UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING AND PHYSICAL SCIENCES

Transportation Research Group

RESTRUCTURING THE SUPPLY CHAIN TO BETTER SERVE RURAL FARMERS: A CASE STUDY OF THAILAND's MANGO SUPPLY CHAIN

by

KORAWIT FAKKHONG

Thesis for the degree of Doctor of Philosophy

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Abstract

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This study addresses one of the Thai Governments key goals related to its food production policy; namely, to create a more inclusive operating environment for rural farmers to improve their transport efficiency and ensure that they remain competitive. Original primary data were gathered on the production of mangoes by rural farmers across Thailand and used to develop a business-as-usual logistics case along with alternative operating scenarios using a range of collaborative logistics options. The Clarke and Wright (CW) saving algorithm was used to quantify the benefits of different potential operating scenarios involving (i) farmers sharing vehicles through a farmer's co-operative, and (ii) using a third-party vehicle to make milk-round collections. An important aspect of the collaboration is the decision on how benefits are to be shared, and how the transportation costs should be distributed fairly among the group. To investigate these issues, two different cost allocation methods were used: the proportional method, based on volume and stand-alone cost, and the Shapley value method, based on co-operative game theory. The results of the collaborative logistics scenarios suggested that farmers who shared their vehicle loading capacity through efficient collection routes reduced the number of vehicles needed and vehicle visits to farms by 40%. This would also reduce transportation costs by 36%, distance travelled by 36% and the total CO_2 emission by 28%. Even in the worst-case, where the large-scale farmers were not willing to cooperate, the vehicle sharing concept realised a 39% a reduction in vehicles needed and 36% on vehicle visits to farms, resulting in a 35% reduction in total transportation cost. The second scenario suggested that assigning a third-party supplied mixture of refrigerated vehicles could reduce the total number of vehicles needed by 62% and 70% on the number of visits to farms, while environmental benefits were 57% reduction in distance travelled and 23% on total CO_2 emissions. Other advantages of a third-party refrigerated vehicle scenario were the likely reduction in product wastage during transit. Although the specific transportation cost increased by 190%, the overall cost reduced by 64% when product wastage was considered. Using a third-party vehicle to make milk-round collections offers the greatest opportunity for the rural farmers. In addition, three different cost allocation methods were investigated. The results suggested that the Shapley value appears to be the most appropriate cost allocation for addressing fairness in a shared fleet concept to assist rural farmers manage that collaboration.

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Research Thesis: Declaration of Authorship

Print name: KORAWIT FAKKHONG

Title of thesis: RESTRUCTURING THE SUPPLY CHAIN TO BETTER SERVE RURAL FARMERS: A CASE STUDY OF THAILAND's MANGO SUPPLY CHAIN

I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

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Fakkhong, K. (2018). 'The Scope for Blockchain Technology to Aid Rural Food Producers in the Thai Agrifood Industry', *Eighth International Conference on Operations and Supply Chain Management (OSCM)*, Coventry University, UK, 9-12 September 2018

Fakkhong, K. et al. (2021). 'Using Collaborative Logistics Scenarios to Better Serve Rural Farmers: A Case Study of Thailand's Mango Supply Chain', *The Logistics Research Network Annual Conference 2021,* Cardiff Business School, UK, 8-10 September 2021.

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The interpretation and remaining errors are entirely mine.

Korawit Fakkhong

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Definitions and Abbreviations

Acronym	Description
3PL	Third-party Logistics Service Provider
ASEAN	Association of Southeast Asian Nations
BAU	Business-as-Usual
CC	Collection Centre
CP	Consolidation Point
CPD	Co-operative Promotion Department
CTM	Collaborative Transportation Management
CW	Clarke and Wright saving algorithm
DLT	Department of Land Transport
DOAE	Department of Agricultural Extension
FAO	Food and Agriculture Organisation (of the United Nations)
GIS	Geographic Information System
MOAC	Ministry of Agriculture and Cooperative
NGOs	Non-governmental organisations
OAE	Office of Agricultural Economics
TAS	Thailand Agricultural Standard
TGO	Thailand Greenhouse Gas Management Organisation
THB	Thai Baht
UTM	Universal Transverse Mercator

Glossary of Terms

Term	Definition
Broker	The representative buyer, or the key supplier from the supermarkets or export companies
Consolidation point	The collecting point located in the rural area close to the food producers or plantations
Extra class mango	The most superior class commands the highest prices, mangoes must be free of defects
Farmer’s organisation	Referred to “co-operative” and “social enterprise”
First-mile	Local transportation from farms to consolidation point, and can range from 1-20 km
Large-scale farmer	The leading and/or high potential farmers, who produce over 120 boxes (3,000 kg) of mangoes per day
Light pick-up vehicle	The non-refrigerated vehicle commonly used by rural farmers to move their products from farm to the consolidation point, with a load capacity of 60 boxes (1,500 kg)
Light refrigerated vehicle	The refrigerated vehicle provided by a third-party with a loaded capacity at 100 boxes (2,500 kg)
20ft refrigerated vehicle	The 20ft refrigerated vehicle provided by a third-party with a loaded capacity at 200 boxes (5,000 kg)
Rural farmers	A group of farmers involved in cultivating mangoes and carrying out other related farming activities in rural area
Rural road network	The majority road network linking rural plantations to the consolidation point and are generally in poor condition making access difficult
Small-scale farmer	Any farmer who has limited land area, financial resources, agricultural inputs, production capability
Social enterprise	Farmer’s organisation that acts as marketing agency and provide support services/agricultural inputs for farmers

Chapter 1 Introduction

1.1 Research Background

With the increasing expansion of supermarkets across all international areas, new business opportunities exist for rural farmers to tap into (Lippe and Isvilanonda, 2010). These are particularly prevalent for those rural farmers who can cultivate their crops all year round and maintain a reliable supply to the supermarkets. But those who cannot, often find themselves excluded from the market due to their production capability, product quality and limited power of negotiation (Reardon, Timmer and Minten, 2012).

Generally, the core requirement imposed by supermarket chains when taking on new farm suppliers is for quality in relation to the products appearance, size, and the production processes involved. This standard is strictly enforced and monitored in every shipment from farms to the distribution centre to guarantee that products standards will be maintained. These challenges impact specifically on rural farmers when trying to access high value market chains, and can be mitigated to some extent when farmers join others in local co-operatives or social enterprises to help in the negotiation and contract management with large clients (Blandon, Henson and Cranfield, 2009; Nimsai, 2012).

When trying to maintain product quality, rural farmers can be particularly constrained by their transportation resources which are often very basic and do not comply with the strict temperature control standards dictated by the clients. They usually use their own vehicle (non-refrigerated light pick-up trucks) as a means to deliver their products from farms to the consolidation points. According to the Office of Agricultural Economics, Thailand (2017), some 3-20% of agricultural products are being lost due to inefficient transportation operations during the post-harvest distribution phase, originating from the farm. Losses subsequently increase to between 10-30% once at the distribution centre, and from 5-15% at the supermarket store, which means that up to 65% of the initial crop can be wasted if the transportation is not effectively managed. Similarly, Soma (2017) mentioned that 17% of agricultural products in Indonesia are wasted primarily at the production stage, and with 46% are wasted at the distribution and consumption stages due to poor infrastructure, inadequate handling skills, and lack of refrigerator storage. Prusky, D., (2011) stated that the proportion of agricultural waste during the post-harvest distribution in Vietnam was 60%, particularly the major fruits such as plum, and mangosteen which were due to the lack of refrigerator storage and effective transportation. Similarly, Sivakumar, D., et al., (2011) reported that post-harvest losses of fresh fruits in Malaysia varied between 20 and 50%, especially losses in mangoes which were 57.9% during transit and storage, resulting from improper post-harvest handling, lack of cold storage, and damage during transportation. The evidence suggests that agricultural waste during transportation operations post-harvest is present as a key challenge for food producers in developing countries.

1.2 Problem Statement

Rural farmers face losing out on the opportunity to access lucrative markets, primarily because their logistics infrastructure cannot meet the standards required by the clients, which results in considerable product losses (Anuount, 2015). This research uses the mango harvest in Thailand as a case study, the data collection at the fieldwork survey showed that the average losses during the primary distribution phase (production at rural farmers being transported through to a local consolidation point) were found to be in the region of 2-5% which increased to 5-10% when travelling between the consolidation point and the distribution centre and/or final market. Under this situation, rural farmers lose out on potential income as defective mangoes will attract a lower price, and loads can be rejected outright if damage exceed 10% of the total shipment. Some clients also operate a "three strikes and you are out" policy where the contract is terminated and the farmer black-listed if loads from a particular farmer are rejected three times.

These inefficiencies can be directly attributable to the transportation system where rural farmers are often completely disconnected from major road, rail lines, and public transport services, and opportunities to tie in with more sustainable collaborative logistics strategies (Cook *et al.*, 2017). Mangoes are typically moved from farms to the consolidation point by the famer's own light pick-up vehicle, but a collective of small groups of farmers have often developed a shared relationship for localised logistics serving the consolidation point. This first-mile transportation can range between 1-20 kilometres and make up only 1-3% of the total supply chain distance between consignor and consignee. However, the first-mile transportation cost incurred by the rural farmers can make up between 5-15% of the total transportation costs. Stellingwerf *et al.* (2018) mentioned that inefficient road transportation causes unnecessary cost and polluting emissions.

The Thai government has expressed a need to address this, to create a more inclusive operating environment for rural farmers to ensure that they can remain competitive. This research directly addresses this issue by using a unique primary dataset of production data to quantify how a range of different collaborative logistics scenarios might benefits rural farmers in the long run. In addition, the collective scenarios developed will be used to demonstrate how the cost of such a new transportation scheme can be split fairly among the rural farmers.

1.3 Research Objectives

This research aims to investigate the opportunities for improving the logistics of food supply chain management associated with rural mango farmers in Thailand, and how they can maximise market opportunities in the long term.

Objective 1: Identify business-as-usual (BAU) food logistics and supply chain management in Thailand's rural agricultural sector, focussing on mango supply. This is done by addressing three research questions.

> **RQ 1:** How does Thailand's mango supply chain operate, and how do rural farmers integrate within the system?
>
> **RQ 2:** What are the key challenges and problems currently faced by rural farmers?
>
> **RQ 3:** What are the BAU operating characteristics of farmers currently working together within co-operative s and/or social enterprises?

Objective 2: Determine how appropriate load consolidation would be undertaken for the collective transport of food products over the first mile from rural farmers to consolidation point?

> **RQ 4:** Which logistics operating scenarios are more suitable and efficient to better serve rural farmers whilst minimising costs?
>
> **RQ 5:** What is the best collaborative logistics scenario to adopt that maximises revenue for the individual rural farmers?

Objective 3: Quantify an acceptable cost allocation for sharing the transportation cost of such a new transportation scheme amongst the participating farmers.

> **RQ 7:** How could the costs of the system be distributed fairly amongst the rural farmers?
>
> **RQ 8:** How would rural farmers join and leave such an arrangement?

Chapter 2 Literature Review

This chapter provides a general background of Thailand's agricultural (section 2.1) and agri-food markets (section 2.2). It discusses the important of agriculture to Thailand's economy, and the characteristics of the mango harvest, which make up a significant proportion of its export. The farmer's organisation and collaborative transportation (section 2.3) are presented. This explains the farmer's organisation roles and characteristics, the advantages of working together with farmer's organisation, as well as alternative collaborative logistics strategy. Section 2.5 discusses Thailand' transportation system in the context of the road transportation as a key means in freight transport. Lastly, it addresses how the transportation cost of collaborative transport could be distributed fairly among the rural farmers (section 2.6).

2.1 Thailand's Agricultural

Thailand is a country endowed with a warm climate, ample fertile land and regular rainfall, which provides one of the best environments for agricultural production in South-East Asia (OAE, 2017). The development of its agriculture continues to play a key role in its economic development. Thailand is an upper-middle income country and is substantially export-dependent, with its agriculture accounting for 2,389 billion THB (£61 billion) in 2020, ranked 14th in term of world exporters of all agricultural products and 6th for fruits products (World Trade Organization, 2021). The agriculture sector is a crucial component of the Thai economy and accounted for 8.9% of the country' GDP in 2015, employing over 46% of the total labour force (Thailand Board of Investment, 2016a).

Thailand's agricultural is divided into six major sub-sectors; crops, livestock, fisheries, forestry, agricultural services, and the processing of simple agricultural product [1] (Vanit-Anunchai, 2006). The OAE (2017) report that the biggest share is derived from the crops sub-sector, which accounted for 68% of agricultural in 2015. Fisheries hold the next largest share at 17%, followed by livestock at 11%, agricultural services at 2%, and 1% from forestry. Rice cultivation production has traditionally been the main staple in Thailand's agriculture, which accounts for nearly 50% of the total agricultural land, 21.5% for field crops (e.g. durian, longan, mangosteen, mango), and horticultural crops (e.g. cabbage, chili, ginger) (Ruenglertpanyakul, 2013; Soni, 2016). The main feature of Thailand's agriculture has been its small-scale farmers, of approximately 5.9 million

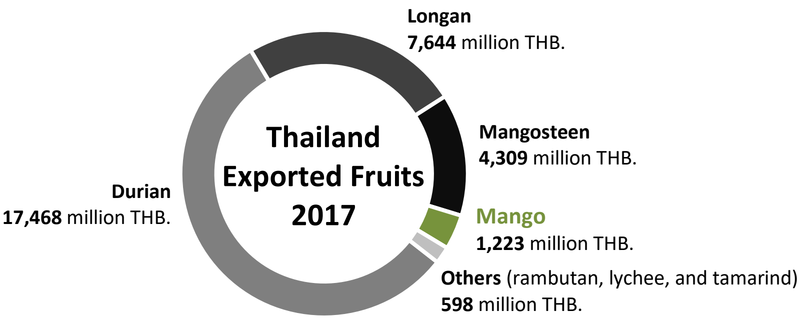
[1] The processing of simple agricultural products are non-agricultural food and drink items made out from agricultural products such as chocolate, sweet drink, beers, and bakery products.

farming families, with an average farm size 25.25 rai (4.04 hectares) per household (Ruenglertpanyakul, 2013).

2.1.1 Tropical Fruit Production

Thailand has favourable growing conditions for variety of tropical fruits (Zang, 2017). Thai fruits are well-known for their quality and have seen a considerable rise in demand across both national and particularly international markets (Ministry of Commerce, 2017), with Thailand remaining the main supplier and largest exporter of fruits in Asia (Win, 2017). The major economic tropical fruits exported are durian with the highest value fruit export at 17,468 million THB in 2017, followed by longan at 7,644 million THB, mangosteen at 4,309 million THB, and mango at 1,223 million THB (DOAE, 2017) (Figure 1). Generally, these fruits are exported in various forms (e.g. fresh, frozen, dried, canned, and juiced), but the majority of mangoes are exported in fresh form (78%), and the rest 22% in dried and processed forms, with an increasing demand coming from supermarkets and international markets (Ministry of Commerce, 2017). Due to the fruits characteristics, durian, longan, and mangosteen have a distinct hard outer shell protecting the soft flesh inside, while mango has a soft skin which is easily damaged during transportation. In addition, the mangoes quality indicators for superior class not only depend on size, and shape, but particularly on surface/colour, where mangoes must be free from defects except for very slight superficial skin colouring (NBACFS, 2015). As a result, mango producers (rural farmers) face losing out on the opportunity and incurring financial losses compared to other economic fruit producers. This is largely because of the inefficient transportation system and a lack of refrigeration during the first-mile phase which directly impacts on mango quality.

Figure 1 Export value of tropical fruits grown in Thailand



Source: Based on Ministry of Commerce (2017), and DOAE (2017)

Different geographical areas of Thailand have different flowering, fruit development, and harvesting season of fruit crops, which makes it possible to produce the same fruits throughout the year. Around 90% of these fruits are harvested between March and September, but particularly between April and May when the season is at its peak, see Table 1.

Table 1 Harvesting percentage of major fruits in Thailand in 2016

Fruits	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tonnes
Durian	1.2	1.4	3.4	13.5	**24.4**	12.1	11.3	**16.8**	9.5	5.0	1.2	0.5	517,955
Longan	14.3	11.9	4.3	2.3	1.0	0.6	12.5	**17.7**	5.4	4.0	11.9	**14.0**	755,651
Mangosteen			0.3	6.7	**18.3**	**23.7**	9.0	14.3	**24.3**	2.6	0.2	0.6	187,755
Mango	6.0	9.2	10.2	**22.6**	**20.0**	**21.1**	3.8	1.7	2.0	2.1	0.9	0.4	2,559,955

Peak season   Off-peak season

Source: Based on the OAE (2017)

For the mango harvest, the Eastern provinces generally cultivate between April and June, while the Northern provinces produce between February and May (Phitsanulok Agricultural Extension Office, 2016). Mango took up the largest agricultural area in 2017, occupying some 2,964,000 rai (314,300 hectares), and producing 2.5 million tons (OAE, 2017), the third of the world's largest producers behind China and India. The revenue generated by 64,000 tons of mango (fresh and frozen forms) came to 3,200 million THB (£81.80 million) in 2017 (Ministry of Commerce, 2017), with the most popular and valuable being "Nam Dok Mai Golden" and "Nam Dok Mai No.4" aimed at the export market which they dominated with 52% of the total export volume in 2016.

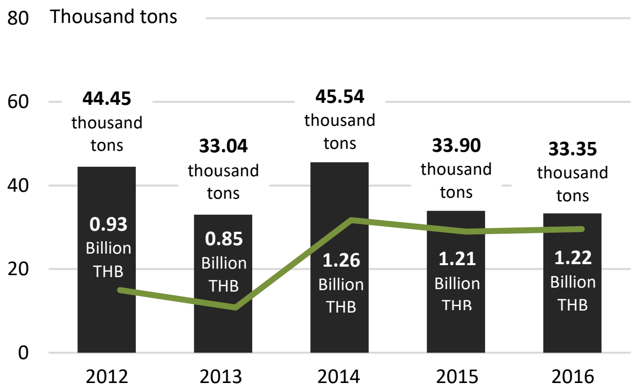


Figure 2 The export volume and value of fresh mango between 2012-2016

Source: Ministry of Commerce (2017)

In 2016, 33.35 thousand tons of fresh mangoes worth 1,223 million THB (£31 million) were exported (DOAE, 2017), with prime markets being Korea, Japan, Russia, and the European Union (Anuount, 2015). In order to ensure quality standards, the mangoes have to fulfil strict buyer requirements that dictate shape, size, and colour. The product must also comply with agrochemical residue limits (the maximum level of a pesticide residue that is legally tolerated in agri-food), as well as the standards for mangoes followed the National Good Agricultural Practice (NBACFS, 2015), and Global GAP certification (FAO, 2003) as described below. The nationally and internationally recognised standard for farm production, aims at safe and sustainable agricultural production to benefit farmers, buyers, and consumers. In addition, since tropical fruits have short shelf lives, it is imperative to have a harvesting and logistics process as efficient as possible to reduce losses whilst minimising profits (Phuong, 2016).

2.1.2 Standards for Mangoes

The Thailand National Bureau of Agricultural Commodity and Food Standards established the Agricultural Standard (TAS 5-1205) in 2015, which is a set of guidelines related to the quality requirement for each class mango (NBACFS, 2015), based on the international standard provided by the Food and Agriculture Organisation of the United Nations (FAO, 2003). This standard sets out following requirements in relation to mango producers, in that their products must be

- Clean, particularly free of any visible foreign matter
- Free of damage caused by pests
- Free from rotting or deterioration, such as to make it unfit for consumption
- Free of abnormal external moisture, excluding condensation following removal from cold storage
- Free of any foreign smell and/or taste
- Firm and fresh in appearance
- Free of damage caused by low and/or high temperature (it should be maintained between 12-18°C)
- Free of black necrotic stains or trails (dark spots)
- Free of marked bruising
- Sufficiently developed and displaying satisfactory ripeness
- When a peduncle is present, it shall be no longer than 1.0 cm.

In addition, the harvesting process must be such that it

- Ensures a continuation of the ripening process until they reach the appropriate level of maturity
- Allow the crop to withstand transportation and handling
- Allow the crop to arrive in satisfactory condition at the consignee’s premises

Mangoes are classified into three class (extra class, class I, and class II), according to the Food and Agriculture Organisation of the United Nations (FAO, 2003), and the National Bureau of Agricultural Commodity and Food Standard (NBACFS, 2015).

Extra Class

This is the most superior class and commands the highest prices. Mangoes must be free of defects with the exception of very slight superficial skin colouring. Figure 3 shows an example mango "Nam Dok Mai Golden" in the "Extra class" which is the most popular and commands the highest value, it is usually consumed ripe and exported to international markets. In 2018, Nam Dok Mai Golden and Nam Dok Mai No.4 together made up 35% of the overall mango harvest (around 139,000 tons) with a total value of 5,608 million THB (£143 million) (DOAE, 2017).

Figure 3 Nam Dok Mai Golden (6.5-7.5 x 12-15 cm, 400-450 grams)

Source:Tropical Green (2017)

Class I

Mangoes in this class must be of good quality but slight defects (e.g. healed bruises, resin exudation, sunburn, and dark spots) as shown in Figure 4 to Figure 6, provided these do not affect the general appearance of the product and its quality.

Class II

This class includes mangoes that satisfy the minimum requirements specified in the Agricultural Standard (TAS 5-1205), the Thailand National Agricultural Standards. Defects may be allowed in shape, skin due to rubbing or sunburn, as show in Figure 4 to Figure 6, provided they retain essential characteristics as regards their quality, their keeping quality and presentation.

In *class I* and *class II*, scattered suberised rusty lenticels, as well as yellowing of green varieties due to exposure to direct sunlight, not exceeding 40% of the surface and not showing any sign of necrosis, are allowed.

Figure 4 The slight defects; healed bruises not exceeding 5-7 cm^2

Figure 5 The slight defects; resin exudation

Figure 6 The skin defects due to sunburn and scattered suberised rusty lenticels

Source: The National Bureau of Agricultural Commodity and Food Standard (2015).

Generally, mangoes are harvested when unripe (at the pre-climacteric stage, or when 80% mature) (Win, 2017), and they must still be green and firm-fleshed. Harvesting is done by hand or using special fruit picking poles. Extreme care must be taken when harvesting as well as during transport as even the smallest of cracks results in rapid deterioration and rotting (Ongkunaruk and Piyakarn, 2011). To ensure the highest quality, it is important for the skin to remain undamaged as even the slightest bruise can result in the fruit deteriorating. According to the National Bureau of Agricultural Commodity and Food Standard (2015), storage and transport should not last longer than 25 days maximum, where a temperatures of 12-18°C is maintained with 85-90% relative humidity, and 5% of O_2 and CO_2.

Varieties of Commercial Mangoes

There are six varieties of mangoes grown commercially. The Nam Dok Mai Golden mango (M1) (Figure 7) is Thailand's most important commercial fruit from an economic perspective due to its premium quality status and strong export market selling for 60-70 THB, (£1.54-1.79) per kg. Fruit must be free of defects to command the best price and are harvested when unripe (80-90% mature) to prolong shelf-life. Individual fruit can weigh 300-450 g and are typically harvested between the middle of December and early of June, particularly March and April. The optimal temperature to be maintained during transport is 12-18°C, and the fruit should ideally reach the final market within 3-7 days of harvesting.

