the current transportation delay time

Table B.20 – Model change of base model under different sensitivity analysis tests regarding statistical distribution for change in truck loading/unloading time

Change in truck loading/unloading time	Change made to base model
Increase 15%	TRIA (1.10, 1.15, 1.20) of the current truck loading/unloading time
Increase 30%	TRIA (1.25, 1.30, 1.35) of the current truck loading/unloading time
Increase 45%	TRIA (1.40, 1.45, 1.50) of the current truck loading/unloading time

APPENDIX C

Alternative model development

Table C.1 – The number of staff increasing for farms A, B and C for individual cold chain design

Activities	Resource requirement (Base model)	Resource requirement (Individual cold chain design)
Harvesting	5 persons	10 persons
Put into basket	Shared the same resources with harvesting process	Shared the same resources with harvesting process
Move to inspection yard	Shared the same resources with harvesting process	Shared the same resources with harvesting process
Release basket	Shared the same resources with harvesting process	Shared the same resources with harvesting process
Cover release	2 persons	4 persons
inspection and cutting	2 persons	4 persons
Put into basket	9 persons	18 persons
Truck loading	5 persons	10 persons
Truck	1 Truck	2 Trucks

Table C.2 – Model change of Individual cold chain design regarding statistical distribution

Fruit supply chain member	Change made to base model
Processor A	To do a pre-cooling process at 1.20 PM for (UNIF (2, 4)) *(1-0.37) hours

Table C.3 – The number of staff increasing for farms A, B and C for consolidated cold chain design

Activities	Resource requirement (Base model)	Resource requirement (Individual cold chain design)
Harvesting	5 persons	10 persons
Put into basket	Shared the same resources with harvesting process	Shared the same resources with harvesting process
Move to inspection Yard	Shared the same resources with harvesting process	Shared the same resources with harvesting process
Release basket	Shared the same resources with harvesting process	Shared the same resources with harvesting process
Cover release	2 persons	4 persons
Inspection and cutting	2 persons	4 persons
Put into basket	9 persons	18 persons
Truck loading	5 persons	10 persons
Truck	1 Truck	1 Truck