Figure 7 Nam Dok Mai Golden mango (M1)

Source: The National Bureau of Agricultural Commodity and Food Standard (2015).

Nam Dok Mai No.4 mango (M2) (Figure 8) is similar to “Nam Dok Mai Golden” but the fruit is light greener when unripe, and the taste is sourer in comparison. It typically commands 40-50 THB (£1.03-1.28) per kilogram with individual fruit weight 300-450 g. They are harvested between the end of December and the middle of June, particularly Market and April. The optimal temperature to be maintained during transport is 12-18°C, and the fruit should ideally reach the final market within 3-7 days of harvesting.

Figure 8 Nam Dok Mai No.4 mango (M2)

Source: The National Bureau of Agricultural Commodity and Food Standard (2015).

Kaew Sawie mango (M3) (Figure 9) directly translates to “eat green”, and as its name suggests is best when unripe or semi-ripe. This is one of the only varieties worldwide that is sweet when unripe, while most other varieties are bitter and sour. This green mango is ranked second in economic importance in Thailand, returning 30-40 THB (£1.03-1.28) per kg. The optimal temperature to be maintained during transport is higher at 18-25°C with the fruit needing to reach the final market within 7-15 days of being harvested. This mango should not be stored cold as a temperature below 12°C will cause the flesh to turn black. Individual fruit can weigh 250-400 g and are typically harvested between the middle of December and the middle of June. In 2018, Kaew Sawie made up 16.29% of the overall mango harvest (around 78,500 tons) with a total value 2,212 million THB (£56 million) (DOAE, 2017).

Figure 9 Kaew Sawie mango (M3)

Source: The National Bureau of Agricultural Commodity and Food Standard (2015).

Fah Lan mango (M4) (Figure 10) is one of the mature green cultivars, similar on appearance to Kaew Sawie mango and has a unique crunchy texture. This mango ranked 5th in economic importance, and commands 27-32 THB (£0.69-0.82) per kg. The optimal temperature to be maintained during transport is 13-25°C, and the fruit should ideally reach the final market within 7-15 days of harvesting. Individual fruit can weigh between 250 and 400 g and are typically harvested between the middle of December and the middle of June, particularly the early of March to the end of April. In 2018, Fah Lan mango made up 4.66% of the overall mango harvest (around 43,900 tons) with a total value 1,080 million THB (£28 million) (DOAE, 2017).

Figure 10 Fah Lan mango (M4)

Source: The National Bureau of Agricultural Commodity and Food Standard (2015).

Phet Ban-Lat mango (M5) (Figure 11) is another mature green cultivar, similar to Kaew Sawie and Fah Lan mangoes but less commercialised. This mango ranked 8^{th} in economic importance, commanding 20-30 THB (£0.51-0.77) per kg. The optimal temperature to be maintained during transport is 13-20°C, and the fruit should ideally reach the final market within 7-15 days of harvesting. Individual fruit can weigh between 250 and 400 g and are typically harvested between the middle of December and the middle of June, particularly March and April. In 2018, Phet Ban-Lat mango made up 0.76% of the overall mango harvest (around 376 tons) with a total value 7.5 million THB (£0.2 million) (DOAE, 2017).

Figure 11 Phet Ban-Lat mango (M5)

Source: The National Bureau of Agricultural Commodity and Food Standard (2015).

Chokanan mango (M6) (Figure 12), also known as “Honey mango” due to its unique taste, ranked 4th in economic importance, commanding 30-32 THB (£0.77-0.82) per kg. The optimal temperature to be maintained during transport is 13-20°C, and the fruit should ideally reach the final market within 7-15 days of harvesting. Individual fruit can weigh between 300 and 500 g and are typically harvested between the middle December and the middle June, particularly between March and April. In 2018, Chokanan mango made up 8.63% of the overall mango harvest in Thailand (around 70,800 tons) with a total value 859 million THB (£22 million) (DOAE, 2017).

Figure 12 Chokanan mango (M6)

Source: The National Bureau of Agricultural Commodity and Food Standard (2015).

Table 2 summarises all these mango characteristics; value, mean weigh of fruit, optimal temperature, maximum transit time, and economic rank.

Table 2 Characteristics of the six main varieties mangoes grown in Thailand

Mango	Value (THB/kg)	Weight (grams)	Temperature (°C)	Transit time (days)	Economic Rank
Nam Dok Mai Golden (M1)	60-70	300-450	12-18°C	3-7	1st
Nam Dok Mai No.4 (M2)	40-50	300-450	12-18°C	3-7	2nd
Kaew Sawei (M3)	30-40	250-400	18-25°C	7-15	3rd
Fah Lan (M4)	27-32	250-400	18-25°C	7-15	5th
Phet Ban-Lat (M5)	20-30	250-400	13-20°C	7-12	8th
Chokanan (M6)	30-32	300-500	13-20°C	7-12	4th

The six main varieties of mango can be grouped into three clusters, based on their value and temperature control requirement as shown in Figure 13.

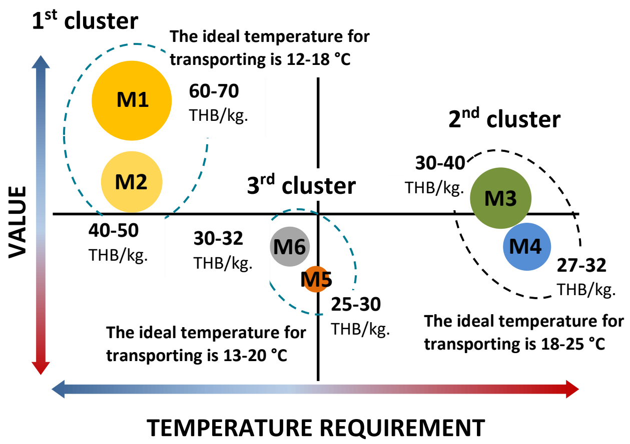


Figure 13 The three main clusters of the six varieties mangoes

As mentioned, mango is one of the most important tropical fruits in Thailand. Nam Dok Mai Golden and Nam Dok Mai No.4 were the main export cultivar, but the production for export-quality fruit is limited since most of the fruit producers are financially constrained from adopting improved techniques, and the logistics system does not adequately compensate farmers for producing high quality fruit (Watanawan *et al.*, 2010). Quality attributes required include free from external damage (e.g. bruises, latex or injury, decay, colour, aroma, firmness, shape, size) (Sivakumar, Jiang and Yahia, 2011). Post-harvest losses are high during the supply chain due to inappropriate logistics management.

Maintenance of mango quality throughout the supply chain depends on many aspects, such as harvesting practices, packing operation, post-harvest treatment (Sivakumar, Jiang and Yahia, 2011), temperature management, transportation, and storage conditions (Orjuela-Castro, Herrera-Ramírez and Adarme-Jaimes, 2017). Temperature management during storage and transportation is a critical factor that affects the fruit quality, since mangoes should be stored and transported in the range 12-25°C (depending on cultivar). According to the OAE (2017), Thailand is suffering from food wastage as a result of losses (between 3-20%) due to inefficient transportation operations during the post-harvest distribution phase starting from the farm. Losses subsequently increase to between 10-30% once at the distribution centre, and between 5-15% at the final store, which means that up to 65% of the initial crop can be wasted if the transportation is not effectively managed.

High-level of loss during the post-harvest distribution could indicate the inefficiency of logistics and supply chain management. The data collected from the survey work shows that most fruits are being lost during the transportation between farms and consolidation point, 2-5% on average (more detail in section 4.2.4). An average 40-60 boxes (1,000-1,500 kg) per day of M1 and M2 mangoes were damaged during the transportation at peak harvesting period, with total losses around 800 boxes (20,000 kg) out of 21,000 boxes (540,000 kg) collected. For the M3 and M4 mangoes, 20-25 boxes (500-600 kg) per day are being lost, with total losses around 400 boxes (10,000 kg) out of 20,000 boxes (510,000 kg). For M5 and M6 mangoes, 30-40 boxes per day are being lost, with total losses of 480 boxes (12,000 kg) out of 9,600 boxes (242,000 kg). Therefore, it is critical that effective logistics management is developed, to maintain better overall mango quality and to reduce post-harvest losses throughout the supply chain.

2.2 Farmer Interaction with the Food Supply Chain Structure

Many actors are involved in the food supply chain, involved moving agricultural products from farmers to the final customers (Schipmann and Qaim, 2011; Alexandratos and Bruinsma, 2012). The typically agri-food supply chain sees a variety of different parties from the upstream food producers, collectors and processors through the downstream traders, wholesalers, distributors, retailers, and final customers (Srimanee and Routray, 2012; Raka and Liangrokapart, 2015). Thailand's agri-food markets can be classified into two types, traditional and modern market chains, show in Figure 14.

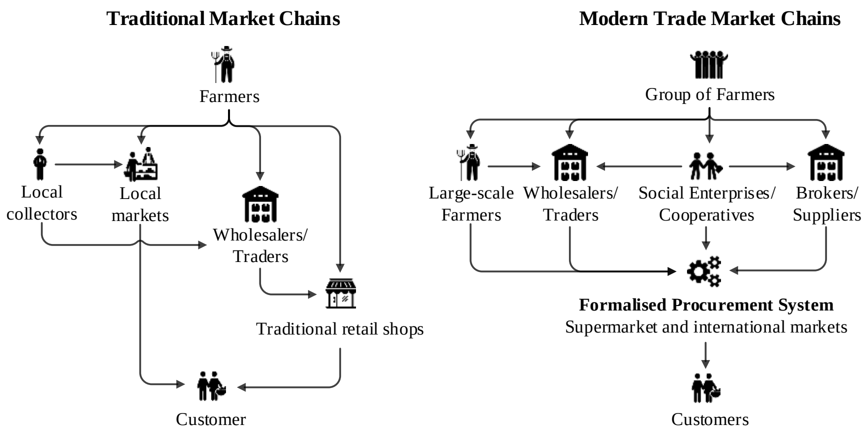


Figure 14 Thailand's agri-food market structure

Source: Based on Vanit-Anunchai (2006) and Nimsai (2012)

In the traditional market, rural food producers have four main sales outlets; (i) directly selling to the retail markets, (ii) through local collector/middlemen, (iii) selling to the local market/wet-market, and (iv) delivery to a wholesaler (Vanit-Anunchai, 2006). In the traditional market chain, the majority of the rural farmers, who have less capacity to delivery/transport their products to the markets, usually sell their products individually through the middlemen who delivery the products to the next stage of supply chain. The rural farmers generally receive a lower price and must deal with demand uncertainly when compared with the farmers who participate in the modern market chains such as supermarkets (Nimsai, 2012).

However, this market structure – that relied on traditional markets has now been transformed into modern market chains. This is becoming an important diver of changes in the food market, particularly in Thailand. The modern market chains are more planed and organised, and utilise standard management systems for distribution, logistics management for delivery to supermarkets and export markets. Therefore, rural food producers now have four new potential selling channels: (i) selling directly to large-scale farmers, (ii) wholesaler/trader, (iii) brokers, and (iv) working together as co-operative/social enterprise. These market channels create more opportunities and benefits, particularly an improved silling price for rural farmers. However, the rural farmers may face challenges such as having difficulty in meeting quality standard requirements. According to relevant studies in the literature and the data collected during the fieldwork, each chain has different characteristics and market potential as detailed below.

Chain I: Farmer → Large-Scale Farmers → Markets

In this chain, the rural farmers are connected with the large-scale farmers with high potential market access. These rural farmers participate in the modern market chains, particularly with the supermarkets as a "sub-contractor" to a large-scale farmer, who participates in this chain under the 'share cropping' system[2] through an informal (verbal) contract. The small rural farmers generally receive agricultural inputs (e.g. fertilisers, financial credits) from the large-scale farmers.

Chain II: Farmer → Large-Scale Farmers → Wholesaler/Trader → Markets

In this chain, the rural farmers are connected with the large-scale farmers similar to *chain I*. The difference is the large-scale farmers will consolidate the products from the small-scale farmers and then sell the products directly to the wholesaler "Talaad-Thai wholesale market" instead of the supermarkets. The rural farmers that participate in this chain generally receive a lower price when compared with *chain I*, but the selling price varies depending on the daily market price. In addition, the wholesaler/trader bought products and did their own packing before delivering the product to the modern trade chains.

[2] Share cropping system is a form of agriculture where a landowner allows the tenant to use the land for a share of the crops produced by their portion of the land.

Chain III: Farmer → Wholesaler/Trader → Markets

In this chain, the rural farmers are selling their products directly to the wholesaler or trader who supplies the modern trade chains. Farmers in this chain generally have a small-medium scale production and are free to sell their products to anybody. In this chain, the wholesaler/trader is a key player, guiding and supporting farmers in the production and advising them on market conditions and quality control issues. In this case, the selling price is determined on a day-by-day basis at the wholesale market similar to *Chain II* but generally receiving a higher price when compared to farmers in *Chains I* and *II*.

Chain IV: Farmer → Farmer's Organisation → Wholesaler/Trader

In this chain, the rural farmers usually sell their products through the farmer's organisations (co-operatives or social enterprises), with the farmers' organisation selling the products directly to the wholesaler. The rural farmers usually move their products from their farm to the consolidation point for the next stage of pre-processing such as grading, cutting, cleaning, packaging, before shipping to the buying point at the wholesaler. In this chain, wholesalers and traders play an important part in the supply chain linking the agricultural products from famers to the final markets. The key important wholesaler in Thailand is 'Talaad Thai'[3] the centre point for the trade of Thai and imported fruits and vegetables. The price participants in this chain receive for their products varies depending on the daily market price which continually fluctuates.

Chain V: Farmer → Farmer's Organisation → Broker

This chain is similar to *chain IV*, the rural farmers mostly sell their products to the farmers' organisation, then sell the product to the brokers, the representative buyer, or key supplier from the supermarkets or international markets. Most farmers participating in this chain have production capability but operate small-scale farms and lack managerial skills. Therefore, they have serious constrains to entering directly into the supermarkets or international markets. The advantage of participation in this chain is that there is a higher volume to sell, creating more economies of scale and higher negotiating power when compared to selling as an individual. These farmers typically receive substantial support from government programs[4], and may also receive support from brokers. This support ranges from technical assistance to subsidies for transportation

[3] Talaad Thai wholesale market represent one of the biggest central fruits and vegetables market in Thailand. It was established with the vision of building largest wholesale market for agricultural products in ASEAN countries.

[4] The farmers who participate in an agricultural co-operative or social enterprise usually receive long-term loans to support their cultivation. For example, restarted farmers receive credit around 1,500 THB (£38) per rai to support their agriculture activities.

costs, training or to acquisition assets such as cold storage facilities, processing machines, which assist the farmers in meeting quality control standards.

Chain VI: Farmer → Farmer's Organisation → Supermarkets

This chain is similar to *chain IV* and *chain V*, in that the rural farmers sell their product to the farmer's organisation, which then sells them directly to the supermarkets. Farmers in this chain usually operate under a formal (written) contract and a long-term production plan where the chain is characterised by better market conditions (stable price and demand). Those participating generally have good production knowledge and managerial skills because of their experience, or training program provided by the farmer's organisation and supermarket. In this chain, the farmers' organisation guides and supports its members in the production process and advises the farmers as to market conditions as well as providing technical assistance in meeting quality standards, and delivery terms.

Chain VII: Farmer → Broker → Markets

This chain is similar to *chain V* but in this case, the rural farmers sell their products directly to the broker instead of selling their product through the farmer's organisation. Participating farmers in this chain have been shown to have good production capacity with managerial skills. Similarly, Nimsai (2012) highlighted that the rural farmers in this chain had higher productivity and capability when compared with farmers who participated in other chains.

2.3 Agri-Food Market Expansion

Agri-food markets have developed from traditional agricultural markets, through modern agricultural markets, which eventually resulted in changes that brought about an agricultural economy (Shannon, 2014; Ninkitsaranont and Sathapongpakdee, 2017). Transactions of food products that were usually made in traditional markets are now increasingly made in modern market chains. Therefore, the food supply chain contains more intermediaries such as supermarkets, and the foods travelling longer distances from farm to consumer, such as through international markets (Schipmann and Qaim, 2011).

The global rise of modern trade markets, especially supermarket chains in both developed and developing countries has been considerable (Reardon, Timmer and Minten, 2012). This trend has emerged in developed counties and is now increasingly common in the developing world (Lippe and Isvilanonda, 2010). Modern trade markets such as supermarkets play an important role as key players in distributing nationally and internationally sourced products, allowing consumers access to fresh foods from many different origins across the world (Nielsen, 2015). The expansion of supermarkets has had an impact on food producers (Nimsai, 2012), since competition within the new market structure has improved their efficiency.

Thailand's food retail sector, particularly supermarkets, have been growing rapidly, in-line with retail trends observed in Indonesia (Slamet, Nakayasu and Ichikawa, 2017), Vietnam and Malaysia (Yeo *et al.*, 2017; Yeo *et al.*, 2018). Nielsen (2015) reported that the majority of the customers now made food purchases at supermarket stores, particularly in North America and Europe, while in Asia, and the Middle East food was still purchased at traditional markets but sales in supermarket chains are growing at a faster rate, as shown in Figure 15.

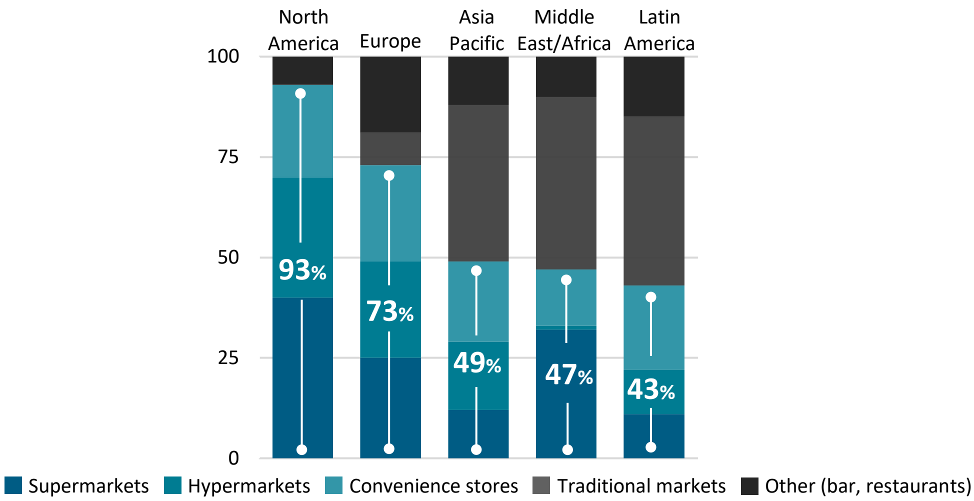


Figure 15 Global food distribution channels in 2015

Source: Nielsen (2015) and FAO (2017)

Changed in consumption patterns, and preference for high-quality food products, are significant factors that made supermarkets successful in gaining market share in many countries (Akkerman, Farahani and Grunow, 2010; Lovreta, Koncar and Stankovic, 2015). Thailand's agriculture has recently diversified from traditional agricultural production, which responded to local demand, to a new kind of production that has been directly triggered by modern trade market chains where the products are required more standardises (Nimsai, 2012). The supermarket chains have shown stronger value growth in Thailand. This has changed considerably as the pattern of retails trade switched from mainly traditional trade toward modern retail trade (Euromonitor, 2018). According to Ngamprasertkit and Welcher (2017), the modern retail trade accounted for about 60% of the total trade sales in 2016. In addition, the modern retail trade continues to grow, particularly convenience stores such as 7-Eleven and Tesco Lotus, with new stores (small-size branch) across Thailand to access more customers (who do not live in the main city), to meet rising consumer demand for quick and convenient meals. Figure 16 shows the positive growth and market share of modern trade retailers in comparison with the traditional market in Thailand.

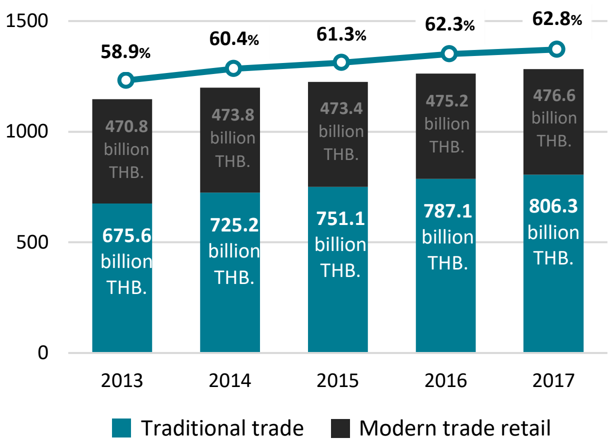


Figure 16 Thailand traditional and modern trade retail sales value

Source: Euromonitor (2018) and Ngamprasertkit and Welcher (2017)

Therefore, the expansion of modern trade market chains presented as a new market opportunity for rural farmers to supply their products to supermarkets and to international market chains. Das Nair, Chisoro and Ziba (2018) pointed out that the modern trade market chains provide an important route and open larger markets for food producers to market their products. Similarly, Ngamprasertkit and Welcher (2017) stated that the development of modern trade market chains created an opportunity for small-scale farmers due to the stable volumes demanded all year round. Wiboonpongse and Sriboonchitta (2004), explained that rural farmers providing products into modern trade market chains have been offered a better price, and have received benefits such as credits and training programs[5] which are not provided by the traditional market.

However, food producers are faced with several threats and obstacles to sell their products to the modern trade market chains, particularly rural farmers. The products from rural farmers are often rejected by the major buyers due to quality assurance standards. A key obstacle to their participation, however, relates to the strict requirements the buyers place on suppliers in term of meeting not only product quality, specification, volume, and delivery but the accompanying data on the product that must be transferred pre- and post-transaction (Nimsai, 2012; Slamet, Nakayasu and Ichikawa, 2017). Challenges are faces by food producers in scaling up their operations for the demands of high-value market chains. Goldenberg (2016) reported that 40% of food products were being rejected because they did not conform to the buyers', and industry standards and inefficient production and transportation systems were a key problem, since the rural farmers have no effective transportation system to move their products in the correct way (Caixeta-Filho and Péra, 2018). The study found that the agricultural products being lost post-harvest ranged from 17-40%

[5] Support ranges from money, agricultural inputs, and crop production training.

at the farm and consolidation point stages, and 3-15% at the retail level, depending on the type of product. The inefficient logistics and improper handling, such as transportation equipment and storage facilities, can be considered a reasonable explanation for many losses between the farm and the market. To mitigate the post-harvest loss, proper transportation and storage facilities must be provided, and optimal storage location and transportation route could be designed and actively promoted (Caixeta-Filho and Péra, 2018). Khapayi and Celliers (2016) pointed out that the government has a crucial role to play in increasing market participation for rural farmers through encouraging group marketing, upgrading road infrastructure, and establishing local collecting points, to enable smooth accessibility to markets. The farmer's organisation concept, both co-operative and social enterprise, has been developed to facilitate linkages between major buyers and individual farmers. This strategy has been setup to enable an improved economic environment and encourage the provision of shared agricultural resources, providing an opportunity for rural famers to manage themselves in the form of an organisation to help overcome the negative impacts from the major buyers such as gaining more power of negotiation, economies of scale (Reardon, Timmer and Minten, 2012).

2.4 Farmer's Organisation

A collaborative working strategy, such as those demonstrated by co-operative and social enterprise, has been applied to the agriculture sector, as a new approach to agribusiness (Dung, 2011). Farmer's organisations, also referred to "co-operatives" and "social enterprises", have grown considerably in many regions of the world. Kumar and Gupta (2013) defined a social enterprise as "a private not for profit organisation that produces or exchanges social utility goods or services aimed at pursing general interest goals, which are carried out in a stable way and as a main economic activity". The farmers' organisation plays an important role in linking rural famers to main the market channels.

2.4.1 Role of the Farmer Organisation

The farmer's organisation plays an important role as middleman in linking rural farmers with the major buyers such as supermarkets and international markets. Nimsai (2012) stated that the farmer's organisation plays an important role as an agri-food supplier in modern market chains, particularly in the organic and pesticide-safe products market in Thailand. Suhaimee *et al.* (2015) also stated that the farmer's organisation was established to improve the knowledge of managerial skills, and increase revenue and income for its member farmers, by providing the essential agricultural inputs/resources. Dung (2011) reported that the agricultural co-operatives in Vietnam played an important role in rural development through the agricultural development schemes in strengthening market access and competitive returns for independent food producers. In Vietnam, the agricultural co-operatives were used to directly manage the land (land preparation, irrigation), organise production activities and the agricultural inputs, as well as marketing of the agricultural products. With the limited functioning of government and private sector in many developing counties, farmer's organisations often seem to be a better way to improve such negotiation power with other supply chain actors, particularly major buyers (Lemeilleur and Codron, 2011), support the agricultural inputs, and also marketing for it member farmers (Le *et al.*, 2016). Fulfilling these roles is crucial for increasing profitability of rural farmers, thereby helping farmers with more sustainable production and long-term participation in the markets. Farmer's organisations can provide agricultural inputs, credit, training, and managerial skill development support, to help rural farmers improve their participation, production, and stability in the markets. A farmer's organisation scheme also increases the level of trust between farmers and the major buyers. Therefore, the agricultural co-operative could be an opportunity for upgrading quality and gaining market access for particular farmers. In addition, farmer's organisations help to develop "national social product brands" which are brands named after important national symbols such as the Royal Project brands in Thailand that became well-known in domestic markets for organic and pesticide-free fruits and vegetables (Nimsai, 2012).

2.4.2 Thailand's Agricultural Co-operative Structure

Thailand's agricultural co-operative is vertically structured in a three-tier system: primary co-operative at the district level, provincial federations, and national federations at the top which operate under the "Co-operative Act B.E. 1999". All agricultural co-operatives in Thailand become members of the Co-operative League of Thailand (CLT) automatically (Patrawart and Sriurai, 2016; Cooperative Promotion Department, 2018). The CLT in functions as an umbrella organisation of the whole co-operative movement, and acts as a facilitator, coordinator, policy developer, and provides educational support in the promotion of all co-operative progress (Cooperative Promotion Department, 2018).

The primary co-operative consists of individual member farmers, while members of provincial and national federations are co-operatives. The members elect the Board of Directors through the annual meeting, with a maximum of 15 persons, for the formulation of co-operative development policies. The Board of Directors then appoints a manager and staff to run the co-operative business. Five or more co-operatives at primary or provincial level can form a provincial of national federation together to undertake join activities on behalf of their affiliates, such as processing and trading of agricultural products. At national level, there is the Agricultural Co-operative Federation of Thailand to which all 77 provincial agricultural co-operative federations are affiliated. In 2016, there were

7,016 registered co-operatives in Thailand, with 3,838 being agricultural co-operatives, and the remaining 3,178 non-agricultural co-operatives such as credit unions, and service businesses.

2.4.3 Advantages and Challenges Associated with Farmer's Organisation

The collaborative working strategy, such as agricultural co-operatives and social enterprises, brings with it advantages and challenges to rural farmers in terms of getting involved in the new market structure, particularly with supermarket and international market chains. Nimsai (2012) stated that social enterprise schemes have become an alternative model for farmer's organisation in many developing countries such as Philippine, India, Malaysia, Pakistan, and Thailand. Most farmers interviewed as part of the research mentioned the advantages of participating in an agricultural farmer's organisation as being improved production, marketing, and support with agricultural inputs such as credit, fertilisers, and chemicals.

Thuvachote (2011) stated that farmer co-operatives provide a significant improvement for Thai farmers, especially income generation and social benefits such as training courses and education support to their members. Some examples were given of successful farmers' co-operative across the region. One such was Tha-Yang agricultural co-operative, which has successfully delivered chemical-free bananas to the Japanese market, adding about 20% above market price to the margins for farmer members. Another successful case involved production of "Phon Yang Kham Beef", later known as "Thailand's best beef". This co-operative generated more income for their farmer members than non-members through the premium prices commanded for their products.

Sathapatyanon *et al.* (2018) reported the partnerships among rice co-operative networks in Thailand reduced production and marketing problems, such as market access, lack of market information benefitting the producer and buyer. Coordination among the co-operatives enabled all partners to better manage their production, such as internal collective action by the members of co-operative, information sharing regarding the demands of the market, and cost sharing of ordering agricultural inputs and transportation cost. However, the participants also stated that the quality standards required, in terms of products quality, transportation systems and cold storage, were the most common challenges to their operation in complying with the requirements of major buyers. Ongkunaruk and Piyakarn (2011) mentioned that mangosteen farmers in Thailand faced difficulties in logistics management because of the perishability and fragility of the products, which resulted from inadequate transportation and cold storage resources, as well as factors such as climate, disease, and insects.

There is waste during harvest and post-harvest which has a negative impact on the long-term operations for the food producers. The damaged products are mainly from the transportation where the products are not moved in the correct way and at the correct temperature. As mentioned in the previous section that 2-5% of the products are getting lost between farms and consolidation point and increased to 5-10% when travelling between local consolidation point and distribution centre or final markets. Under this situation, the damaged products will attract a lower grade price (premium grade price at 60-70 THB, while lower grade price at 30-40 THB), and sometime can be rejected outright if damage exceed 10% of the total shipment. This can impact to their long-term operations where the purchasing contract will be terminated and the farmer black-listed if the products from a farmer are rejected three times. In addition, the field work showed that damaged products during transportation led to annual losses of between 10,000-27,000 kg, equating to financial losses of approximately 547,000 THB (£14,005). In 2017, the Office of Agricultural Extension in Thailand reported that the financial losses of agricultural products, particularly major commercial fruits during the post-harvest distribution phase were approximately 268 million THB (£6.8 million). However, the observed data at the fieldwork shown that the damaged products or those products does not pass the quality check will generally be transformed into new products such as mango ice-cream and mango sheet (sundried mango).

2.4.4 Collaborative Transportation System

In recent year, several strategies and logistics models have been developed in order to increase general supply chain efficiency. Collaboration in transportation involves stakeholders, i.e. producers, collectors, shoppers, distributors, and retailers, co-operating to improve the sustainability of supply chain through increased efficiency of resources, such as sharing storage facilities, depots, and vehicles. The level of collaboration between the participants determines the success of the supply chain overall. Vertical collaboration involves co-operation between members of the same supply chain, whereas horizontal collaboration involves co-operation between organisations that can provide similar goods and/or services at the same level within a supply chain (Ouhader and El Kyal, 2017; Gansterer and Hartl, 2020).

Collaborative transportation, or shared-fleet operations, is where two or more organisations co-operate over the use of a carrier's fleet to move their loads or combine loads into one vehicle (Chan and Zhang, 2011; Cleophas *et al.*, 2019). Simatupang and Sridharan (2002) defined collaborative transportation as a holistic process where "two or more independent organisations work jointly to plan and execute supply chain operations with greater success than when acting in isolation". This approach is becoming of interest to the Thai Government as a potential method for better managing agricultural supply chains, where strategic alliances are built between two or more organisations. The goal of collaborative transportation is to improve services efficiencies between the parties, with the main benefits being cost savings (Karolefsky, 2001), and the distribution of increased profits between co-operating carriers (Ouhader and El Kyal, 2017). There is recognition that a more collaborative approach to transportation has become a critical means of addressing sustainability issues whilst also helping to reduce empty running vehicle (Cleophas *et al.*, 2019), and improve safety (Simatupang and Sridharan, 2002).

A comprehensive review of recent research in the domain was conducted by Gansterer, Hartl and Wieser (2020) who found that a cost saving of 20-30% could be generated by carriers collaborating in such a way. Similarly, Stellingwerf *et al.* (2018) also found that a logistics co-operative, in Dutch supermarket chains, saved 41% of the total transportation cost by implementing joint route planning. Burton and Ruediger (2016) found that suppliers and retailers across North America agreed that collaboration, especially in reverse logistics processes, was key to reducing wasted truck miles, environmental impacts, and cutting transportation cost. Cruijssen, Cools and Dullaert (2007) reported that horizontal co-operation by using third-party logistics increases the company's productivity for core activities and reduces the cost of non-core activities. Cleophas *et al.* (2019), Wang *et al.* (2018a), Wang *et al.* (2018b), and Yao, Cheng and Song (2019) conducted computational studies which demonstrated that collaborative transportation can lead to "significant emission and cost reductions through reducing the number of delivery vehicles needed". Stellingwerf *et al.* (2018) also found that collaborative transport by joining route realised a 30% reduction in the total emission, as well as a reduction in the total travelling time by 53%.

Most of these studies focused on the collaborative last-mile delivery, particularly in urban areas. However, literature remains scarce on collaborative first-mile collection, particularly in rural areas. Hardy and Koontz (2010) mentioned that urban and rural landscapes can have very different biological systems, with collaborative management efforts in each setting impacted by different sets of variables, from human capital (income, education), social capital (trust, network), to the financial and technical resources made available by government and related organisations, such as NGO and academic units. Rural farmers are often completely disconnected from major road, rail lines, and public transport services, and opportunities to tie in with more sustainable collaborative logistics strategies (Cook *et al.*, 2017). Bosona and Gebresenbet (2011) conducted computational studies that demonstrated two different logistics operating scenarios in food distribution, based on 90 local food producers and 19 food collection centres (CC) from all over Sweden. The two scenarios were: 'producers transport their products to the CC' where the food producers delivered their products to the CC without coordination in transportation, and 'coordinated collection of products to CC', where food producers were assigned to each route, using software to optimise delivery distance and time. The computational results suggested that collaborative transport reduced the number of routes by 68%, driving distance by 50% and product delivery time by 47%. The study also claimed that the collaborative transport strategy could make a positive improvement to potential markets, logistics efficiency, and environmental issues.

Bosona *et al.* (2013) and Bosona *et al.* (2011) demonstrated that the collaborative transportation among the food producers in Sweden led to significant reduction in the total transport distance, time, and number of routes. They investigated four logistics operating scenarios: (i) fragmented distribution where all food producers deliver their products to their customer separately; (ii) uncoordinated collection and coordinated distribution, where the products are transported from food producers to the CC, before delivering to the retails, (iii) coordinated collection and coordinated distribution, where the collection of products to CC and delivery to the retails were considered to be coordinated; and finally (iv) integrated collection and distribution, where both collection and distribution were to be coordinated for every route, the driver receiving information for collecting the products from the producers while delivering to the retailers at the same time. The results suggested that the best improvements were gained in scenario 4, the transport distance was reduced by 62%, and 83% in the total number of vehicles visit. In Scenarios 2, a significant saving was gained in transport distance by 39% reduction, and 30% in the total number of vehicles visit. While scenario 3, the transport distance was reduced by 43%, and 65% in the total number of vehicles visit. In addition, the results suggested that the vehicle utilisation increased by 30-40% of loading capacity and increased the sustainability of the local food system.

Fikar and Leithner (2020) investigated the impacts of collaborative logistics activities through the development of a simulation and optimisation-based decision support system (DSS). The DSS combined simulation techniques to estimate demand and food quality losses, with a metaheuristic optimisation to generate delivery routes. Five different logistics operating scenarios were developed: (i) each food co-operative pick up its own orders; (ii) food co-operatives collaborate to jointly collect orders; (iii) each farmer delivered their own products to food co-operatives; (iv) farmers collaborated to jointly deliver orders; and (v) all deliveries are outsourced to third-party logistics provider. The experiments were based on fresh food transportation, particularly infrequent orders and small quantities from 59 vegetable farmers and 60 food co-operatives in Austria. They found that scenarios 2 and 4 resulted in a substantial reduction in travel distances and reduction in the number of vehicles required, which resulted from the increasing order quantity within a single vehicle tour. However, the delivered food quality potentially deteriorated due to additional joint loading activities. Therefore, employing a third-party logistics provider was particularly beneficial if food quality is of focus.

2.5 Thailand's Transportation Systems

Thailand's transportation system for carrying domestic and international cargoes is diverse and includes road, rail, air, and coastal transport systems. Thailand has well-developed road networks linking each province across the country, while its two large deep seaports and six international airports are connected to international shipping routes (Chura, 2015; Thailand Board of Investment, 2016b). Thailand's transportation networks were facilitated by the government's policy under the campaign to promote Thailand as an ASEAN (the Association of Southeast Asian Nations) logistics hub (Chura, 2015). The government has devoted considerable effort to alleviate the country's trade and logistics inefficiencies.

Thailand has implemented its 12th National Economic and Social Development Plan (2016-2021), which is 5-year vision in accordance with the 20-year strategic plan and reform (2017-2036), with a goal of enhancing security, prosperity, and sustainability (Kunadhamraks, 2012; NIDA, 2017). This strategic plan aims to distribute prosperity across different regions through development, by upgrading the existing infrastructure such as the road network in the countryside to support the development of areas along the economic corridor[6], promoting a new international airport "the Royal Thai Navy airport" into a third airport for the Thai capital, and initiating a high-speed rail project linking to main export gateway of two main airport and deep seaports (NIDA, 2017). As a result, Thailand was ranked 32nd among 160 countries in logistics competency, and 2nd among ASEAN countries in 2018 (World Bank, 2018).

2.5.1 Road Transport

Thailand is dominated by road transport which account for approximately 86% of the total freight volume moved across the country, followed by coastal transport at 11%, 2% from rail, and 1% by air (Thailand Board of Investment, 2016b). Road infrastructure is the most developed mode of transportation with over 698,424 km (436,515 miles) across the country. Of these, 8% (51,936 km) constitute the highway[7] network connecting each region of the country, 7% (48,597 km) are roads under local government jurisdiction, 0.03% (224 km) are motorways covering Bangkok and surrounding industrial areas, while 85% (597,667 km) are classed as rural road networks (MOTOC, 2017).

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[6] Economic corridors connect economic in a given area, whose member states are Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Vietnam, and Thailand

[7] Major road networks are mostly reinforced concrete roads and asphalt concrete roads with a four-lane divided highway.

The 13 highways (Economic Corridor routes) connecting Thailand to its neighbours is the highest number among the ASEAN countries (Kunadhamraks, 2012), which play an important role in trade among ASEAN countries. The routes, such as North-South Economic Corridor (NSEC), and East-West Economic Corridor, provide effective and efficient transport from Thailand to its neighbour markets (Asian Development Bank, 2016). Pomlaktong *et al.* (2014) reported that the fresh fruits transported from Thailand to neighbouring markets, such as China, normally uses sea freight transport from Lam Chabang deep seaport to Guang Zhou seaport, which takes around 8-10 days and leaves only a few days to distribute the products. However, the potential route will shorten the period to transport the products from Thailand to China to only 3 days by road transport.

Truck transport dominates the freight transport industry in Thailand. Pomlaktong *et al.* (2014) reported that 427.5 out of 507.7 million tons or 80% of freight in Thailand is transported by trucks, with only 2% (11.5 million tons) moved by rail. The rest is split among inland waterway, coastal, and air transport. Truck transport is dominated by light pick-up vehicles (small trucks with loading capacity at 1.5-2 tonnes), particularly agricultural products such as fruits and vegetables. The Department of Land Transport (2018) reported that the total number of trucks, include non-fixed route/3PL trucks and private trucks accounted for 1.13 million vehicles. This number consisted of light pick-up vehicles[8] at 55% (611,475), van at 7% (78,825), chemical and liquid trailers at 2% (21,160), container truck for danger products at 1% (10,680), trailer polling at 9% (101,769), tractor trailer at 8% (89,758), semi-trailer at 10% (113,620), large-tractor trailer at 0.2% (1,303), off-road trucks[9] at 0.8% (8,006), and specific-use trucks at 7% (85,461). The World Bank (2018) reported that Thailand's freight transport services exhibit some inefficiencies, including ageing fleets of truck with low load limits and poor fuel efficiency, low penetration of multi-modal logistics providers, and limited use of Electronic Data Interchange for facilities shipment delivery and supply chain management. In addition, the use of older, more polluting trucks was identified as a key issue that leads to the abrasion of road, air pollution, and high accident rate, as well as affecting the product quality (Kunadhamraks, 2012; Pomlaktong *et al.*, 2014).

2.6 Cost Allocation

Collaborative transportation is gaining popularity and is crucial for a sustainable operation and environmental benefits (Simatupang and Sridharan, 2002; Cleophas et al., 2019; Fikar et al., 2020). The data collected shown that the rural farmers are positioned at the different location e.g. plantations, and each has the same destination (at consolidation point). One of the major issues in

[8] Truck cabs, with two doors and room for two extra passengers with open space behind.
[9] Trucks that work on mines and large construction sites, in farm transport.

collaborative transport is fairly splitting the shared transportation cost among the farmers. Many sharing mechanisms or cost allocations have been proposed, some based on simple proportional rules and others based on theoretical concepts found in game theory. A simple approach for cost allocation is to use a proportional allocation based on the overall volume or weight of the products transported (Guajardo and Rönnqvist, 2016). A more advanced approach is to use co-operative game theory (Liu and Cheng, 2019) such as the Core generated by Gillies (1959), the Nucleolus studied by Schmeidler (1969). A frequently used cost allocation method is the Shapley values suggested by Shapley (1953).

2.6.1 Cost Allocation Methods

Several problems arise when two or more organisations collaborate through joint transportation (each entry is concerned with its own benefit). Many researchers have resorted to different co-operative game solutions to coordinate the supply chain, such as the proportional method based on volumes or stand-alone cost (Frisk *et al.*, 2010; Nguyen, Dessouky and Toriello, 2014; Sun *et al.*, 2015; Guajardo and Rönnqvist, 2016; Liu and Cheng, 2019; Giménez-Gómez, Peris and Subiza, 2020; Kayikci, 2020), or the Shapley value (Lozano *et al.*, 2013; Vanovermeire and Sörensen, 2014; Vanovermeire *et al.*, 2014; Sun *et al.*, 2015; Kayikci, 2020), and among others.

The problem was defined by Guajardo and Rönnqvist (2016) when different consignors bundle their orders, and hire transport services from the same carrier. The motivation is that consignors together can negotiate better rates with the carrier than they can individually, for example by requiring a full truckload instead of a partial truckload service. They then need to decide how to share the total cost of transport.

Different allocation mechanisms have been proposed: simple proportional method, the Shapley value, Nucleolus, ad hoc, dual or shadow prices methods. This type of problem is addressed in Nguyen, Dessouky and Toriello (2014), where five suppliers, with average daily demand smaller than a full truckload, shipped cut flowers to the same destination. They proposed a policy that charges each supplier a proportion of the total cost equal to the proportion of demand in the current shipment that belong to the supplier. That is, let c be the total cost for the outgoing shipment to a destination, and let β_i be the proportion of volume that originates from supplier i. Then the supplier will pay $c\beta_i$. The proportional methods are those where each player j is assigned a share w_j of the total cost $c(N)$. The simplest one is the 'egalitarian' method which assigns equal cost shares to all the players (divide the cost equally among individual) (Guajardo and Rönnqvist, 2016; Giménez-Gómez, Peris and Subiza, 2020).

Giménez-Gómez, Peris and Subiza (2020) researched how to fairly allocate the total cost, a situation where some individuals, located at different places, want to be connected to a source in order to obtain goods or a service. The total cost C_m is divided equally among the individuals; $\alpha_i = \frac{1}{n}C_m, i = 1,2,\dots,n$. However, this may not be fairly allocated when some players were allocated 4 monetary units whereas their cost to the sources is 1 monetary unit. They introduced a possible way to share the benefits obtained from co-operative equally by $\alpha_i = c_{ii}^* \frac{C^* - C_m}{n}, i = 1,2,\dots,n$, when c_{ii}^* is the individual joint contribution of the amount C^*.

Other commonly used easy to compute methods are "cost allocation based on volume" (Frisk *et al.*, 2010; Nguyen, Dessouky and Toriello, 2014; Liu and Cheng, 2019) based on the volume or demand quantities, and "stand-alone costs" (Sun *et al.*, 2015; Liu and Cheng, 2019). Frisk *et al.* (2010) computated cost allocation methods in collaborative forest transportation. One of the proposed methods was an allocation based on volumes or quantities, $y_i = w_i c(N)$, where w_i is equal to participant i's share of the total transported volume or alternatively.

The Shapley value was introduced by Shapley in (1953) as a method of joint cost allocation. The Shapley value aims at the 'fair' allocation of collective costs or gained savings between the collaborating participants based on the relative (marginal) contribution of each participant to their co-operative activities. Kolker (2018) gave an example of meritocracy fairness in that the more one brings to the coalition, the more one gets in the division of the accumulated gains. Vanovermeire and Sörensen (2014) and Vanovermeire *et al.* (2014) also integrated the cost allocation strategy with the different transportation partners, using the Shapley value method for the optimisation of collaborative transport, to ensures that the operational plan is acceptable for all partners. A case study of three companies in Belgium achieves a 25% decrease in transportation costs. Allocating this collaborative gain with Shapley value, the individual gains range from 19-37%.

Lozano *et al.* (2013) conducted a co-operative game theory using the Shapley value, Nucleolus, T-value, Core centre, and Minmax core methods, to allocating benefits of horizontal co-operation among the four potential companies, which were considering the possibility of a horizontal co-operation through the merging of their transportation demand, using their own fleet and subcontracting a 3PL carrier. The cost allocation methods gave similar (stable and fair) benefits for all partners of the collaboration. The results suggested that the participants obtained 35.20% cost savings from the Shapley value method, whereas Nucleolus method can achieve 37.80% cost savings, 36.70% by T-value, 36.90% by Core centre, and finally 37.60% by Minmax core method.

Kayikci (2020) conducted computational testing of cost allocation in international sea-rail multimodal freight transportation between four partner organisations. The three cost allocation methods, proportional cost allocation based on volumes transported, decomposition, and the Shapley value methods, were compared with the non-collaborative form in order to prove that the collaborative transportation could achieve more cost savings for the participant organisations. The study suggested that applying the Shapley value method provided higher cost savings for all participants compared to the other methods (4.2% cost savings allocated by proportional method, 9.9% by the decomposition method, 15% by the Shapley value). In addition, the study suggested that allocating the coalition costs or benefits impartially presents a key point, since the proposed allocation method should convince the participants to act according to the collaborative goal and improve collaboration stability.