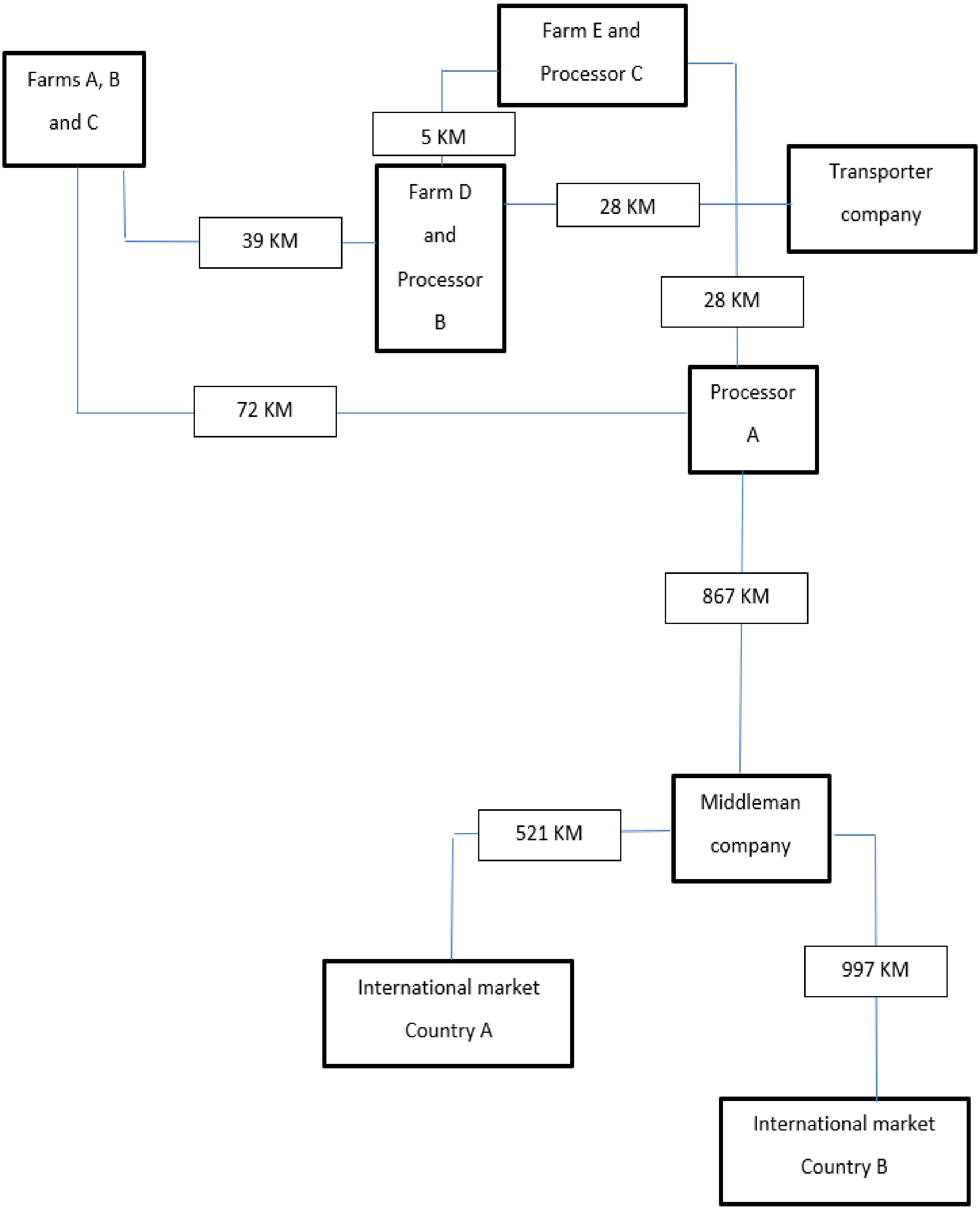


Figure C.1 – The distance between the supply chain member

Table C.4 – The number of staff and trucks increasing for farms D and E for consolidated cold chain design

Activities	Resources requirement (Base model)	Resources requirement (Consolidated cold chain design)
Harvesting	14 persons	28 persons
Selection of quality mango	Shared the same resources with harvesting process	Shared the same resources with harvesting process
Put into basket	Shared the same resources with harvesting process	Shared the same resources with harvesting process
Truck loading	2 persons	4 persons
Number of trucks	2 Trucks	4 Trucks

Table C.5 – The number of staff increasing of processors B and C for consolidated cold chain design

Activities	Resource requirement (Base model)	Operation time (Base model	Resource requirement (Consolidated cold chain design)	Operation time (Consolidated cold chain design)
Cover release	4 persons	8.00 AM - 5.00 PM	8 persons	6.00 AM – 12.00 PM
Inspection and cutting	2 persons	8.00 AM - 5.00 PM	4 persons	6.00 AM – 12.00 PM
Put into basket	3 persons	8.00 AM - 5.00 PM	3 persons	8.00 AM - 5.00 PM
Put into trolley	Shared the same resources with put into basket process	8.00 AM - 5.00 PM	Shared the same resources with put into basket process	8.00 AM - 5.00 PM
Move to grading yard	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Lay down mangoes to yard	2 persons	8.00 AM - 5.00 PM	2 persons	8.00 AM - 5.00 PM
Decide grading	2 persons	8.00 AM - 5.00 PM	2 persons	8.00 AM - 5.00 PM
Put plastic bubble AA	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Put plastic bubble A	Shared the same resources with put plastic bubble AA process	8.00 AM - 5.00 PM	Shared the same resources with put plastic bubble AA process	8.00 AM - 5.00 PM
Put plastic bubble B	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Put plastic bubble C	Shared the same resources with put plastic bubble B process	8.00 AM - 5.00 PM	Shared the same resources with put plastic bubble B process	8.00 AM - 5.00 PM
Packing AA	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Packing A	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Packing B	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Packing C	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Move to weighing AA	Shared the same resources with Packing AA process	8.00 AM - 5.00 PM	Shared the same resources with Packing AA process	8.00 AM - 5.00 PM