2.6.2 Concepts of Fairness

The principle of fairness generally is characterised by equity among the participants in their relations to co-operative scheme. Although each solution and concept for the total cost allocation can meet some fairness standards, none of them are able to meet all the standards. Judgement rules are needed to define fairness and evaluate cost allocation methods. According to Ye, Zhang and Dekker (2017), the difficulty in the cost allocation lies in the fairness criterion, which requires the allocation mechanisms to satisfy allocation maximisation, fairness, and cost minimisation. Key fairness criteria have been identified in relevant studies. Sun *et al.* (2015), Liu and Cheng (2019) developed five fairness criteria or axioms, which took multiple fairness standards into consideration in cost allocation to the shipper in pickup and delivery services: (i) total route cost should be completely allocated; (ii) every participant's cost should be non-negative; (iii) cost allocation should not be influenced by the direction of tours (i.e. if 0-1-2-3-0 and 0-3-2-1-0 are two routes, which have the same total costs); (iv) the cost allocation should be monotonic in the participants' contribution to the route cost (i.e. the cost allocation to client *i* does not increase if the cost of a link involving client *i* goes down), (v) the excess rate of cost allocation should be as small as possible. These criteria were used to evaluate different cost allocation methods in this research.

Stable cost allocations are at the core of co-operative game theory. The core of a cost allocation consists of a way to identify which organisation, department, or individual participant that provides or consumes the products or services being shared. In the case of this research, it is the participant farmers in the co-operative scheme to share each others vehicle capacity. According to Anily, and Haviv (2017), the core can be considered as alternative proof of the fairness of the co-operative game, suggesting a fair and equitable way to split the total cost from the grand coalition. Similarly, Kimms, and Kozeletskyi (2016) state that the core element is a vector that completely allocate the total cost among all participants from the grand coalition and assigns to each participant, which cannot be dominated by any other sub-coalition. In this research, a coalition leads to a subset of rural farmers working together, which then induces a cost for these farmers according to the cost allocation (described in Chapter 6). The core of the co-operative game is the set of feasible allocations to which the farmers are assigned as part of a specific coalition which cannot simultaneously reduce the cost to all of them in another allocation, if allocation is in the core. There is not a better allocation for the farmers within the same coalition in that allocation. The core condition is that no participant in the coalition should get more total cost compared to its valuation and there should be no incentive for the coalition to go it alone.

Guajardo and Rönnqvist (2016) mentioned that a proportional allocation based on volumes or stand-alone cost is a simple approach for cost allocation, whose fairness can be verify based on the overall volumes or weight of the products transported. The total volumes contributed by each participant has a large impact on the cost allocations. Kayikci (2020) also said that the proportional allocation mechanism is seen as the most commonly used method in practice, since profit revenues obtained through collaboration are distributed equally on the basis of the volume of transport or individual cost level as a result of the collaboration undertaken between the participants.

The proportional method for sharing the benefits of the collaboration among the different participants is a simple mechanism allocation, but does not guarantee a fair and equitable distribution of the benefits of the collaboration (Lozano *et al.*, 2013). Cruijssen, Dullaert and Fleuren (2007) showed that distributing savings proportionally depend to a single indicator: volumes shipped, stand-alone cost before co-operation, distance travelled, or number of customers served. They also highlighted that in the long-term operation, some participants will inevitably become frustrated since their true share in the group's success is undervalued. For example, if cost sharing takes place according to the volumes shipped, a certain participant who delivers a large volume in a short distance will get the large share of the costs, while other participants with small volumes on the same route, but who are located far away, receive a very small cost share. Therefore, a more theoretically grounded approach is needed and the one most appropriate seems to come from co-operative game theory, such as the Shapley value method.

The Shapley value aims at the 'fair' allocation of collective benefits or cost savings between the collaborating participants based on the relative marginal contribution of each participant to their co-operative activities. Fairness can be verified based on the principle of the more one brings to the coalition, the more one gets out of the division of the accumulated gains, in other words, the participant would get some share, regardless of whether or not they make a marginal contribution to the welfare of the coalition (Kolker, 2018). The idea is that when different participants co-operate, the increased probability of a vehicle carrying another load on its trip, can significantly decrease overall transportation costs (Frisk *et al.*, 2010). Vanovermeire *et al.* (2014), Kayikci (2020) stated that the Shapley value concept is one of the well-known distribution methods in collaborative game theory and the most commonly used in practice, where the cost is distributed according to the weighted average of the marginal contributions of each participant in the coalition. This implies that the cost effect that each participant generates when they are added to the coalition is used to determine the allocation benefits. The Shapley value provides important properties that make its usage efficient. (Kimms, 2016) highlighted that the existence and uniqueness of the Shapley value is given for every cooperative game, which is an advantage in contrast to the core, where non-emptiness is not always given and in the case of a non-empty core, every player has different preferences toward different core elements. Under this condition, each participant gaines with an incentive to form the coalition. Secondly, is the property of balanced contribution which prevents partners from withdrawal from the coalition, as the Shapley value ensures the amounts that each player would gain or lose by the other's withdrawal should be equal. As this advantage is held only for the Shapley value when compared to other cost allocation mechanisms. However, in the case when the core is empty where the coalition is not stable (eg. some participants may break out and start their own coalition). Frisk, 2010, mentioned that the epsilon-core was proposed to keep the grand coalition stable and note the existence of a coalition that would have an incentive to break out. An epsilon-core add a minimum penalised slack in the constraints defining the core. This 'slack' means that the actual cost of each coalition is enlarged by a small positive amount which can be seen as the extra cost required to form a coalition.

2.7 Conclusions

This chapter constitutes the background to justify the importance of this research. It introduces Thailand's agriculture and its significance of agricultural in rural areas particularly mangoes which contribute to a significant proportion of the country's economy. With the expansions of modern supermarket trade chains, new business opportunities arise for rural farmers, however, they face many challenges when trying to access this particular market. The core requirement imposed by supermarket chains is for quality in relation to the product appearance, size, and the production process involved. Some of these challenges can be mitigated to some extent when farmers join an agricultural co-operative or social enterprise to help them in the negotiation, contract management, and sourcing of agricultural inputs such as credit and fertiliser.

The literature and survey work has shown that the high product wastage rates directly relate to post-harvest transportation where the products are not moved in the most appropriate way and at the correct temperature. As a direct result, 2-5% of the products is lost between farms and consolidation point and another 5-10% between the local consolidation point and distribution centre or final markets. The BAU operations shown that the cost of product wastage accounted for

78% of the total cost when the product was damaged at 1% and increased up to 97% when the product was damaged at 10%. Thailand's freight transport services exhibit some inefficiencies such as an ageing truck fleet with low-capacity limits and poor fuel efficiency. Use of inefficient trucks also leads to the air pollution and higher accident rates. Therefore, the Thai government has expressed a need to address this issue, to create a more inclusive operating environment for rural farmers to ensure that they can remain competitive.

When trying to maintain product quality, rural farmers can be constrained by their transportation resources and do not comply with the strict temperature control standards dictated by major buyers. The literature explains the operating model currently used and the opportunity for collaborative transportation operations that might be beneficial to rural farmers in the long run. Collaborative transportation or shared-fleet operations is where two or more organisations co-operate over the use of a carrier's fleet to move their loads or combine loads into one vehicle. This approach is to improve service efficiencies between the parties, with the main benefit being cost savings. According to the literature, collaborative transportation could save 20-30% of the transportation cost, 50% of distance travelled, and 40% on CO_2 emission. However, the literature shown has that most of these studies focused on the collaborative last-mile delivery in urban areas, which remains scarce on collaborative first-mile collection particularly in rural areas.

In addition, a significant aspect of the collaboration between two or more organisations is deciding how to share the benefits, and how the combined transportation costs on the same route should be fairly distributed. Many cost allocation mechanisms have been proposed, some based on simple proportional rules and others based on theoretical concepts found in game theory. suggests that the Shapley value appears to be the most appropriate cost allocation for addressing fairness in a shared fleet concept to assist rural farmers. However, there is no concept that totally satisfies all fairness, as each method contains some benefits and drawbacks. This research offers more options for participants to choose the cost allocation method in collaboration. The cost allocation mechanism will be demonstrated in Chapter 6, where the transportation cost is distributed fairly amongst the rural farmers.

Chapter 3 Research Methodology

Section 3.1 provides an overview of the methodology used, and the stages of data collection are dealt with in section 3.2, while section 3.3 discusses the data analysis and the alternative collaborative logistics scenarios. Section 3.4 presents the cost allocation methods used to demonstrate how to share the transportation cost fairly among the rural farmers. The chapter ends with an explanation of the model design and implementation (Section 3.5).

This approach taken used mixed research methods, combining qualitative and quantitative techniques to help describe the business-as-usual operating characteristics of a group of farmers in Thailand. This provided essential knowledge for understanding the problems and challenges faced by rural farmers, their business relationships, their current production processes, and their different models of operation through social enterprises and co-operatives. The quantitative data includes farm demographics and current production and transportation methods, which were used to determine how appropriate consolidation would be for the collective transport of product from rural farmers to consolidation points and final markets.

3.1 Scope of the Study

The research design, data gathering, analysis, and interpretation have been based on a case study approach which focussed around primary data collection in Thailand. The case study was Thailand’s fresh fruit industry and specifically the mango supply chain, which has considerable export potential but suffers from excess waste due to inefficient logistics practices. Mango production was selected due to its significant export market value and its overall contribution and importance to the Thai economy. Data collection involved a mixture of gathering historical agricultural production records from government sources and new primary data through in-depth interviews and focus group discussions with farmers and their associated co-operatives. The in-depth interviews and focus group discussions were undertaken with the rural farmers who are part of the farmers’ co-operative in Phitsanulok and Chiang Mai provinces. These represent two of the five provinces in Thailand that produce the largest volumes of the most popular varieties of mangoes, namely “Nam Dok Mai Golden” and “Nam Dok Mai No.4” and contribute 21% of the overall annual production across the region (OAE, 2017).

3.2 Data Collection

Data collection took place in Thailand from 23 December 2018 and 26 March 2019, to help understand the key challenges faced by rural farmers and to investigate the opportunities for improving the logistics and food supply chain management. The study received ethical approval from the University of Southampton research ethics committee, number 45356. Data collection sources were historical production records from government record from The Office of Agricultural Economic, Ministry of Agriculture and Co-operatives, and new primary data through in-depth interviews and focus group discussions with groups of farmers, social enterprises, co-operatives, brokers, retailers, and government institutions.

3.2.1 Overview of Data Collection

Data collection was divided into six stages as follows;

Survey step 1: The Thailand government's sources of secondary data related to food production, particularly mango supply, the annual reports were investigated through The Office of Agricultural Economics, and The Ministry of Agriculture and Co-operatives, which were formally approached, and information requested. The results were the agricultural production figures by farm, region, and the overall export figures to different countries. This information was necessary for an understanding of the industry background related to rural agri-food supply chain management.

Survey step 2: Face-to-face, in-depth interview was undertaken with a key stakeholder in the Government including the Chief Executive Officers of the Co-operative Promotion Department in The Ministry of Agriculture and Co-operatives, who has responsibility for the administration of agricultural policies, forestry, support and development of farmers and co-operative systems. A semi-structured interview questionnaire, detailed in Appendix C.1, was designed to gather data on the government regulations and development programs on co-operative and social enterprises.

Survey step 3: Face-to-face interviews were undertaken with representatives from the forefront modern trade retailers in Thailand, e.g. Central Food Retail, Gourmet Fresh Market, and Rising (Thailand) Ltd. This included brokers and traders who act as major buyers of food products from rural farmers. Information was gathered on their procurement system, specific requirements, policies, market trend as well as how they work with their suppliers (rural farmers) for getting product from farm to the markets. A semi-structured interview questionnaire used to gain the information with the commission agents, detailed in Appendix C.2 and C.4.

Survey step 4: Face-to-face interviews were undertaken with three organisations, two agricultural co-operatives (San Pa Thong and Jom Thong) and one social enterprise (Hin Lad agricultural), who support rural farmers with agricultural activities such as agricultural inputs, credits, and training. In-depth interviews were used to gather information about the business characteristics, co-operative working concept, and challenges faced in their operations particularly the process of getting products from farms to the consolidation point and final market, as detailed in Appendix C.3. In addition, the historical data such as procurement, selling, and transportation were collected, which were used to quantify how appropriate consolidation would be for the collective transport of the product from farm to the consolidation point.

Survey step 5: Focus groups were undertaken with groups of farmers who were operating as part of co-operatives and social enterprise, at the social enterprise's office after their monthly meeting, using a semi-structured interview questionnaire, detailed in Appendix C.5. The 81 individual farmers belonged to the co-operatives (20 farmers from Jom Thong, and 12 farmers from San Pa Thong) and the social enterprise (49 from Hin Lad). Face-to-face interviews were also undertaken with individual famers (20 of those from Hin Lad) to gain more specific information on their operations. These interviews were undertaken at individual farms, and at the consolidation points, as shown in Appendix C.6. The focus groups and individual farmer in-depth interviews aimed to determine how their relationship with the farmer's organisations worked in terms of transactions, transportation, quality assurance and financial transactions. Quantitative data were collected, such as their production capacity, farm size, distances, and related transportation costs.

Survey step 6: In the final stage, the key research findings were presented remotely to the two groups of rural farmers (9 farmers out of 49 from HL's agricultural social enterprise), to determine how the proposed co-operative transportation schemes work for them and obtain feedback on any negative issues that arose, as presented in Section 7.1, using the set of question shown in Appendix C.6. The qualitative data from the focus group discussion were collected to gain more information on their opinions about implementing alternative transportation schemes.

3.2.2 Data Collection Strategies

Snowball sampling technique

A snowball sampling approach was used to contact the research informants. This is most commonly known as the "non-probability" sampling technique, and used when it is difficult to identify members of the desired population (Saunders, 2011). This sampling method involves a primary data source nominating another potential primary data source. There are two steps to create a snowball sample: (i) identify one or more units in the desired population; and (ii) use these units to find further units. The original list of the respondents was based on information from government officers, from the key respondent in organisations participating in the study, from participant farmers in farmer's organisation, and from farmer's organisation that participating with the supermarket and international market chains.

In-Depth Interview and Focus Group Discussion

In-depth interviews were specifically designed and undertaken with the government officers, the representative of major buyers, and rural farmers. They were encouraged to discuss the semi-structured questions set, which covered their business characteristics, food transactions (the processes for managing products such as cultivating, harvesting, processing, and transporting), market channels (the different market channels the rural farmers are involved in), transportation and procurement activities (involving the negotiation, contract setting, grading, and payment), and development of agriculture particularly the supply chain for mangoes, as shown in Appendix C.

The focus group discussions with rural farmers were undertaken in the survey step 5. The rural farmers who participated were encouraged to discuss freely, covering their production, selling channels, and transportation activities, with minimum interruption from the interviewer. The rural farmers were invited by the co-operative and social enterprise manager and the focus group discussions and in-depth interviews were undertaken mainly at the social enterprise's office after their monthly meeting. In addition, face-to-face in-depth interviews with 20 individual famers out of the 49 farmers from Hin Lad social enterprise, were undertaken at the individual farms to gain more specific information on their operations and understand how the products were produced and transported from the plantations to the consolidation point. The rural farmers received an incentive of 150 THB (£4) for participating in the focus group discussions and in-depth interviews. The semi-structured questions were used to keep the discussion section on the track. In addition, handwritten notes and audio recordings were taken for analysis and review.

The collected data were used to understand the agribusiness characteristics and create a dataset which was subsequently used to simulate alternative first-mile collaborative transportation options. The nature of each key stakeholder's role in the food supply chain, co-operative, broker, modern trade retail, and group of farmers is outlined in Table 3.

Table 3 Data sources and key informants

No.	Organisations		Position
1	Jom Thong Co-operative	Agricultural Co-operative	Manager
2	Farmer member	20 Individual Farmers	Farmer
3	San Pa Thong Co-operative	Agricultural Co-operative	Manager
4	Farmer member	12 Individual Farmers	Farmer
5	Hin-Lad Social Enterprise	Agricultural Co-operative	Manager
6	Farmer member	49 Individual Farmers	Farmer
7	Rising (Thailand) Ltd.	Broker (exporter)	Sourcing and buying representative
8	Central Food Retail (TOP supermarket)	Modern trade retail	Vice President Buying Produce
9	Gourmet Fresh Market (The Mall Group)	Modern trade retail	General Manager Senior Department Manager Senior Merchandising Manager
10	Co-operative Promotion Department	Government Institution	Chief Executive Officers of CPD

This references the key stakeholders in the food industry, producer (rural farmer), co-operative/social enterprise, modern trade market (supermarket), exporter (buyer/trader), and government institution. Their many years of experience provided them with a thorough understanding of the industry, making them a rich source of relevant information.

3.3 Data Analysis

There are two main phases of data analysis. The fieldwork data were used to understand the business-as-usual characteristics, problems faced by rural farmers, and create a dataset for developing an alternative first-mile collaborative transportation system that would benefits rural farmers and reduce product waste.

3.3.1 Analysis of Historic Production Data

The collected data were transcribed, and all the transcripts and field notes reviewed, to get the general understanding of the data before analysis. This information helped mapping the agri-food supply chain system, business-as-usual characteristics, the current state of food logistics and supply chain management, as well as identifying the key problems and challenges faced by the rural farmers particularly those who are working together with a farmers' organisation.

The first phase, to explore the major challenges that affect the participant farmers, began with the identification of the logistics activities, particularly transportation – how the products are moved from the farms to the consolidation point and distributed to the markets, that indicated the business-as-usual operations (to answer the first research objective). Reviewing all interview transcripts, the broad categories of logistics activities, particularly transportation, were identified.

The interview transcripts were reviewed to understand how the mango supply chain operates, particularly through the farmers' organisation chain, the key challenges currently faced by rural farmers, and the characteristics of farmers currently working within farmers' organisation. The quantitative data in this stage was also used to simulate alternative first-mile collaborative transportation options. The current transportation costs, distances travelled, time taken, empty box space, along with fuel use and CO_2 emissions, were all quantified, based on the farmers' current vehicles.

3.3.2 Alternative Collaborative Logistics Scenarios

Scenario 1: Sharing Vehicles Through a Farmer Co-operative Scenario

The business-as-usual investigation showed that rural farmers used their own vehicles to move their products from their plantations to the consolidation point on different routes. This first-mile transport ranged between 1-20 km making up between 1-3% of the total supply chain distance but could comprise 5-15% of the total transportation costs. The first scenario looked at the merits of implementing a vehicle sharing system via a farmer's co-operative, where rural farmers work together in sub-groups to improve transportation efficiency by maximising vehicle utilisation. This could be beneficial from both operational aspects (reduction in the number of vehicles needed and vehicle visit farm, and total transportation cost) and environmental aspects (reduction in total CO_2 emission, and total travelled distance). In this specific scenario, the light pick-up vehicles with a loaded capacity of 60 boxes used by the rural farmers were shared to quantify the improvement derived from such a collaboration.

Scenario 2: Using Third-Party Vehicles to Make Milk-round Collections Direct from Farmers

In this scenario, a vehicle operated by a Third-party logistics provider would make scheduled collections from individual farmers as part of a structured round, dropping consolidated loads at a drop-off point for onward collection for the final markets. The Third-party logistics provider would be employed by the farmers collective on behalf of the rural farmers who would all contribute to the cost and would provide the transportation service on behalf on the farmers to the consolidation point. Three specific cases with the two different types of vehicles was undertaken i) light refrigerated vehicles with a loaded capacity of 100 boxes, and ii) 200 boxes for 20ft refrigerated, and iii) both mixed vehicles were explored, where in the first case, only light refrigerated vehicles were assigned, and in the second case, where only 20ft refrigerated vehicles were used. Finally, a mixed refrigerated vehicle fleet was assigned for collecting the products. For the details of the vehicles used in each scenario will be presented in Table 6.

Worst-case scenario

In addition, two situations were covered assuming in the ‘best-case’, all the farmers were willing to co-operate in the proposed transportation schemes, whilst in the ‘worst-case’, the large-scale farmers who produce over 120 boxes (45% of the total sample) would not be willing to share their vehicle and would go it alone, sticking to their current delivery strategy. The large-scale farmers opted out of the collaboration scheme in this case. Therefore, the sensitivity analysis is used to measure how the benefits of collaborative transport change if the number of large-scale farmers joining the scheme are not willing to co-operate and stick with their own transportation strategy.

To illustrate sensitivity analysis, the results in Table 4 show that at the peak-period of the harvesting season between 12-15 March 2018, there were 27 farmers (55%) who produced less than 60 boxes a day and using only one vehicle for moving their products, 13 farmers (27%) produced average at 61-120 boxes, 5 farmers (10%) at 121-180 boxes, one farmer (2%) at 181-240 boxes, 2 farmers (4%) at 241-300 boxes, and one farmer (2%) at over 360 boxes a day and making 7 round trips for delivering their products.

Table 4 The characteristics of each farmer based on the production capacity and number of vehicle visits farm.

Loads (boxes)	Number of farmers	No. of vehicles visit farm (round trip)	Farmer	%
1-60	27	1	1, 2, 3, 19, 25, 26, 30, 36, 37, 40, 42, 43, 47, 48, 50, 52, 54, 57, 58, 65, 66, 67, 69, 71, 72, 73, 74	55%
61-120	13	2	4, 11, 21, 23, 33, 34, 39, 45, 51, 56, 60, 68, 78	27%
121-180	5	3	6, 9, 15, 62, 59	10%
181-240	1	4	17	2%
241-300	2	5	14, 53	4%
301-360	0	6	-	0
361-420	1	7	16	2%
Total	**49**			**100%**

The expected value

$$\text{Expected value } E(X) = \sum_{i=1}^{n} X_i P(X_i)$$

where;

$E(X)$ – expected value

X_i – possible value

$P(X_i)$ – probability of each of variable's possible value

Then;

$$E(X) = (1)(0.55) + (2)(0.27) + (3)(0.10) + (4)(0.02) + (5)(0.04) + (6)(0) + (7)(0.02)$$

$$E(X) = 1.81$$

The expected value (central tendency) of 1.81 is the mean number of vehicle visits to farms in the BAU operation. The results in Table 5 show the sensitivity analysis results from different cases, with the second column showing the benefit or cost saving based on the best-case, where all the farmers are joined in the collaborative scheme. And the remaining columns provide the benefits as the number of farmers joining in the collaboration scheme changes. When all the farmers (n=49) joined in the proposed transportation scheme "sharing vehicle", the best-case generated cost savings at 11,241 THB (36%) when compared to the BAU operations. In case where one large-scale farmer who produced higher than 360 boxes a day was assumed to opt out, the cost savings was found to be 11,203 THB (36%), the result is similar to the case of 3 farmers (who produced higher than 240 boxes) and 4 farmers (who produced higher than 180 boxes) where the cost savings were 11,049 THB (36%), 2% different from the best-case. In the case where 9 out of 49 farmers opted out, the cost saving was found to be 10,747 THB (35%), and the benefit decreased by 5.9% from the best-case. The cost saving is highly sensitive to changes in the number of farmers who are assumed to opt out. Where this increased to 22 farmers, the cost saving was found to be 6,019 THB (19%), and the benefit decreased by 46% from best-case.

Table 5 Impact of a change in the number of farmers in collaboration scheme.

	All joined	**1 opted out (>360 boxes)**	**3 opted out (>240 boxes)**	**4 opted out (>180 boxes)**	**9 opted out (>120 boxes)**	**22 opted out (>60 boxes)**
No. of farmer remaining	49	48	46	45	40	27
BAU cost (THB)	30,922	30,922	30,922	30,922	30,922	30,922
Sharing vehicle scenario (THB)	19,681	19,719	19,873	19,899	20,175	24,903
Cost savings (%)	11,241 36%	11,203 (36%)	11,049 (36%)	11,023 (36%)	10,747 (35%)	6,019 (19%)
% Change from best-case	-	0.3%	2%	2%	4.0%	46%

Table 6 shows the different vehicles used in the alternative transportation scenarios. The cost of using a light pick-up vehicle with a fully-loaded capacity at 60 boxes (1,500 kg) was found to be 136

THB (£3.48) for standing costs and 4.82 THB (£0.12) per km for running costs (DLT, 2019). The two refrigerated vehicles operated by a Third-party logistics provider, were the light and 20ft refrigerated vehicles. These were designed to transport perishable foods with a fully loaded capacity at 100 boxes (2,500 kg), and 200 boxes (5,000 kg) respectively. The operating cost for the light refrigerated diesel vehicle was 277 THB (£7.09) per day (standing cost), while the running cost was 7.72 THB (£0.20) per km (DLT, 2019). The standing cost for 20ft refrigerated vehicle was 380 THB (£9.71) per day, and 9.01 THB (£0.23) per km for the running cost.

Table 6 The different vehicles used in the BAU and alternative transportation scenarios

	Light pick-up vehicle (1500 kg)	**Light Refrigerated vehicle (2,500 kg)**	**20ft Refrigerated vehicle (5,000 kg)**
General information			
Container size (cm)	150 x 210 x 170	169 x 288 x 176	200 x 500 x 210
Loading capacity (boxes)	60	100	200
Fuel	Diesel	Diesel	Diesel
CO_2 emission at Fully loaded ($kgCO_2$/tonne-km)	0.21	0.18	0.14
Annual kilometre (km)	30,000	100,000	100,000
Asset cost (THB)	533,000 (£13,625)	897,000 (£22,929)	1,500,000 (£38,344)
Replacement cost[10] (THB)	106,600 (£2,725)	169,000 (£4,320)	500,000 (£12,781)
Life (Years)	10	8	8
Depreciation cost [11] (THB/year)	42,640 (£1,090)	91,000 (£2,326)	125,000 (£3,195)
Driver[12] (THB/day)	315 (£8)	315 (£8)	315 (£8)
Fuel price (THB/litre)	30.15 (£0.8)	30.15 (£0.8)	30.15 (£0.8)
Fuel consumption (litre/km)	0.10	0.18	0.22
Maintenance[13] (THB/year)	10,660 (£272)	22,750 (£582)	31,250 (£799)
Tyre life (km)	120,000	70,000	70,000
Tyre price (THB/wheel)	4,500 (115)	8,000 (£204)	8,000 (£204)
Vehicle Tax[14] (THB/year)	1,050 (£26)	2,250 (£57)	3,450 (£88)
Insurance (THB/year)	5,950 (£152)	7,960 (£203)	10,260 (£262)
Standing costs			
Depreciation (THB/day)	116.82 (£3)	249.32 (£6)	342.47 (£9)
Vehicle Tax (THB/day)	2.88 (0.07)	6.16 (£0.16)	9.45 (£0.24)
Insurance (THB/day)	16.30 (£0.42)	21.81 (£0.56)	28.11 (£0.72)
Running costs			
Fuel (THB/km)	3.02 (£0.08)	5.43 (£0.14)	6.63 (£0.17)
Driver (THB/km)	1.15 (£0.03)	1.15 (£0.03)	1.15 (£0.03)
Maintenance and Tyre (THB/km)	0.66 (£0.02)	1.14 (£0.03)	1.23 (£0.03)

Source: Department of Land Transport (2019)

[10] The replacement cost is based on average cost for a second-hand vehicle
[11] The depreciation and maintenance costs are based on farm and non-farm activities
[12] The driver cost is based on the National Wage Rate (No.10), January 1, 2020 (Phitsanulok province)
[13] The average maintenance cost of the truck being operated is 25% of the depreciation cost (DLT, 2019)
[14] Vehicle tax is based on the Vehicle Act, Thailand, B.E. 1979

Effect of a Change in the Percentage of Product Wastage

Sensitivity analysis shows how the benefits of each potential operating scenario will change with changes in the levels of product wastage. Table 7 demonstrated that an increase of 1% of product wastage could result in a net reduction for the overall cost when the cost of product wastage was included. The BAU operation showed that the cost of product wastage accounted at 78% of the total cost when the product was damaged at 1% and increased to 97% when the product was damaged at 10% of the total shipment (the total cost was 1,126,742 THB with 1,095,820 THB coming from the cost of product wastage, while 3% from the transportation cost). Based on the fieldwork survey, the average losses during the transportation between farms and local consolidation point were found to be 2-5% and increased to 5-10% when travelling between the consolidation point and distribution centre or final market.

As mentioned, the first scenario looked at the merits of implementing a vehicle sharing concept via a farmer's co-operative. Therefore, the key results in Table 7 suggested that the total cost was reduced by 36% (from 30,922 THB to 19,681 THB) at the 0% of product waste, while the reduction on the total cost was reduced by 8% (from 140,504 THB to 129,263 THB) when changing the levels of product wastage rate to 1%. When the product wastage rate changing to 5%, the total cost was reduced by 2%, and the total cost was reduced only 1% when the product wastage rate increased up to 10%. Based on the BAU operations, the product wastage rates were found to be at 2-5% between farms and the consolidation point.

However, using the existing vehicle does not address the problem of product wastage. A vehicle operated by a Third-party logistics provider was introduced for solving the problem of product wastage by moving the products in a temperature-controlled environment. The results in Table 7 suggested that the total cost increased by 206% over the BAU operations when a Third-Party light refrigerated vehicle was assigned if a product wastage rate of 0% in BAU operations. However, the total cost will be reduced by 33% when the product wastage in BAU operation increased to 1%, and the benefit of assigning Third-Party light refrigerated vehicle increased to 84% reduction when the product wastage was increased to 5%. Assigning a suitable refrigerated vehicle could save 92% when the product wastage rate was at 10%. The results also similar with the case of assigning mixed Third-Party refrigerated vehicles. However, in the case of assigning 20ft refrigerated vehicle, the total cost was increased by 164% if the product was not damaged (0% of product wastage), while the total was reduced by 42% when the product wastage rate was at 1%. The benefit increased up to 86% when the product wastage increased to 5%, and the total cost was reduced by 93% when the product wastage was increased up to 10%.

Table 7 Effect of a change in percentage of product wastage on transportation cost.

% of product wastage	**0%**	**1%**	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
W_{avew} (kg)	0	5479	10,958	16,437	21,916	27,395	32,874	38,353	43,832	49,311	54,791
C_{wst} (THB)	0	109,582	219,164	328,746	438,328	547,910	657,492	767,074	876,656	986,238	1,095,820
TC_{own} - BAU	30,922	30,922	30,922	30,922	30,922	30,922	30,922	30,922	30,922	30,922	30,922
TC_{total} - BAU (C_{wst}+TC_{own})	30,922	140,504	250,086	359,668	469,250	578,832	688,414	797,996	907,578	1,017,160	1,126,742
C_{wst} (%)	0%	78%	88%	91%	93%	95%	96%	96%	97%	97%	97%
$TC_{Sharing\ vehicle}$	19,681	19,681	19,681	19,681	19,681	19,681	19,681	19,681	19,681	19,681	19,681
TC_{total} - Sharing vehicle	19,681	129,263	238,845	348,427	458,009	567,591	677,173	786,755	896,337	1,005,919	1,115,501
Net reduction (compared to BAU)	**11,241** (36%)	**11,241** (8%)	**11,241** (4%)	**11,241** (3%)	**11,241** (2%)	**11,241** (2%)	**11,241** (2%)	**11,241** (1%)	**11,241** (1%)	**11,241** (1%)	**11,241** (1%)
TC_{total} – 3PL light refrigerated	94,768	94,768	94,768	94,768	94,768	94,768	94,768	94,768	94,768	94,768	94,768
Net reduction (compared to BAU)	**-63,846** (-206%)	**45,736** (33%)	**155,318** (62%)	**264,900** (74%)	**374,482** (80%)	**484,064** (84%)	**593,646** (86%)	**703,228** (88%)	**812,810** (90%)	**922,392** (91%)	**1,031,974** (92%)
TC_{total} – 3PL 20ft refrigerated	81,630	81,630	81,630	81,630	81,630	81,630	81,630	81,630	81,630	81,630	81,630
Net reduction (compared to BAU)	**-50,708** (-164%)	**58,874** (42%)	**168,456** (67%)	**278,038** (77%)	**387,620** (83%)	**497,202** (86%)	**606,784** (88%)	**716,366** (90%)	**825,948** (91%)	**935,530** (92%)	**1,045,112** (93%)
TC_{total} – 3PL mixed refrigerated	89,526	89,526	89,526	89,526	89,526	89,526	89,526	89,526	89,526	89,526	89,526
Net reduction (compared to BAU)	**-58,604** (-190%)	**50,978** (36%)	**160,560** (64%)	**270,142** (75%)	**379,724** (81%)	**489,306** (85%)	**598,888** (87%)	**708,470** (89%)	**818,052** (90%)	**927,634** (91%)	**1,037,216** 92%)

3.3.3 Calculating Costs, Routing and Environmental Impacts

The objective in the second phase was to develop a more inclusive, alternative first-mile collaborative transportation system that benefits the rural farmers and reduces product waste. The data from the government and from in-depth interviews were used to create a production and logistics database. The government data provided an overview of production across the region and related production costs. In addition, the data from the interviews provided specific details of the rural farmers in the focus area. This information was used to provide the base calculation, the transportation cost structure, distance travelled, time taken, utilised and spare vehicle capacity, and CO_2 emissions.

Sternad (2019) stated that the costs calculations in road freight transport are divided into direct costs, related to the provision of transport services, and indirect costs. Therefore, the government's data was used for estimating the operating cost when assigning vehicles, as demonstrated in

Table 6. Total vehicle costs are calculated using Equation 3.1.

$$\text{Transportation Cost } (TC) = \mathrm{C}_{dep} + \mathrm{C}_{fuel} + \mathrm{C}_{main} + \mathrm{C}_{ins} + \mathrm{C}_{reg} + \mathrm{C}_{dri} + \mathrm{C}_{ind} \quad (3.1)$$

where

C_{dep} – depreciation costs

C_{fuel} – fuel costs

C_{main} – maintenance costs

C_{ins} – insurance costs

C_{reg} – registration cost

C_{dri} – driver's labour costs

C_{ind} – indirect costs

In the calculation of transportation cost, a depreciation cost (C_{dep}) represents the replacement value of the underlying asset, the vehicle. When calculating the depreciation basis, the vehicle has a value 10% of the asset value after the expiry of the amortisation period (based on a cost for second-hand vehicle). The depreciation cost is calculated using Equation 3.2.

$$\text{Depreciation Cost } (C_{dep}) = \frac{(PV_{ve} - RV_{ve})}{RV_{ve}\ (years)} \quad (3.2)$$

where

PV_{ve} – vehicle purchase value (THB)

RV_{ve} – vehicle rest value (replacement cost) (THB)

RV_{ve} – vehicle depreciation period (useful life) (year)

Fuel cost (C_{fuel}) is the fuel consumption per kilometre and the price of fuel. The data shows that the average fuel consumption for the light pick-up vehicle is 0.1 litter per km, 0.18 for light refrigerated vehicle, and 0.22 litter per km for 20ft refrigerated vehicle (DLT, 2019). The average fuel price for Diesel B7 is 30.15 THB (£0.77).

$$\text{Fuel Cost } (C_{fuel}) = FP_{THB/l} \text{ x } FC_{l/km} \tag{3.3}$$

where

$\text{FP}_{THB/l}$ – fuel price (THB per litter)

$\text{FC}_{l/km}$ – fuel consumption (litter per kilometre)

Maintenance costs (C_{main}) include the cost of routine maintenance, repairs, and other costs associated with maintaining the vehicle such as tyres, oil, and other routine costs (Sternad, 2019). The cost of maintenance increase with distance travelled. In this study, the average maintenance cost of the truck that being operate is around 15-25% of the depreciation cost provided by the department of Land Transport (DLT, 2019). The maintenance cost is calculated using Equation 3.4.

$$\text{Maintenance Cost } (C_{main}) = \frac{C_{dep}\ x\ 25\%}{K_{annual}} + C_{tyres} \tag{3.4}$$

where

C_{dep} – depreciation costs (THB per year)

K_{annual} – annual kilometre travelled (km)

C_{tyres} – tyres costs (THB per km)

$$\text{Tyres Cost } \left(C_{tyres}\right) = \frac{TY_{wheel} \text{ x } TY_{price}}{TY_{life}} \tag{3.5}$$

where

TY_{wheel} – tyres (wheels)

TY_{price} – tyres price (THB)

TY_{life} – tyres life (km)

The cost of insurance (C_{ins}) includes the cost of basic insurance, carrier liability insurance, and other costs associated with insurance of vehicle operations (Sternad, 2019). Here, the average value of the insurance followed the figures provided by the Department of Land Transport (DLT, 2019).

The registration fee or vehicle tax (C_{reg}) for a vehicle includes the cost of the technical inspection, the annual levy, the renewal of registration, and other related things with the registering the vehicle (Sternad, 2019). The Department of Land Transport (DLT, 2019), set the registration fee for light pick-up vehicle at 1,050 THB (£26) per year, 2,250 THB (£57) for the light refrigerated vehicle, and 3,450 THB (£88) for the 20ft refrigerated vehicle, as in Table 6.

Driver's labour cost (C_{dri}) includes the driver's gross salary, daily allowance, recourse, travel expenses, and other costs (license, education, medical examinations) (Sternad, 2019). In this study, the driver's labour cost was found to be 315 THB (£8.05) per day, based on the National Wage Rate (No.10), January 1, 2020 (Phitsanulok province), the area of the study (Ministry of Labour, 2020).

Indirect costs (C_{ind}) are costs that are not directly related to a specific cost. The costs incurred at the level of the whole enterprise involved running the company such as office supplies, administration, facilities, and marketing (Sternad, 2019).

The transportation costs were separated into standing (fixed) cost and running (variable) cost. The relevant studies (Bokor and Markovits-Somogyi, 2015; Sternad, 2019) classified the depreciation, insurance, registration among standing costs, whilst the costs of fuel, driver's labour, and maintenance were classified into running costs. Similarly, Litman and Doherty (2015) costed vehicle use into standing costs (insurance, registration, depreciation), which are unaffected by mileage, and running costs (maintenance, fuel, packing and tolls), which increase with mileage.

The standing costs related to the vehicle operations range from the cost of depreciation, insurance, registration fee, and indirect costs (Sternad, 2019). The standing cost can be calculated from Equation 3.6.

$$\text{Standing Cost } (SC) = C_{dep} + C_{reg} + C_{ins} + C_{ind} \tag{3.6}$$

where

C_{dep} – depreciation costs (THB per day)

C_{ins} – insurance costs (THB per day)

C_{reg} – registration (vehicle tax) costs (THB per day)

C_{ind} – indirect costs

The major components of running costs include costs of fuel, maintenance, and driver's labour costs (Litman and Doherty, 2015; Sternad, 2019). The running cost can be calculated from Equation 3.7.

$$\text{Running Cost } (RC) = C_{fuel} + C_{main} + C_{dri} \tag{3.7}$$

where

C_{fuel} – fuel costs (THB per litter)

C_{main} – maintenance costs (THB per km)

C_{dri} – driver's labour costs (THB per km)

Cost Calculation in the case of "Farmer own Vehicle"

It is very likely that when farmers make decisions, they will only consider the running costs, when they are doing the work themselves and using their own vehicle. It is unlikely that they will include the standing costs associated with their current operations. Therefore, the cost of transport in case of a farmer owned vehicle (TC_{own}) can be calculated according to Equation 3.8.

$$\text{Transportation Cost } (TC_{own}) = (RC \text{ x } D_{tv}) + C_{wst} \quad (3.8)$$

where

RC – running costs

D_{tv} – distance travelled (kilometre)

C_{wst} – product wastage during transit (THB)

As mentioned in section 1.2, the average losses during the primary distribution phase from farms to the local consolidation point were found to be 2-5% and increased to between 5-10% when travelling between consolidation point and the distribution centre or final market. Therefore, the cost of product wastage during transit was taken into account. The product wastage cost (C_{wst}) can be calculated according to Equation 3.9.

$$\text{Product Wastage Cost } (C_{wst}) = Q_{kg} \text{ x } W_{avrw} \text{ x } SP_{sell} \quad (3.9)$$

where

C_{wst} – product wastage during transit cost (THB)

Q_{kg} – total loaded (kg)

W_{avrw} – average lost (%)

SP_{sell} – selling price (THB per kg)

Cost Calculation in case of "Using a Third-party Vehicle"

The cost of transport when using a Third-party vehicle, both light refrigerated and 20ft refrigerated, will be charged for both standing and running costs. The transportation cost is then calculated as a sum of the standing and running costs. Based on the distance travelled for the route under consideration, the total transportation cost (TC_{3rd}) when assigning a Third-party vehicle can be estimated from Equation 3.10.

$$\text{Transportation Cost } (TC_{3rd}) = SC + (RC \text{ x } D_{tv}) + C_{wst} \quad (3.10)$$

where

SC – standing costs

RC – running costs

D_{tv} – distance travelled (kilometre)

Furthermore, obtaining accurate routing information is vital for realistic simulation and scenario development. This is made all the more important where the geographical terrain is challenging, and secondary (rural) road systems are predominant. The data gathered from the interviews with rural farmers (shown in Appendix C.6) were used for mapping the farm locations and assigning the routing between farms and consolidation point. However, to accurately represent the rural road structure linking farms to the consolidation point, “Google Earth 3D”, GIS application software was used to identify the farm, associated plantations and routes, allowing the travel distance and driving times between farms and the consolidation point to be quantified. The Universal Transverse Mercator (UTM) coordinates of the 78 mango plantations were identified as show in Figure 17.

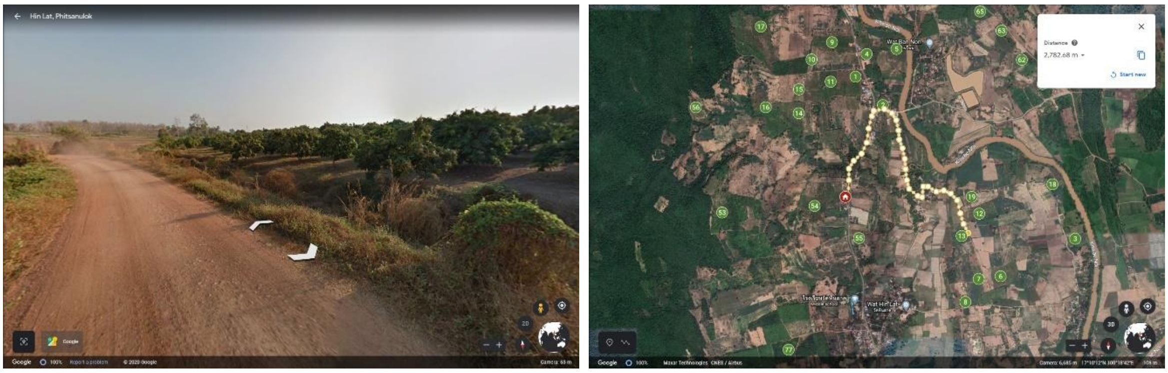


Figure 17 The rural road condition and mango plantation locations

Source: Google Earth 7.6 (2020)

The data obtained from the fieldwork showed that the rural road network connecting the plantations to the main arterials consisted predominantly of gravel and earth tracks (Figure 17) with a single lane width varying from 2 to 2.5 metres allowing. Only small vehicles not exceeding 5 metres in overall length ere used to access the plantations. The data collected also showed that the mean driving speeds were at 30.5 km per hour on the main roads, decreasing to 10-20 kph when driving on these rural connectors. The total time spent on driving (T_{dri}) can be calculated from Equation 3.11.

$$\text{Driving Time } (T_{dri}) = \frac{D_{tv}}{S_{avrs}} \qquad (3.11)$$

where

T_{dri} – driving time (hour)

S_{avrs} – average speed (km/hour)

D_{tv} – distance travelled (km)

In addition, the fieldwork showed that the mean loading times for a full truck load of 60 boxes were observed to be 30 minutes at the originating farm, whilst unloading a full vehicle at the consolidation point took 15 minutes on average. Therefore, the required time for loading and unloading one unit was 0.5 minute at farm area and 0.25 minute at consolidation point. The loading time (T_{load}) can be calculated according to the Equation 3.12.

$$\text{Loading Time } (T_{load}) = Q_{box} \ x \ UD_{avrs} \tag{3.12}$$

where

T_{load} – loading time (minute)

Q_{box} – loading unit (container box)

UD_{avrs} – the require time to load and unload one unit (minute/unit)

For the environmental aspect, data from the Thailand Greenhouse Gas Management Department were used to determine the CO_2 emissions for the vehicles used. The total CO_2 emissions was based on three parameters: distance travelled, loads, and specific CO_2 emissions factor. The CO_2 emissions factor suggested by the Thailand Greenhouse Gas Management Organisation (2019) for a light pick-up vehicle was 0.21 kgCO_2/tonne-km when fully loaded, and 0.30 kgCO_2/tonne-km when empty running. In case of light refrigerated vehicle, the CO_2 emissions factor was 0.18 kgCO_2/tonne-km at fully loaded, and 0.33 kgCO_2/tonne-km when empty running, while the 20ft refrigerated vehicle was 0.14 kgCO_2/tonne-km when fully loaded, and 0.31 kgCO_2/tonne-km when empty running, as shown in

Table 6. The assumption of CO_2 emissions (EM_{CO2}) can be calculated according to Equation 3.13.

$$\text{Total CO}_2 \text{ emission } (EM_{CO2}) = D_{tv} \text{ x } CL_{load} \text{ x } CF_{fac} \tag{3.13}$$

where

EM_{CO2} – the total CO_2 emissions

D_{tv} – distance travelled (kilometre)

CL_{load} – total loaded (tons)

CF_{fac} – CO_2 emission factor (kgCO_2/tonne-km)

3.4 Allocating Cost to Farmers Participating in a Transport Collaboration

In order to minimise the total cost, and ensure the quality of logistics, collaboration in transportation between two or more organisations is becoming an important approach to find efficient solutions (Esper and Williams, 2003; Guajardo and Rönnqvist, 2016). A significant aspect of the collaboration is deciding how to share the benefits, and how the combined transportation costs on the same route should be distributed fairly among the members. Two models have been applied in this study to quantify how the cost of collaborative transport is fairly split among rural farmers, the proportional method, based on volume and stand-alone cost allocation, and the Shapley value.

3.4.1 Proportional Method

The proportional method is the most frequently and widely used method for allocating cost, since it is easy to understand and easy to compute. The method uses information pertaining to each participant of a cost object as a separate entity to determine the cost allocation weight, which assigns cost shares to all participants based on volumes or demand quantities (Frisk *et al.*, 2010; Nguyen, Dessouky and Toriello, 2014; Liu and Cheng, 2019). An alternative is based on stand-alone cost (Sun *et al.*, 2015; Guajardo and Rönnqvist, 2016; Liu and Cheng, 2019).