Table C.5 – The number of staff increasing of processors B and C for consolidated cold chain design (continued)

Activities	Resource requirement (Base model)	Operation time (Base model	Resource requirement (Consolidated cold chain design)	Operation time (Consolidated cold chain design)
Move to weighing A	Shared the same resources with Packing A process	8.00 AM - 5.00 PM	Shared the same resources with Packing A process	8.00 AM - 5.00 PM
Move to weighing B	Shared the same resources with Packing B process	8.00 AM - 5.00 PM	Shared the same resources with Packing B process	8.00 AM - 5.00 PM
Move to weighing C	Shared the same resources with Packing C process	8.00 AM - 5.00 PM	Shared the same resources with Packing C process	8.00 AM - 5.00 PM
Weighing 2 AA	Shared the same resources with Packing AA process	8.00 AM - 5.00 PM	Shared the same resources with Packing AA process	8.00 AM - 5.00 PM
Weighing 2 A	Shared the same resources with Packing A process	8.00 AM - 5.00 PM	Shared the same resources with Packing A process	8.00 AM - 5.00 PM
Weighing 2 B	Shared the same resources with Packing B process	8.00 AM - 5.00 PM	Shared the same resources with Packing B process	8.00 AM - 5.00 PM
Weighing 2 C	Shared the same resources with Packing C process	8.00 AM - 5.00 PM	Shared the same resources with Packing C process	8.00 AM - 5.00 PM
Weight adjustment AA	Shared the same resources with Packing AA process	8.00 AM - 5.00 PM	Shared the same resources with Packing AA process	8.00 AM - 5.00 PM
Weight adjustment A	Shared the same resources with Packing A process	8.00 AM - 5.00 PM	Shared the same resources with Packing A process	8.00 AM - 5.00 PM
Weight adjustment B	Shared the same resources with Packing B process	8.00 AM - 5.00 PM	Shared the same resources with Packing B process	8.00 AM - 5.00 PM
Weight adjustment C	Shared the same resources with Packing C process	8.00 AM - 5.00 PM	Shared the same resources with Packing C process	8.00 AM - 5.00 PM
Box cover and stamp	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Move to box wrap	2 persons	8.00 AM - 5.00 PM	2 persons	8.00 AM - 5.00 PM
Wrap box	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM
Move to transportation preparing yard	1 person	8.00 AM - 5.00 PM	1 person	8.00 AM - 5.00 PM

Table C.6 – Model change of consolidated cold chain design regarding statistical distribution

Fruit supply chain members	Change made to base model
Farms A, B and C	To transport mangoes to processor B instead of processor A by using statistical distribution TRI (35, 40, 45) minutes
Processor A	To do a pre-cooling process at 3 PM for (UNIF (2, 4)) *(1-0.37) hours
Processors B and C	To do a pre-cooling process at 3 PM for (UNIF (2, 4)) *(1-0.37) hours
Transporter	To modify the delivery path which directly transports to middleman firm after finished truck loading at processor C by using TRIA (11, 12, 13) hours

Table C.7 – Model change of alternative model under different scenarios regarding statistical distribution for increase in supply uncertainty

Scenario Test	Change made to base model
Increase in supply uncertainty	UNIF (0.5, 0.7) is multiplied to the hour entities created to enter the system

Table C.8 – Model change of alternative model under different scenarios regarding statistical distribution for change in operating cost

Scenarios Tests	Change made to base model
Change in operating cost	UNIF (1.5, 2.0) is multiplied to the current labour cost
	UNIF (1.5, 2.0) is multiplied to the current electricity cost
	UNIF (1.5, 2.0) is multiplied to the current fuel cost