The cost allocated can be obtained from the formula $y_i = w_i c(N)$, where w_i is equal to participant i's share of the total transported volume or stand-alone cost. The method requires a first calculation of the proportionate share of transportation cost for each farmer on a stand-alone basis, and then applying each farmer's proportion toward the costs farmers are seeking to allocate. The proportion can be obtained following Equation 3.14.

$$w_i = c(\{i\})/c(N) \tag{3.14}$$

where
w_i – participant i's shared proportion
$c(\{i\})$ – actual volume or cost of participant i
$c(N)$ – total volume or cost of the coalition

and the cost allocated can be obtained from Equation 3.15.

$$y_i = w_i c(N) \tag{3.15}$$

where
y_i – cost allocated to the participant farmer i
w_i – participant i's shared proportion
$c(N)$ – total volume or cost of the coalition

The cost allocated to the participant farmers can be obtained based on the proportion of the transportation loads or the stand-alone operating cost. This is the key to obtaining the cost allocation to the rural farmers. However, it may provide allocations that are not seen as fair since some farmers' plantations are located far away from the consolidation point when compared to other farmers, but their loads are totally the same, making their costs similar.

3.4.2 The Shapley Value

The proposed transportation scheme of the coalition has been obtained based on the CW saving algorithm. The transportation cost arising from collaboration can then be calculated by comparing collaborative and non-collaborative cases. When the coalition with minimum cost is obtained in the stage of proposed transportation scheme, the benefit in the collaboration will be quantified and allocated to each participant farmer. Let $C(\{i\})$ be the cost of farmer i in non-collaborative scenario, and $\sum_{i\in S} C(\{i\})$ be the total cost of farmers in coalition S. The transportation cost of coalition is denoted as $C(S)$. Assume the benefit generated in the coalition is $v(S)$, then it is equal to $\sum_{i\in S} C(\{i\}) - C(S)$. The benefits of participant farmers are equal to 0 in the non-collaborative scenario. The objective of benefit sharing is to allocate the benefit fairly to all participant farmers F_s, as shows in equation 3.16 where φ_i is the benefit allocated to farmer i.

Objective:

$$\varphi_i = F_s\big(v(S)\big)\forall i \in S \tag{3.16}$$

Subject to:

$$\sum_{i\in S} \varphi_i = v(S) \tag{3.17}$$

$$\sum_{i\in S} \varphi_i \geq v(S)\ \forall S \in S \tag{3.18}$$

Constraint (3.17) represents that the benefit is fully allocated to participant farmers. Constraint (3.18) verifies the stability of the allocation of the Shapley value in the sense that there is no sub coalition such farmers would get better benefits deviating from the grand coalition S.

The next step is to allocate the transportation cost to individual farmer. The Shapley value method was applied as a means to allocate the transportation cost in the collaborative transportation scheme (Kolker, 2018). The method assigns a unique distribution (among the participant farmers), which is the average of the marginal contribution of one player after all possible combinations have been considered. The proposed Shapley value method for cost allocation consists of following steps:

Let $\mathrm{N} = (1, \ldots, \mathrm{n})$ be the set of all participant farmers in a coalition. Define $v\{S\} = \sum_{i\in S} C\,(\{i\}) - C(S)\forall S \in N$ as the saving cost of coalition S, and $C(S)$ as the transportation cost of the coalition S, and $\sum_{i \in S} C(\{i\})$ be the total cost of farmers of coalition N. Thus, the characteristics function values are from Equation 3.16.

$$v(S) = \sum_{i \in S} C(\{i\}) - C(S)\ \forall S\ \in N \tag{3.19}$$

where

$v(S)$ – the saving cost coalition S

$\sum_{i \in S} C(\{i\})$ – the total cost of farmers in coalition N

$C(S)$ – transportation cost of the coalition S

Equation 3.20 denotes the savings obtained from coalition S. Define $\varphi_i(s)$ as the marginal contribution of farmer i when joining into a coalition S, where $v(S)$ be the marginal contribution with i, and $v(S \backslash \{i\})$ is the marginal contribution without i.

$$\varphi_i(s) = v(S) - v(S \backslash \{i\}) \tag{3.20}$$

where

$\varphi_i(s)$ – marginal contribution of participant farmer i

$v(S)$ – the marginal contribution with farmer i

$v(S \backslash \{i\})$ – the marginal contribution without farmer i

Calculate the savings assigned to each farmer by summing all their marginal contributions in any possible coalition S, where δ_i is the saving cost allocated to farmer i, and $(n - |s|)!\,(|s| - 1)!$ is the possible sequence when farmer i joins coalition S, and n is the total number of participant farmers in coalition S. This is described by Equation 3.21.

$$\delta_i = \sum_{s \in S \backslash i} \frac{(n - |s|)!\,(|s| - 1)!}{n!}\ \varphi_i(s) \forall i\ \epsilon N \tag{3.21}$$

where

δ_i – saving cost allocated to farmer i

$(n - |s|)!\,(|s| - 1)!$ – the possible sequence when farmer i joint the coalition

n – total number of participants in coalition s

$|s|$ denotes the number of farmers in the coalition when farmer i join S. Note that s also denotes the sequence when farmer i joins coalition S. A practical example is provided in Section 6.1.2 to gain a better understanding of the proposed Shapley value method. The Shapley value method is unique due to the determinate imputation.

In addition, the allocation in the core indicates the stability, in the sense that there is no subset S such that its participant farmers would get better benefit by deviating from the grand coalition. Therefore, the benefit of subset S should be less than the benefit allocated to farmer i, when its participant in the grand coalition. Shi, Y., et al., 2020, highlighted that it is important to verifying the stability of the method for benefit sharing, which is the common way to verify its effectiveness. Therefore, the non-emptiness of the Shapley value method will be checked (described in section 6.1.2).

The Shapley value is based on four axioms formulated by Shapley (1953). These axioms express the cost allocation computed according to this solution concept satisfy the properties of "efficiency, symmetry, dummy property and additivity" (Frisk *et al.*, 2010). Symmetry means that if two arbitrary participants i and j, have the same marginal cost (MC) with respect to all coalitions not containing i and j, the cost allocated to these two participants must be equal. The dummy property states that if participant is a dummy in the sense that they neither help nor harms any coalition they may join, then their allocated cost should be zero. Finally, additivity says that, given three different characteristics cost function c_1, c_2 and $c_1 + c_2$, for each participant the allocated cost based on $c_1 + c_2$ must be equal to the sum of the allocated costs based on c_1 and c_2, respectively. The Shapley value provides a cost allocation that is unique, however, there is no guarantee that it is stable, e.g. it does not necessarily satisfy individual rationality. It can be proven the Shapley value is the only value that fulfils the above four axioms.

3.5 Models for Simulating Collaborative Transportation

A key element investigated in this research is optimising the route plan, in which the goal is to find efficient paths for transporting agricultural products from farms to the consolidation point. The Vehicle Routing Problem (VRP) was first introduced in 1959 by Dantzing and Ramser and plays a central role in the field on physical distribution and logistics, involving the design of minimum cost delivery routes. The goal of the VRP is to generate a minimum set of routes that satisfy all customers' demand. The Clarke and Wright (CW) saving algorithm is the most widely known heuristic for the VRP (Pichpibul and Kawtummachai, 2012). The simplicity of the algorithm, and the quality of the solution it produces, contributes to the algorithm's widespread acceptance.

3.5.1 The Clarke and Wright Saving Algorithm

The CW saving algorithm was introduced in 1964 by Clarke and Wright. It produces feasible routing solutions to minimise the transportation problem, when two routes ($0, i_1, \ldots, i_n, 0$) and ($0, j_1, \ldots, j_m, 0$) can feasibly be merged into a single route ($0, i_1, \ldots, i_n, j_1, \ldots, j_m, 0$). Let $r_1 =$

$\{0, i_1, \dots, i_n, 0\}$ be a route visiting n farmers, where node *0* represents the consolidation point and $r_2 = \{0, j_1, \dots, j_m, 0\}$ is a second route visiting m farmers. When these two routes are merged into a single route, the following two options are explored.

$$r_{12} = \{0, i_1, \dots, i_n, j_1, \dots, j_m, 0\}$$
$$r_{21} = \{0, j_1, \dots, j_m, i_1, \dots, i_n, 0\}$$

The d_{ij} denotes the distance between farm i *and* j and d_{0i} (d_{i0}), the distance from the consolidation point to farmer i (from farmer i to the consolidation point). The basic CW saving algorithm expresses the cost savings obtained by joining two routes into one route as illustrated in Figure 18, where point *0* represents the consolidation point.

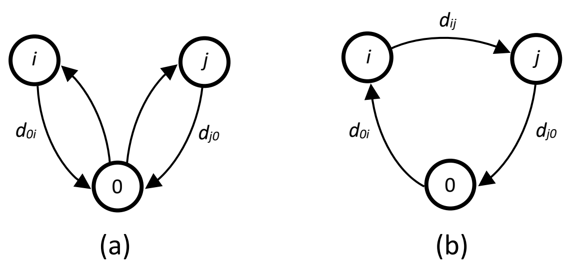


Figure 18 Merging two routes

The basic concept is to find a feasible set of vehicle routes that minimise the total travelling distances and the total number of vehicles used so that each farmer's demand is satisfied. Based on the business-as-usual case in Figure 18(a) farmer i and j each use their own vehicles to load their product before taking them to the consolidation point and returning with the empty container boxes to their farm using separate routes. The travelled distances D_{BAU} on each route can be calculated from Equation 3.22. An alternative solution is to merge the two routes, which maximises the savings, since only 1 vehicle is required to do the work instead of two, for example in the sequence $i - j$ as illustrated in Figure 18(b). The savings that result from driving the route in Figure 18(b) instead of the two routes in Figure 18(a) can be calculated from Equation 3.21. The travelling distances between the two given routes i and j by d_{ij}, and the total travelled distance D_{cw} is calculated according to Equation 3.20.

$$D_{BAU} = d_{0i} + d_{i0} + d_{0j} + d_{j0} \quad (3.22)$$

where

D_{BAU} – total travelled distance in BAU operation

d_{0i} – travelled distance between CP and farm i

d_{i0} – travelled distance between farm i and CP

d_{0j} – travelled distance between CP and farm j

d_{j0} – travelled distance between farm j and CP

The total travelling distances D_{cw} in Figure 18(b) can be calculated as

$$D_{CW} = d_{0i} + d_{ij} + d_{j0} \tag{3.23}$$

where

D_{CW} – total travelled distance between two given routes i and j

d_{ij} – travelled distance between farms i and j

By combining the two routes into one route, the total saving S_{ij}

$$S_{ij} = d_{0i} + d_{j0} - d_{ij} \tag{3.21}$$

Generally, the saving from merging any two routes (r_1 and r_2) is show in Equation 3.22

$$Savings\ (r_{12}) = d_{i_n 0} + d_{0 j_1} - d_{i_n j_1} \tag{3.22}$$

Several studies have suggested that where applied, the CW saving algorithm has increased routing and lowered operating cost (Pichpibul and Kawtummachai, 2012; Halim and Yoanita, 2015; Straka, Lenort and Besta, 2015). In order to simulate the logistics operating scenarios, the CW saving algorithm, as described in Section 3.5.1, was used to find a feasible set of vehicle routes that minimised the total travelling distances and also maximised the vehicle loading capacity (vehicle with greatest loading capacity) so that each farmer's demand was satisfied. In this case it was assumed that the number of vehicles required was not fixed, but the different potential operating scenarios would still try to minimise the number of vehicles used.

3.5.2 VRP Spreadsheet Solver

The VRP Spreadsheet Solver is an open-source application that has been designed for simplicity solve a vehicle routing problem, developed by Güneş Erdoğan, 2013. It unifies excel, GIS and metaheuristics, and capable of solving vehicle routing problems with up to 200 customers (nodes). The VRP Spreadsheet Solver keeps the data about the elements of a VRP in separate worksheets. The workbook initiates with only the worksheet named VRP Solver Console. The remaining worksheets consists of location, distance, vehicle, solution, and visualisation. The VRP Spreadsheet Solver package was applied into this research to find out the possible routes and used for benchmark result against the CW saving algorithm. The VRP Solver algorithm was developed based on many solutions such as a heuristic where two or more routes can be merged into a single route (Clarke and Wright, 1964), Large Neighbourhood Search (Pisinger and Ropke, 2007), the heuristic for pick-up or delivery with time windows, Iterated Local Search (Subramanian et al., 2010), and Genetic Algorithm (Vidal et al., 2014). VRP Spreadsheet Solver can solve the vehicle routing problem, based on features related to selective visits to customers, pickups and deliveries, time windows, vehicle used, distance constraint, and the final destination of the vehicles. The VRP Solver algorithm aims to minimise the cost of transportation operations where the demand of each client must be satisfied (in this case is rural farmer), vehicle capacity must not be exceeded for any vehicle, and total distance should be minimised.

Güneş Erdoğan define the vertex set V_D to contain the deport $(s), V_C$ to contain the client, and $V = V_D \cup V_C$, and $V_M \subseteq V_C$ as the set of clients that must be visited. Let $\mathrm{G} = (V, A)$ be the complete directed network. The profit servicing a client $i \in V_C$ as p_i, the pickup service amount for the client as q_i, the delivery service amount as $q\hat{}_i$, and the service time required by the client as s_i. In addition, $[a_i, b_i]$ being the time interval for the client, note that there is a time interval for each depot vertex.

In addition, K being as the set of vehicles, and define for each vehicle as $k \in K$ the origin depot of the vehicle as $o^k \in V_D$, the work start time of the vehicle as T^k, the fixed cost of using the vehicle as f^k, the capacity of the vehicle as Q^k, the distance limit as D^k, the driving time limit as $D^{\hat{}k}$, the working time limit as W^k, and the return depot of the vehicle as r^k. Associated with each arc $(i, j) \in A$, there is a distance d_{ij}. In addition, for each vehicle $k \in K$, there is a travel cost c_{ij}^k on arc (i, j).

The parameters related to the operational constraints, Ω is equal to 1 if the vehicle have to return to their specific return depot, and 0 otherwise. Let β equal to 1 if there is a backhaul constraint, and 0 otherwise. In addition, Θ to be equal to 1 if the time windows can be violated at the cost of a penalty Π per unit time, and 0 otherwise.

Denote x_{ij}^k to be equal to 1 if vehicle k traverses arc (i, j) and 0 otherwise. Furthermore, y_i^k be equal to 1 if vehicle k visits and serves vertex i and 0 otherwise. The amount of the pickup product and the delivery product carried by vehicle k on arc (i, j) is defended as w_{ij}^k and z_{ij}^k respectively. In addition, t_{ij}^k is the time at which vehicle k arrives at vertex i and v_i as the amount of violation of the time window of vertex i. The formulation for the VRP Spreadsheet Solver is;

$$maximise \sum_{i \in v_C} \sum_{k \in K} p_i y_i^k - \sum_{(i,j) \in A} \sum_{k \in K} c_{ij}^k x_{ij}^k - \sum_{j \in V_C} \sum_{k \in K} f^k x_{o^k, j}^k - \Pi \sum_{i \in V} v_i \tag{3.23}$$

$$subject\ to \sum_{k \in K} y_i^k = 1 \ \ \forall i \in V_M \tag{3.24}$$

$$\sum_{k \in K} y_i^k \leq 1 \ \ \forall i \in V_C \backslash V_M \tag{3.25}$$

$$\sum_{j \in V\{i\}} x_{ij}^k \leq \sum_{j \in V\{i\}} x_{ji}^k \ \ \forall j \in V_C, \mathrm{k} \in \mathrm{K} \tag{3.26}$$

$$\sum_{p\in S,q\in V\setminus S} x_{pq}^{k} \geq y_{i}^{k} \quad \forall i \in V_{C}, \mathrm{k} \in \mathrm{K}, \mathrm{S} \subset \mathrm{V} : o^{k} \in \mathrm{S}, i \in \mathrm{V}\setminus\mathrm{S} \tag{3.27}$$

$$\sum_{p\in S,q\in V\setminus S} x_{pq}^{k} \geq \Omega y_{i}^{k} \quad \forall i \in V_{C}, \mathrm{k} \in \mathrm{K}, \mathrm{S} \subset \mathrm{V} : i \in \mathrm{S}, r^{k} \in \mathrm{V}\setminus\mathrm{S} \tag{3.28}$$

$$\sum_{j\in V_c} x_{o^k,j}^{k} \leq 1 \quad \forall k \in \mathrm{K} \tag{3.29}$$

$$\sum_{k\in K} x_{i,j}^{k} \leq 1-\beta \quad \forall (i,j) \in \mathrm{A} : q_i > 0 \text{ and } q\hat{}_j > 0 \tag{3.30}$$

$$\sum_{j\in V\{i\}} w_{i,j}^{k} - \sum_{j\in V\{i\}} w_{j,i}^{k} = q_i y_i^k \quad \forall i \in V_c, \mathrm{k} \in \mathrm{K} \tag{3.31}$$

$$\sum_{i\in V_c} w_{i,r^k}^{k} = \sum_{j\in V_c} q_i y_i^k \quad \forall k \in \mathrm{K} \tag{3.32}$$

$$\sum_{j\in V\setminus\{i\}} z_{ji}^{k} - \sum_{j\in V\setminus\{i\}} z_{ij}^{k} = q\hat{}_j y_i^k \quad \forall i \in V_c, \mathrm{k} \in \mathrm{K} \tag{3.33}$$

$$\sum_{i\in V_c} z_{o^k,j}^{k} = \sum_{j\in V_c} q\hat{}_j y_i^k \quad \forall k \in \mathrm{K} \tag{3.34}$$

$$t_i^k + \left(d\hat{}_{ij} + s_i\right)x_{ij}^k - W^k\left(1 - x_{ij}^k\right) < t_j^k \quad \forall (i,j) \in \mathrm{A} : j \in V_c, \mathrm{k} \in \mathrm{K} \tag{3.35}$$

$$a_i \leq t_i^k \leq b_i - s_i + v_i \quad \forall i \in V_c, \mathrm{k} \in \mathrm{K} \tag{3.36}$$

$$v_i \leq \mathrm{M}.\Theta \quad \forall i \in V_c \tag{3.37}$$

$$t_i^k = T^k \quad \forall k \in \mathrm{K} \tag{3.38}$$

$$t_i^k + \left(s_i + d\hat{}_{ij}\right)x_{i,r^k}^k \leq b_{r^k} + v_{r^k} + \mathrm{M}(1-\Omega) \quad \forall (i,j) \in \mathrm{A} : i \in V_c, \mathrm{k} \in \mathrm{K} \tag{3.39}$$

$$w_{ij}^k + z_{ij}^k \leq Q^k x_{ij}^k \quad \forall (i,j) \in \mathrm{A}, \mathrm{k} \in \mathrm{K} \tag{3.40}$$

$$\sum_{(i,j)\in A} d_{ij} x_{ij}^k \leq D^k \, \forall (i,j) \in \mathrm{A}, \mathrm{k} \in \mathrm{K} \tag{3.41}$$

$$\sum_{(i,j)\in A} d\hat{}_{ij} x_{ij}^k \leq D^{\hat{}k} \, \forall (i,j) \in \mathrm{A}, \mathrm{k} \in \mathrm{K} \tag{3.42}$$

$$\sum_{i\in V_c} s_i y_i^k + \sum_{(i,j)\in A} d\hat{}_{ij} x_{ij}^k \leq W^k \quad \forall (i,j) \in \mathrm{A}, \mathrm{k} \in \mathrm{K} \tag{3.43}$$

$$x_{ij}^{k} \in \{0,1\} \ \ \forall(i,j) \in \mathrm{A}, \mathrm{k} \in \mathrm{K} \tag{3.44}$$

$$y_{i}^{k} \in \{0,1\} \ \forall i \in V_c, \mathrm{k} \in \mathrm{K} \tag{3.45}$$

$$v_i \geq 0 \ \ \forall i \in V_c \tag{3.46}$$

$$w_{ij}^{k} \geq 0 \ \ \forall(i,j) \in \mathrm{A}, \mathrm{k} \in \mathrm{K} \tag{3.47}$$

$$z_{ij}^{k} \geq 0 \ \ \forall(i,j) \in \mathrm{A}, \mathrm{k} \in \mathrm{K} \tag{3.48}$$

The objective function (equation 3.23) aims at maximises the total profit collected minus the travel cost of vehicles, fixed cost of using vehicles, and the penalty for violating time windows. This is a key equation function for solving the problem where the aim is to maximise the operational and environmental benefits by reducing the transportation cost of using vehicles, and time taken during the collection, and distance travelled which results in CO_2 emissions reduction. In this case, the penalty for violating time windows is not included. The equations 3.24 to 3.26 have been used to identify the constraints related to the case study where the vehicles visit the farms and return to the consolidation point. At first state the constraints set the visit rules for the clients by the vehicles. Constraint (equation 3.25) enforce a visit to the clients that must be visited, and constraint (equation 3.24) ensure that every client is visited at most once. According to the two different scenarios "best-case" where all participant farmers joined the co-operative scheme and "worst-case" where large-scale farmers were assumed to opt out, the equations 3.24 to 3.25 have been used to identify the participant farmer that must be visited. Constraint set (3.26) is a weak from of the well-known flow conservation constraints, which require a inflow of there is an outflow, and accommodates the VRP variants in which the vehicle does not have to return to its depot. Constraints (equation 3.27) provide the connectivity between the origin depot of vehicle k and the clients visited by this vehicle, and constraints (3.28) dictate the vehicle to return to its depot of it is required. Constraints (equation 3.29) state that each vehicle can be used at most once, whereas the backhaul constraint is enforced by constraint (equation 3.30). In the first scenario where the farmers share their vehicle with other farmers, equations 3.26 to 3.28 allow the vehicles not to return to the consolidation point, while in the second scenario where the Third-party vehicles have been assigned, these equations have been used to allow the vehicles to return to the consolidation point.

The constraints (equation 3.31 and 3.32) were the constraints that set the customer requirements, the flow conservation for the pickup product. Similarly, the flow conservation for the delivery product is provided by constraints (equation 3.33 and 3.34). Based on the characteristics of the case study, the first-mile collections, equations 3.31 and 3.32 have been used to identify the demand or the requirements, how many boxes of mango have to be collected at each farm. BAU operations over a 7-month period showed that the total number of mangoes during the off-peak period reduced compared to the peak period of harvesting season. Constraints (equation 3.35) are formulated based on the Miller-Tucker-Zemlin subtour elimination constraints and provide the framework for the time windows. The lower and upper limits of the time window for each client, and the variable to account for violation are stated in constraints (equation 3.36 and 3.37).

The final set of constraints state the restrictions related to vehicles. Constraints (equation 3.38 and 3.39) set the start of the working time for vehicle k, and ensures that the vehicle returns to its depot on time if it is required to. Constraint (equation 3.40) prohibit the violation of the vehicle capacities. This equation has been used to ensure that all vehicles visit tours and are not exceeding the set vehicle capacity. The reader is referred to the first scenario, where the loading capacity for light pick-up vehicles was set at 60 boxes, while in the second scenario, loading capacity for light refrigerated and 20ft refrigerated vehicle was set at 100 and 200 boxes, respectively. Constraints (equation 3.41 and 3.43) state the travelling distance, driving time, and working time limits for each vehicle, respectively. Finally, constraints (equation 3.44 and 3.48) are integrality and non-negativity constrains. In this study, travel distance limit, driving time limit, and working time limit for each vehicle were not considered, however, the study still attempted to minimise the travelling distance and driving time for vehicles benefit from the alternative potential operating scenarios.

The VRP Spreadsheet Solver keeps the data about the elements of a VRP in separate worksheets. Initially, the VRP Solver Console worksheet contains the various parameters. The remaining worksheets are locations, distances, vehicles, solutions, and visualisation. The cells with a black colour background are set by the VRP Spreadsheet Solver application and cannot be modified. The cells with a green colour background are parameters to be set by the user. The cells with a yellow colour background are to be computed by the application, but they are able to edit by the user for what-if analysis. In addition, the cells with a red colour background are signal an error e.g. vehicle violating the capacity.

VRP Solver Console

Figure 19 displays a screenshot of VRP Spreadsheet Solver where it stores and provides information to the rest of the worksheets. It contains various parameters regarding the size of the problem being solved and its characteristics including the number of depots, points of visit, number of vehicle types, and time windows. These related data must be filled out in the cells with a green colour background.

Sequence	Parameter	Value	Remarks
0.Interface	Language	English	Please refer to the manual for modifying the interface.
	Optional - Bing Maps Key		You can get a free trial key at https://www.bingmapsportal.com/
1.Locations	Number of depots	1	[1, 20]
	Number of customers	49	[5, 200]
2.Distances	Distance computation method	Manual entry	Recommendation: Use 'postcode, country' format for addresses
	Duration computation method	Bing Maps driving durations	
	Bing Maps travel mode	Driving	
	Bing Maps route type	Fastest	Recommendation: Use 'Fastest'
	Bing Maps route detail level	3	[0, 10]
	Average vehicle speed	30	
3.Vehicles	Number of vehicle types	1	
4.Solution	Do the vehicles return to their depot(s)?	Yes - only once at the end	
	Time window type	Hard	
	Backhauls?	No	If activated, delivery locations must be visited before pickup locations
5.Optional - Visualization	Visualization background	Bing Maps	
	Location labels	Location IDs	
6.Solver	Warm start?	Yes	
	Show progress on the status bar?	Yes	
	CPU time limit (seconds)	60	Recommendation: At least 120 seconds

Figure 19 VRP Solver Console worksheet

Location

Figure 20 displays a screenshot of location worksheet, details about the locations including their names, address, coordinates, time windows, and pickup and delivery service requirements. It is possible to prohibit the vehicles from visiting certain points of visit using the option in this worksheet, for quick what-if analysis without data modification. In addition, the coordinates can be input manually, or used from external source – the GIS web service.

Location ID	Name	Ad	Latitude (y)	Longitude (x)	Time window start	Time window end	Must be visited?	Service	Pickup amou	Deliv	Profit
0	Depot		17.1726790	100.3209980	00:00	23:59	Starting location	0:00	0	0	0
1	Customer 1		17.1827055	100.3218844	00:00	23:59	Must be visited	0:00	80	0	0
2	Customer 2		17.1803427	100.3242823	00:00	23:59	Must be visited	0:00	96	0	0
3	Customer 3		17.1691822	100.3411319	00:00	23:59	Must be visited	0:00	88	0	0
4	Customer 4		17.1846020	100.3228564	00:00	23:59	Must be visited	0:00	264	0	0
5	Customer 6		17.1660477	100.3345920	00:00	23:59	Must be visited	0:00	448	0	0
6	Customer 9		17.1855710	100.3198300	00:00	23:59	Must be visited	0:00	384	0	0
7	Customer 11		17.1822880	100.3197070	00:00	23:59	Must be visited	0:00	240	0	0
8	Customer 14		17.1796555	100.3169162	00:00	23:59	Must be visited	0:00	720	0	0
9	Customer 15		17.1816525	100.3169370	00:00	23:59	Must be visited	0:00	480	0	0
10	Customer 16		17.1801510	100.3140240	00:00	23:59	Must be visited	0:00	1200	0	0
11	Customer 17		17.1868235	100.3136342	00:00	23:59	Must be visited	0:00	684	0	0
12	Customer 19		17.1726847	100.3320645	00:00	23:59	Must be visited	0:00	48	0	0
13	Customer 21		17.1953800	100.3182529	00:00	23:59	Must be visited	0:00	188	0	0
14	Customer 23		17.2033667	100.3199977	00:00	23:59	Must be visited	0:00	192	0	0
15	Customer 25		17.1992660	100.3196610	00:00	23:59	Must be visited	0:00	100	0	0
16	Customer 26		17.2030972	100.3244874	00:00	23:59	Must be visited	0:00	128	0	0
17	Customer 30		17.2095500	100.3188210	00:00	23:59	Must be visited	0:00	72	0	0

Figure 20 Locations worksheet

Distances

Figure 21 displays a screenshot of distances worksheet, it contains the distances and travel durations between every two points that are specified in the locations worksheet. This worksheet provides a distance matrix, which will be used for computing the shortest or fastest route and estimating the time requirement.

Method:			
From	**To**	**Distance**	**Duration**
Depot	Depot	0.00	0:00
Depot	Customer 1	1.36	0:00
Depot	Customer 2	0.99	0:00
Depot	Customer 3	4.25	0:00
Depot	Customer 4	1.50	0:00
Depot	Customer 6	3.30	0:00
Depot	Customer 9	2.00	0:00
Depot	Customer 11	1.68	0:00
Depot	Customer 14	1.83	0:00
Depot	Customer 15	1.94	0:00
Depot	Customer 16	2.36	0:00
Depot	Customer 17	2.85	0:00
Depot	Customer 19	2.54	0:00
Depot	Customer 21	3.04	0:00
Depot	Customer 23	3.83	0:00

Figure 21 Distances worksheet

Vehicles

Figure 22 displays a screenshot of vehicle types worksheet, which contains the data about the vehicle types, capacity, costs, distance limit, and operation parameters. This worksheet allows the number of vehicles of each type can be set. The data includes cost parameters such as the cost per unit distance and the cost per trip, as well as operational parameters such as the depot, capacity, driving time limit, and the distance limit of the vehicle.

Starting depot	Vehicle type	Capacity	Fixed cost per trip	Cost per unit c	Duration multiplier	Distance limit	Work start time	Driving time limit	Working time limit	Return depot
Depot	T1	60	136.00	4.82	1.00	50.00	08:00	11:00	10:00	Depot

Figure 22 Vehicle types worksheet

Solution

Figure 23 displays a screenshot of the solution worksheet, it is generated to contain the list of stops for each vehicle specified in the vehicle worksheet and uses the information in the location worksheet regarding service time, pickup, delivery amount, as well as distance and duration from distance worksheet to compute the arrival times and cost of operation.

Total net profit:	-573.80							
Warning: The data has changed since the last solver run / feasibility check.								
Vehicle:	V1	Stops:	3	Net profit:	-164.09			
Stop count	Location Name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load
0	Depot	0.00	0:00		08:00	0:00	0	0
1	Customer 4	1.50	0:00	08:00	08:00	0:00	0	11
2	Customer 17	2.98	0:00	08:00	08:00	0:00	0	39
3	Depot	5.83	0:00	08:00		0:00	0	0
4								
5								

Figure 23 Solution worksheet

Therefore, the VRP Spreadsheet Solver, an open-source Excel based tool was applied to this research to find out the possible routes and used for benchmark results against the CW saving algorithm.

3.5.3 Implementation of the Algorithm

CW Saving Algorithm

Python was chosen for the implementation of this algorithm as it is an efficient environment to perform the experiment. The implementation was undertaken using the dataset where the problem size was 78 plantations managed by 49 rural farmers. The different potential operating scenarios were: (i) farmers sharing a vehicle through a farmer co-operative, and (ii) using a Third-party vehicle to make a milk-round collection. These were tested in the simulation for both the best-case and worst-case participation scenarios.

First, the algorithm checked whether the demand of any given farm exceeded the loading capacity of the vehicle type being considered. Where more than one vehicle is needed to collect all the produce, the algorithm uses a return trip until the demand is lower than the capacity of the vehicle, and in the case where only one vehicle is needed to collect the produce, the algorithm allows combined visits to other farms on the same route. Note that the different vehicles in the potential operating scenarios have different maximum load capacities, with the light pick-up vehicle allowing 60 boxes (1,500 kg), the light refrigerated vehicle 100 boxes (2,500 kg), and 200 boxes (5,000 kg) for the 20ft refrigerated vehicle. Therefore, the light pick-up vehicles that were commonly used in the BAU operations are assigned in the first scenario (sharing vehicle), while two different refrigerated vehicles both light and 20fr refrigerated vehicles were assigned in the second scenario (using Third-party refrigerated vehicles). Where different CW is applied to a vehicle with lower capacity, then in a post-process, the algorithm merges the most convenient routes into a single route undertaken by the vehicle with the higher capacity. For a given iteration, the savings S_{ij} are calculated and sorted in descending order of saving (ranked the saving S_{ij}). The pair of routes with the highest savings are merged, if the total demand on the route does not exceed the vehicle load capacity. The process is repeated until the list of savings is empty, i.e. no further routes can be merged.

VRP Spreadsheet Solver

VRP Spreadsheet Solver was used to perform the experiment. The implementation was undertaken using the same dataset as mentioned above, where the problem size was 78 plantations with 49 rural farmers. In addition, the different potential operating scenarios were explored (i) farmers sharing a vehicle through a farmer co-operative, and (ii) using a Third-party vehicle to make a milk-round collection. The different vehicles in the potential operating scenarios have different maximum load capacity, the light pick-up vehicle that was commonly used in the BAU operations with loading capacity at 60 boxes (1,500 kg), this vehicle type is assigned in the first scenario (sharing vehicle). While Third-party refrigerated vehicles both light and 20ft refrigerated vehicles were assigned in the second scenario. The light refrigerated vehicle allowing 100 boxes (2,500 kg), and 200 boxes (5,000 kg) for the 20ft refrigerated vehicle.

The VRP spreadsheet solver first performs a feasibility check of the data and searches for possible reasons of infeasibility. The search identifies farmers that must be visited but cannot be serviced by a vehicle within specific pick-up or delivery volume constraint, as well as time window limits. The solver also compares the overall carrying capacity of the vehicle to the total pick-up or delivery requirement of the farmers. According to Erdoğan, 2017, the VRP spreadsheet solver performs well for up to 100 customers under the two main variants of the VRP, the capacitated VRP and the distance constrained VRP.

Two different algorithms (CW saving and VRP Spreadsheet Solver) were used for solving the same problem under the same constraints to corroborate the findings and provide a sense check. The VRP Spreadsheet Solver took great computational time (120 second per run) compared to the Python based CW saving algorithm (45 second per run).

Chapter 4 Agricultural Business Characteristics

This chapter discusses the agricultural business characteristics related to rural farming in Thailand, determined from the fieldwork surveys. Government policy for Thailand's agriculture is presented in Section 4.1, while a discussion on the food retailers and the impact of their procurement policies on rural farmers and governance is covered in Section 4.2. Section 4.3 addresses the business-as-usual operating practices of rural farmers, and their involvement in farmer's organisations and collectives. The chapter also quantifies the BAU operation, for the case study on logistics consolidation processes in Section 4.4.

4.1 Government Policy and the Development of Thai Agriculture

In-depth interviews were undertaken with the government institutions, including Chief Executive Officers of the Co-operative Promotion Department (The Ministry of Agriculture and Co-operatives) to gather data on the government's development programs on co-operative and social enterprise schemes. This section focuses on the results derived from those interviews. It explains government policy and support related to food production in Thailand as well as how farmer's organisations (co-operatives and social enterprises) have developed over the past 10 years.

4.1.1 Government Agricultural Policy and Support

Thailand has implemented its 12th National Economic and Social Development Plan (2016-2021), a 5-year plan within the 20-year strategic plan and reform (2017-2036) (NIDA, 2017), under a vision of security and prosperity for all regions through development, by upgrading the existing infrastructure such as building the logistics infrastructure network to support the development of the country. The government has invested 3.4 trillion THB in a 8-year development plan of major construction, of which 53% (1.8 trillion THB) was spent in road transport improvement with the aims of improving capacity enhancement for both highway networks linking production areas of Thailand, and its neighbouring countries (NIDA, 2017).

Thailand's agricultural diversification was facilitated by the government's policy. The liberalisation of both national and international markets followed a campaign to promote Thailand as the world leader in the production of safe, excellent quality, and high-value food products, as known as "Thailand Kitchen to the World" (Thailand Board of Investment, 2016a). In 2015, the government approved 10 target industries, which included agriculture, to be mechanism to drive economy for the future development, through the National Industrial Development Master Plan. The principle industries for the engine of growth are: (1) Automotive, (2) Smart electronic, (3) Medical and wellness tourism, (4) Agricultural and biotechnology, (5) Further foods, (6) Robotics, (7) Aviation and logistics, (8) Biofuels and biochemical, (9) Digital, and (10) Medical hub.

The strategic development master plan includes three main sub-plans: (i) Domestic transport linkages and international connectivity with neighbouring countries, (ii) National logistics development and enchantment of supply chain management and transportation services, (iii) industrial estates and ports development to support the growth strategy (NIDA, 2017). Furthermore, the Marketing Development Department working with the private sector, particularly the modern trade chains and farmer's organisations, to develop policy and support the integration of food producers, particularly small-scale farmers into the modern trade supply chain. The government also supported the farmer's organisation schemes through the National Economic and Social Development Plan, (the 12th Plan for 2016-2021 (NIDA, 2017)), in order to sustain development and improve quality of life for smallholders. The support ranges from sources of credit to training programme and supporting marketing.

The government injected large sums of budget into the rural economy, a total of 143 billion THB through different forms of funds and soft loans where the farmers receive the lowest interest rate. However, these financial injections in the short term are not sustainable and a more long-term approach to tackle the root problems in agriculture such as produce quality, production costs, and productivity (Benbourenane and Ornanong, 2021) are warranted. In addition, agricultural co-operatives and social enterprises have to bear high transaction costs to sell their products due to poor transportation systems, high transportation costs, and damage to products on the way to markets. Therefore, to assist the food producers, the government provides different training schemes for small-scale farmers such as farmer's business skills, product processing, packaging, and branding development (DOAE, 2017) aim to equip the farmer with management skills and improve their productivity, as well as create the centre market for agricultural products.

The Chief Executive Officer of the Co-operative Promotion Department (CPD) stated that at the macro level, the significant observable feature in the agricultural farmer's organisations is support from the government. Through the CPD, the government of Thailand has continuously invested large resources in programmes for the development of agricultural farmer's organisations. The important schemes were the establishment of central markets for agricultural products, and the 'Marketing Organisation for Farmers' which created a marketplace and promotes the direct sale of agricultural products by food producers. In addition, the CPD also provided training programmes to support farmers, such as a one-day course on organic and pesticide-free farming, as well as offering specific funding support for organic and pesticide-free farming.

> "The Marketing Organisation for farmers has been created to provide a marketplace and promote the direct sale of agricultural products as well as providing production inputs for farmers at a fair price" (Chief Executive Officers of CPD).

A number of successful projects help to integrate rural farmers into modern market chains, such as the social enterprise named "the Royal Project". The Royal Project (RP) was initiated by His Majesty King Bhumibol Adulyadej and was established in 1969 in the North of Thailand to solve the problems of deforestation, poverty, and opium production, by growing alternative crops (Royal Project Foundation, 2012). The RP has developed household subsistence farming into commercial-based production under the Good Agricultural Practice (GAP), emphasising quality standards which enable them to receive a better price and market opportunities. There are 37 RP development centres being operated in the rural areas, covering 115 villages, from five provinces in the North (Chiang Mai, Chiang Rai, Lamphun, Phayao, and Mae Hong Son provinces) with a total of 12,300 household members. The interaction is between farmers and social enterprise in the production, collection, grading, and packaging process as well as delivery to the final markets. The RP work together with farmers on production planning according to market demand, and the member farmers receive their production quota based on their performance in the previous year. The member farmers can receive some agricultural inputs, financial credit, and marketing support. In addition, the RP also arranges contract farming to facilitate risk-sharing from production failures due to uncontrollable events such as disease or poor weather. This social enterprise is a good example of a successful social enterprise scheme that helps rural farmers develop and take advantage of modern trade market chains.

The CEO also stated that the CPD and, related government organisations, had been involved in organic and pesticide-free farming by providing policy, support, certifications, research and development. However, the responsibility for the agricultural policy lies mainly in the hands of different departments within the Ministry of Agriculture and Co-operative. For example, the Department of Agricultural Extension is responsible for the training support for the farmers, while the Department of Agriculture provides certification and accreditation. The Ministry of Public Health support with chemical residue test issues.

Production data are collected by the relevant government organisations and consist of: the main commodity and production base, cross border trade, and domestic consumption, trade and exports. This information was applied as supporting data when setting up the project development plan.

> "The agricultural production data are used to provide additional source of transportation demand from the production area to the major distribution network such as ports, and airports" (Chief Executive Officers of CPD).

4.1.2 How have Farmer's Organisations Developed since 2010?

Chapter 2 discussed supply chain management and structure that impact on the Thailand agriculture industry, and the market structure that relied on the traditional markets has now transformed into modern trade market chains. Recently, major supermarkets and similar overseas markets, have become the dominant markets for agricultural products. These potential markets give rise to a change in the purchasing system, where rural farmers are starting to face new challenges caused by radical changes in the agri-food system, particularly a growing demand with requirements for higher production standards. This can be observed from the positive growth and market share of modern trade retailers in Thailand. The market share of the modern retailers has significantly increased from 58% in 2013 to 63% in 2017, with the sales value increasing from 675 billion THB to 806 billion THB in 2017 (Ngamprasertkit and Welcher, 2017) (more detail about the agri-food market expansion was described in Section 2.3). The standard requirements imposed by major buyers is an important current issue in the procurement system. This has led to a situation where rural farmers have to upgrade their quality standards to meet market specifications.

Therefore, the idea of farmers' organisations was introduced, such as co-operatives and social enterprises. Their support is key to the success of small-scale farmers in scaling up to high value market chains, particularly retailers and supermarket chains. Collaborative working in farmer's organisations has been used to empower groups of farmers to participate with the supermarket and international market chains (Reardon, Timmer and Minten, 2012). Most of Thailand's agricultural farmer's organisations remain confined to their main functions, like distribution of agricultural inputs such as credit, and fertilisers. However, over the past 10 years, these organisations have tried to transform themselves and implement new strategies in this new market environment. Some farmer's organisations have undertaken value-added operations through processing, grading, and branding products, in order to gain competitive market advantage (Thuvachote, 2011).

For example, San Pa Thong agricultural co-operative created its own brand for their agricultural products, e.g. 'San Pa Thong Dried Longan', to distinguish its products from others. Fresh longan that does not meet the market standards are processed into dried products and sold under San Pa Thong brand, which is mainly exported to China. In addition, the farmer's organisation also received support from the government, particularly the Thai-Trade department in China, which acts as the middlemen for business matching between sellers and buyers. Similarly, the Hin Lad agricultural social enterprise also expanded their value-added services (a fresh product that fail to meet a market standard requirement) such as developing mango ice-cream and mango sheet (sundried mango). The data show that fresh mango, which does not pass the enterprise's stringent preliminary quality check, can be used to make other products such as mango ice-cream and mango sheet. In this case, the social enterprise gained support from the government and Naresuan University for equipment and training.

Meanwhile, some farmer's organisations attempted meet address consumer demand by offering higher-quality products such as pesticide-free or organic foods. The interviews showed that Hin Lad agricultural social enterprise has successfully delivered pesticide-free mangoes to supermarkets and international markets, mainly in Korea and Russia. Some agricultural farmer's organisations are working together with the private sector. The aim of this working strategy is to gain the advantages of a private company, such as strong marketing channels, popular brands. For example, Jom Thong agricultural co-operative has a contract agreement to supply premium longan and mangoes to Tesco Lotus in the Northern part of Thailand, particularly Tesco Lotus fresh market, for their consumers in the premium market segment.

4.2 Food Retailers and Rural Farmers

With the increasing expansion of modern trade chains, new business opportunities exist for rural farmers to tap into, as a potential (high value) market. These are particularly available to those rural farmers who can cultivate their crops all year round, while maintaining a reliable supply to supermarkets. However, rural farmers are often excluded from the market due to constraints such as limited production capacity, shortage of agricultural inputs, variable product quality, and limited power of negotiation. The interviews were undertaken with major buyers from Central Food Retail, and Gourmet Fresh Market and a broker from Rising (Thailand) company to understand the impact of their procurement policies place on rural farmers, as well as their procurement process of getting products from farm to final market.

4.2.1 Supplier Selection Criteria and the Requirements Placed on Rural Farmers

Regarding supplier selection and the requirements placed on the rural farmers, the key stakeholders said that 60-80% of the total fresh fruits and vegetables sold in their stores came from local sources, particularly groups of farmers and agricultural co-operatives. The Vice President from TOP supermarket stated that their products mainly came from two sources: local farmers mainly from agricultural co-operatives and/or social enterprises, and international suppliers, with over

60% of their products coming from local sources. In addition, the company also worked together with many agricultural co-operatives and groups of farmers across the country to obtain high-quality products. Similarly, at Gourmet Fresh market, 80% of the fresh fruits and vegetables sold in their stores were sourced from the local farmers. Both participants stated that one of their company missions was to support local food producers and to promote Thailand agricultural products. The companies have also done a Memorandum of Understanding (MoU) with the government and agricultural co-operative in terms of local sourcing to promote agricultural products, particularly fresh fruits and vegetables, as well as to provide an opportunity for local food producers to participate in the high-value markets.

However, the major buyers make their purchases mainly from co-operatives/social enterprises, or dedicated large-scale farmers to reduce transaction costs, buying large volumes, and dealing with a few suppliers for better quality control. Strict requirements are placed on food producers, not only for their product quality, specification, volume, hygiene, and delivery, but also the accompanying data that must be transferred pre- and post-transaction. As already mentioned, one of the important factors driving the change in argi-food markets is the rapid rise of supermarkets and international markets. The supermarket chain has increased its share of food retailing around the world. Consequently, in many developing countries, rural farmers face many challenges when trying to supply their products to supermarket or international market chains (Shannon, 2014).

The senior department manager from the Gourmet Fresh Market mentioned that not only the quality of the product was the most important factor for supplier selection, but also the quantity, and safety (the product must comply the Good Agricultural Practice), meeting the standards required. In addition, the ability to track and trace the product information is also considered in the supplier's selection. Although the product quality was the most important factor, the products must also meet market standards, particularly of food safety. For example, the food producers must hold at least the farming and GAP certifications, but other certifications such as pesticide-free or organic farming certifications will be an advantage in term of market opportunity and marketing.

The processes for becoming a supermarket supplier starts from the product specification, farm location, production capability, and related information being sent to the sourcing department, followed by a farm inspection. The sourcing team will visit the food producer's farm to make sure, and help, the food producers meet the farming standards. For example, the sourcing team will provide information and support through training programmes to the food producers for achieving the GAP certification and specific farming certifications, such as pesticide-free or organic certifications. In addition, the product specification information required by the company will be given to the food producers, such as cutting, packing, packaging, and transportation requirements, as well as the payment conditions. Once the food producers and their products meet the basic standards, they will be listed as preferred contractors.

4.2.2 Rural Farmer Procurement Processes and Contract Management

The procurement processes by which rural farmers are contracted by major buyers can be described as follows. The rural farmers have to forecast the amount of their expected output for the whole season and report to the co-operative or social enterprise at the flower forcing period[15]. The farmers and the farmer's organisation board members will then arrange the harvest schedule (verbal), to prevent oversupply at the consolidation point. Because the capacity at the HL's consolidation point is 18,000-20,000 kg per day, therefore the harvest schedule is allocated to its member farmers to ensure that the product will not over their capacity.

The fruit takes 90-120 days after flowering to reach maturity and ready to harvest. When the fruit is ready, the farmer's organisation and key buyers (brokers, representatives from supermarkets) visit the farm to check the product quality (and collect some for testing their size, colour, taste, and chemical residues). The survey showed that the supermarket representatives or brokers generally visit the rural farmer's plantation 2-3 times per year (the beginning of the season and in the middle of harvesting, during the peak period). However, 12.5% of the rural farmers had been visited 4-6 times a year (multiple visits in most cases because for specific inspection by the major buyers). The farmers said they had to sign the written contract, through the farmer's organisation, with the broker or supermarket company once the farm visit was complete, and the price has been agreed, with the settlement of the formal contract occurring within 7 days of the farm visit.

Generally, the contract agreement between the rural farmers and major buyers contains the basic information such as the terms of contract, and also specific deals such as information about grading conditions, selling price (often at a price that is established in advance). Grading criteria and selling prices are presented in

Table 8. Some major buyers also agreed to support the farmers through their farmer's organisation, by supplying agricultural inputs, providing production advice, and assisting transporting products. However, rural farmers have experienced failing to sell their products at the agreed prices or in the agreed quantity with 82% of the 49 participating farmers starting that their products had been rejected or the final selling price was lower than the selling prices agreed in the contract, which

[15] The period during which the mango tree will receive favorable conditions/treatments for its healthy growth to bear fruit, such as watering, fertilisation, and pruning

resulted from their products not meeting the standards required at the distribution centre. More details about the rejected products will be described in Section 4.2.4.

4.2.3 Product Grading and Quality Requirements

Due to the pressure of agri-food market demand, the quality standard requirement is one of the most important factors in the current procurement system. Customers and regulatory authorities expect high-quality produce. This led to a situation where rural farmers have to upgrade their product quality to meet market specifications, such as certification requirements and quality management. Therefore, it is important for rural farmers to upgrade quality standards of their production to comply with market requirements. The main standards imposed by the major buyers, such as supermarket and exporters, are mainly appearance, size, safety of products. These are strictly enforced and monitored in every shipment from the suppliers, while some major buyers will send their representative to visit the farm during the first-mile collection between farm and consolidation point.

> “The quality standard is currently the central focus of the procurement office of the Central Food Retail” (Vice President Buying Produce from TOP supermarket).

When the products are delivered to the consolidation point or food distribution centre, quality inspection of the goods is carried out. This is an important step in quality assurance, as the inspector carries out spot tests to observe the appearance, size, and colour. Only products that pass quality approval will later go on sale. The standards for mangoes, which is a set of guidelines related to the quality requirement for each class mango, were presented in Section 2.1.2. The Central Food Retail and Gourmet Fresh Market have developed leading manufacturing standards that cover all their own brand products, and work with their suppliers to ensure they are complied with. For example, the national and global Good Practice Agricultural (GAP) is an audit performed at their suppliers (plantation) focussing on the responsible use of pesticide in farming. In addition, they also have a routine testing programme by buyer’s central laboratory to ensure that the products are safe and meet their expect quality. The quality standards become crucial to differentiate the modern trade market’s produce from that of the traditional market.

According to the interviews, the quality at the consolidation point will determine the final price, thus if the product was damaged after harvesting, the price will decrease, or the product rejected. The buying price is set at the consolidation point followed the grading process which assesses size, colour, and occasionally a sweetness test. These criteria divided mangoes into 4 main grades; “A”, “B”, “C”, and “S” see
Table 8. Note that the prices given below were for the 2018 season.

Table 8 Grading criteria for setting buying price for M1 and M2 mangoes

Grades	Size (grams)	Surface/Colour	Shape	Price (THB/kg)	Proportion (%)
A	>350	No scars or other surface defect	Well-shaped	60-70	60%
B	300-350	Surface defect less than 5%	Well-shaped	40-50	20%
C	<300	5-10 surface defect	Unshaped	30-40	15%
S	<300	>10% surface defect	Unshaped	15-20	5%

Generally, mangoes are usually harvested when they begin to change outer colour from deep green to light green (when 80% mature), to guarantee the quality when the product reaches the final customers. However, the quality of the product on final inspection dictates the level of financial return for the rural farmers and this can often be adversely affected by the transportation leg. For example, the products that were identified as A grade at the consolidation point might receive the lowest price as C grade or all rejected if the products were declared damaged at the buyer distribution centre.

4.2.4 Transportation Requirements and Policies Impacting Rural Farmers

The process of getting produce from farm to the consolidation point was observed during the fieldwork survey. When the farmer agrees the contract, the mangoes are then harvested and moved to the consolidation point for the next stage of pre-production processes. Mangoes are usually harvested when nearly mature (at the pre-climacteric stage, or when 80% mature) for optimum ripeness to guarantee the quality when the product reaches the final customers. In addition, harvesting is done by hand picking, or using special fruit picking poles, with extreme care being needed during picking as even smallest blemish to the skin can result in rapid deterioration. The mangoes are then transported in a standard container box (37 x 55.5 x 30.5 cm) or 25 kg, as shown in Figure 24, by farmer owned (light pick-up truck) vehicle with maximum payload of 60 boxes (1,500 kg).

Figure 24 Container box commonly used when moving the produce

At the farmer's organisation's consolidation point, pre-product processes are applied such as un-bagging (the carbon bag used to protect mangoes from the fruit fly and maintain the fruit in a good state), cleaning (washing the fruit to make it free from dust, dirt, latex or any foreign materials), grading (usually done manually by a worker who sorts damaged, diseased and rotten fruit by hand,

and weighting), cutting (cut the stem at the top of the fruit), packing (apply the pocket shockproof protection transport packing), and storing in the container box to make them ready for shipping out to the markets or next production stages. A Third-party logistics provider will be arranged (for last-mile transport) by the farmer's organisation's board member to move the products from the consolidation point to the distribution centre and/or steaming factory in case of selling for international markets. The heat treatment operation disinfects the mango of fruit flies before export following the international standards requirement.

On transportation issues, 82% (n=49) farmers in Hin-Lad's agricultural social enterprise mentioned that rejected shipments receiving a lower price than the contract agreement was the key challenge in working with the supermarket chains. Although they do everything that buyers advise, their products still have a chance of being rejected or sometimes receiving a lower price than agreed due to products being damaged after harvesting. Lack of assets such as cold storage (pre-cooling process), and an effective transportation system (temperature-controlled refrigerated truck) were the main problems resulting in damaged products.

The co-operative and social enterprise managers also mentioned that the products sometimes were rejected by major buyers. Around 5-10% of the products are usually damaged per shipment, which will incur a lower price, and sometime the whole shipment was rejected if the damaged product is over 10% of the total shipment. Hin-Lad's manager said that the whole shipment was rejected on average once per season, leading to annual financial losses of 547,000 THB (£14,005) per season based on the premium price grade.

The supermarket companies wanted perishable products, including mangoes to be transported in refrigerated vehicles, and to be in the distribution centre within the arranged time window. This time window given to the suppliers depends on the type of products carried, but perishable loads are generally received from early morning up to midday. Once the products arrive at the distribution centre, the quality checking is immediately applied before being passed to the next production process or onward to their store.

An acceptable rate of damaged product is less than 10% of the total shipment, so that all damaged products over 10% results in the shipment being rejected and the suppliers sent a formal notification. Gourmet Fresh Market stated that they randomly check every shipment. If the products are damaged, but it less than 10% of the total shipment, the whole shipment is still accepted, but those damaged products will be paid at the lowest price. However, if over 10% of the total shipment is damaged, the whole shipment will be rejected. In addition, if the suppliers continue to supply damaged products, they will be blacklisted (special inspection will be required) and in the worst case, their purchase contract would be terminated. The supermarket companies added that, if over 10% of the products were damaged and it was a first-time for the supplier, they will receive a formal notification, and special inspection would be required for their next shipment. However, if they supply damaged products on three more subsequent occasions, their purchasing contract would be terminated until they can guarantee that they can supply high-quality products again.

Similarly, the Central Food Retail said that products received at the distribution centre will be randomly checked to make sure that produce reaches the company standards before shipping out to their store. Simple criteria are used to divide produce into 3 classes: 'Excellent' (no defect) – accept without condition, 'Good' (fewer than 10% defect) – accept with a condition such as the damaged products will be paid at lowest price, and 'Poor' (defects more than 10%) – reject the whole shipment. The company works closely with their suppliers to help the food producers produce high-quality products. The sourcing department will arrange a farm visit (audit) programme once or twice a year on average, to meet the suppliers or the local food producers for discussions about market conditions as well as to collect some samples for quality checking. The sample products from farm will sent to their central laboratory.

4.3 Rural Farmer Operating Practices

In-depth interviews and focus group discussions were undertaken with the two co-operatives and one social enterprise, as well as the individual farmers who participated in their farmer's organisations. The data collected were used to understand the operating principle and practices, rules for joining, benefits, logistics practices and operations.

4.3.1 Farmer Co-operative – Operating Principals and Practices

The collaborative working model of co-operatives and social enterprises have been part of Thailand's agricultural sector for long time. The private not-for-profit organisation produces, and exchanges social utility goods or services aimed at pursing general interest goals, which are carried out in stable way and as a main economy activity.

San Pa Thong (SPT) Agricultural Co-operative

SPT is an agricultural co-operative, one of the largest in the Northern part of the region (Chiang Mai province), was established through the Co-operative Promotion Department in 1975. It consists of 18 co-operative board committees working with 113 small groups of farmers and consists of 9,049 farmer members in total. An average group consists of 30-50 farmers producing varieties of agricultural products, mainly rice, longan, and mango. Sixty-two groups (54%) produce mainly rice, particularly “Thai Hom Mali Jasmine rice”, while the rest produce mainly longan and mango.

SPT agricultural co-operative’s mission is to provide a variety of agricultural inputs, credit resources, all necessary agricultural equipment, to support the farmer members for sustainable farming activity and achieve their living income. In addition, the co-operative also supports its members in marketing and seeking out new market channels, along with training programmes and production resources. The pre-processing processes are also provided by the co-operative, such as cutting, cleaning, packing, and transporting, as well as transforming the product into new form, such as dried.

The average yearly household income of farmers selling their products to the co-operative was about 415,000 THB (£10,608), significantly different compared with farmer in Chiang Mai province who earned about 240,000 THB (£6,134), reported by the National Statistical Office (2018). Note, however, that the household income was difficult to measure in the survey and these member’s incomes were the average based on the interview with the manager of the SPT agricultural co-operative.

The members of the SPT agricultural co-operative sell 80% of agricultural products to the co-operative, and the rest they sell to the local markets or keep for own consumption. In the case of rice, 10% of the total product will be kept for their own consumption, while 1% is for seeding. Some members also sell their agricultural produce at the local markets as a result of market competition. In addition, the co-operative manager stated that the products from non-member farmers were also accepted, but the members have the first priority. Some 7-10% of the agricultural products were purchased from non-member farmers.

Member Farmers selling to the SPT agricultural co-operative normally have four main market channels, wholesaler, broker, supermarket, and co-operative self-marketing. 45% of the total products were sold to a broker, particularly an exporter, 25% to supermarket chains, 10% to a wholesaler (Talaad Thai Centre Food market), and 10% was self-marketed. The members in the co-operative received greater benefits from the market opportunities offered by the co-operative.

Jom Thong Agricultural Co-operative (JT)

JT agricultural co-operative was established by the Co-operative Promotion Department in 1980, with 9 board committees working with 1,750 farmer members in Chiang Mai province. It mainly produces longan, rice, and mangoes for modern trade and international markets, with the total production area of 15,000 rai (2,400 hectares). 60% of the production area produces longan, 30%

corn and rice cultivar, and the rest of the area produces Nam Dok Mai mango, and Nam Dok Mai No.4.

Once, the farmers become a co-operative member, they receive agricultural resources support from the co-operative, such as fertiliser, chemical, credit, and training programmes. The mission of the JT agricultural co-operative is very similar to other agricultural co-operative, to provide the agricultural inputs support, source of credit, transportation service, and training programmes for its members for sustainable farming activity and achieving a living income for member farmers.

Ninety percent of the agricultural produce was sold to the co-operative, while the rest was sold in the traditional market, such as the local market and self-marketing. For rice, around 10% of the total product is kept for their own consumption, and 1-2% for seeding.

Farmers selling to the JT agricultural co-operative normally have four market channels, wholesaler, broker, supermarket, and self-marketing. The survey indicates that 45% of the total products sold to the broker, particularly exporter, 15% to supermarket chains, 20% to wholesaler, and 10% self-marketing for the rest of products. Most of premium grades such as A and B grades are sold to supermarket chains and brokers.

Hin-Lad Agricultural Social Enterprise (HL)

HL agricultural social enterprise was stablished by a group of farmers as a social enterprise in 2005, consists of 49 farmers, who collectively managed 78 plantations with 9 board members (the representative farmers) working together in Phitsanulok Province. Its goal is to achieve a particular community mission, provide a variety of production inputs, potential credit sources, marketing, and training to its members. The HL social enterprise farmers cultivate a production area of 1,286 rai (206 hectares). The majority of farmers in the HL social enterprise are small-scale farmers. 17.5% (n=49) of the rural farmers held production areas over 50 rai (8 hectares), while 82.5% held smaller areas just under 20 rai (3.2 hectares). This farming collective produce six varieties of commercial mango: “Nam Dok Mai Golden”, “Nam Dok Mai No.4”, “Kaew Sawie”, “Fah Lan”, “Phet Ban-Lat”, and “Chokanan”, producing around 53,000 boxes (1,335,000 kg) of mangoes annually. 41% of the total mangoes produced were “Nam Dok Mai Golden” and “Nam Dok Mai No.4” with average of 547,000 kg per year. The majority of HL farmers produce pesticide-free mangoes, but only 42% of them hold pesticide-free certificate[16], while the rest hold only a farming certificate, and 60% of their plantations produce multiple products (e.g. plantation A produce M1, M2, and M3 mangoes).

[16] The pesticide-free certification is proof that the products contain no pesticide residues with the limits of residue standard in marketplace

This social enterprise advertises its services to help rural farmers with market access, particularly high-value markets such as supermarkets and international markets. It provides agricultural inputs[17] to support its members at lower price, along with the quota system, which is determined by four criteria: farmer's experience, participation with group, availability of land/plantation, and quality of produce in the last season.

The average yearly household income of members selling their products to HL social enterprise was about 379,000 THB (£9,688), about 80% of the total household income. The members from HL social enterprise sell 90% of agricultural products to it, while 10% was sold into the traditional markets, such as local market and farmer self-marketing.

Farmers selling to the HL social enterprise normally have two main market channels – broker and supermarket. Over 60% of the total produce is sold to the broker, particularly an exporter, 20% to supermarket chains, and the remaining 10% for self-marketing. Most of the premium product, particularly 'A grade', will be sold to the brokers for the international markets such as China, Russia, and Korea. Therefore, the members receive greater benefits of the selling price from the market opportunities offered by the social enterprise. The data from the HL agricultural social enterprise will be used as a case study to quantify how appropriate consolidation is for the collective transport of the product from farm to the consolidation point. The business-as-usual operation will be presented and described in Section 4.4.

4.3.2 Rules for joining as Member Farmers

To become farmer's organisation member, there are some basic requirements. First, the member farmers must have a registered address with the local government office and their farm area must be located in the area of farmer 's organisation covered. Secondly, member farmers are required to hold at least a farming certificate and attend a training programme on the Good Agricultural Practice (GAP) farming system organised by the Department of Agriculture. Thirdly, farmers who intend to apply have to pay an application fee. For SPT and JT agricultural co-operatives, the farmers have to pay an application fee around 50 THB (£1.28), while to be a member in HL social enterprise the farmer has to pay 49 THB (£1.25). Once the application is approved by the board committees, the farmers can then access the farmer's organisation support. The member farmer benefits of participating in the farmer's organisation are described below.

In addition, once the farmer is a member of farmer's organisation, a member must comply with the following requirements: observe and obey all rules and regulations adopted by the board

[17] The agricultural inputs include fertilisers, CO_2 bags, and container boxes

committee of the organisation, attend general membership meeting, such as monthly meeting for production planning and harvesting, patronise the organisation's business and services, participate in the membership education programmes, and other training activities and affairs of the organisation.

4.3.3 Member Farmers Benefits

Rural farmers and farmer's organisations work together in production planning, collecting, grading, packing, marketing, and negotiating for its members, as well as delivering the product to the final markets or the next stage of production. Eighty-two percent (n=49) of rural farmers, particularly small-scale farmers, realised that the market opportunity is greater when working with the social enterprise, while the remaining 17.50% felt there was no significant different when compared with self-marketing. However, 85% agreed that working with a social enterprise provided them with advantages in operation, particularly with agricultural inputs, training, and market information. The farmer's organisations provide soft loans below the market rate of interest. For example, the members of HL agricultural social enterprise are eligible for a soft loan of 20,000 THB (£511) with no interest rate for 1 year. Similarly, JT agricultural co-operative provided a soft loan for their members of 40,000 THB (£1,022), and long loan of 500,000 THB (£12,780) with a low rate of interest. In addition, members also purchase agricultural inputs at a lower market price, such as fertiliser and chemical products, with credit in advance. SPT agricultural co-operative also provides other support such as life insurance, and elderly allowance for those aged 60 or over.

Eighty percent of rural farmers owned a light pickup vehicle or E-Taen (Thai tractor) for moving their products from farm to the consolidation point or final markets, while the remainder generally hired other farmers to deliver their produce. For SPT and JT agricultural co-operatives, the organisations provide transportation services for those members who have no vehicle for moving their produce. The JT agricultural co-operative supports the transportation service for the members, with a lower cost of transportation that average 10 THB (£0.25) per container box.

Members are also eligible to rent a container box, which will be used during the harvesting and transporting processes. The farmer's organisations allow their members to rent the container box (37 x 55.5 x 30.5 cm or 25 kg on average) with a quota (1000 kg for 20 container boxes), and deposit 5 THB (£0.13) per box. At the flower forcing period, the rural farmers have to forecast the amount of their expected output and report to the farmer's organisation; then the board committees will arrange the container boxes for their members.

In summary, rural farmers in farmer's organisation schemes are more organised, particularly those in co-operatives and able to access key farming resources and marketing information, and benefit from market opportunities offered by these organisations. The members in farmer's organisation seem to be more profitable than those who are not. Research on the role of social enterprises in Thai supply chains conducted by Nimsai (2012) mentioned that the average household income of farmers participating in social enterprise schemes were 17% higher than non-participant farmers. In addition, his research also mentioned that the farmers participating with the social enterprise scheme gained more advantages in term of agricultural inputs (seeds, chemical, fertiliser, and labour) and expenditure per rai (1 rai = 0.16 hectare) was 6% lower than the non-participant farmers.

4.4 Case Study: Quantifying BAU Operations

To quantify how appropriate consolidation is for the collective transport of the produce from farm to the consolidation point, farmer members of HL agricultural social enterprise were interviewed about business-as-usual characteristics and challenges faced in their operations, particularly the process of undertaking the first-mile collection from plantations. The 49 farmers managed 78 plantations and grew mangoes for HL's social enterprise in Phisanulok Province. This province is one of the largest mangoes producing regions in Thailand, produces 21% of the national annual total across the region, particularly of 'Nam Dok Mai Golden' and Nam 'Dok Mai No.4'. Table 9 shows the farm and household characteristics of farmers who are members of the HL's social enterprise. The average production areas of the sample of 49 farmers were 16.27 rai (2.60 hectare), with average yearly incomes from agriculture, particularly mango produce, about 379,734 THB (£9,707). Forty-eight percent of the rural farmer had been farming over 20 years and had been members of the social enterprise for 10 years on average. The average travelling distance between farm and consolidation point was found to be 8.65 km, and the majority of plantations are 2.97 km away from the main road on average.

Table 9 Farm and Household characteristics of participating farmers

Variable	N	Mean	Srd. Dev.
Average Production area (rai)	49	31.7	33.2
Average mango production (kg/year)	49	33,373	15,758
Year of farming (year)	49	19	8.5
Year of participating in social enterprise (year)	49	11	1.3
Yearly incomes (THB/year)	49	502,161	457,359
Yearly incomes from agricultural (THB/year)	49	379,734	208,252
Distance between farm and CP (km)	49	8.7	2.6
Distance between farm and main road (km)	49	3.0	1.1
Proportion of family labour	49	4.3	1.4

4.4.1 Characteristics of HL's Mango Production

Generally, mangoes are sold to the market between the middle of December and early June. However, 80% of the mangoes are marketed between February and April, particularly the middle of March to the end of April, as show in Figure 25. The 6 varieties of mangoes have different harvesting intervals over a 7-months period. Each bar represents the daily volume of mangoes that were harvested from farms and sent to the consolidation point.

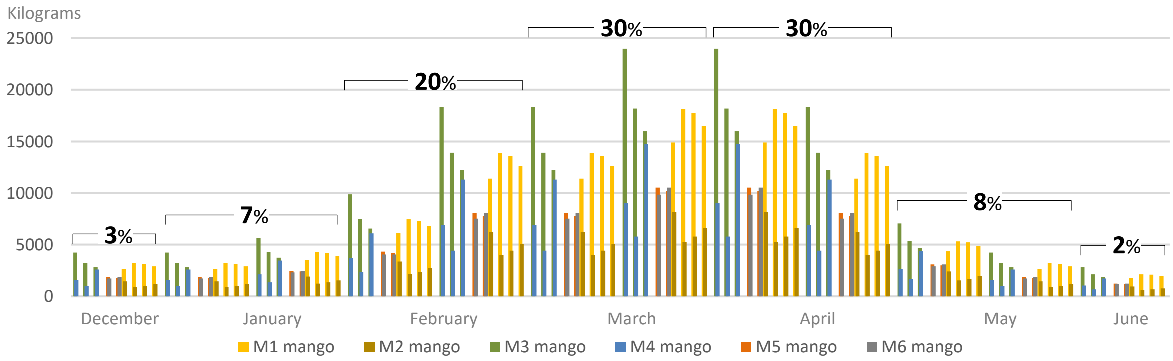


Figure 25 Daily harvest for 6 main varieties mangoes over a 7-month in 2018

Source: Based on the data collection at fieldwork with 49 farmers

In the current operation, each mango is harvested twice in a month, M1 and M2 mangoes are being harvested in the second and fourth week taking 4 days on average, while the M3 and M4 mangoes and M5 and M6 mangoes are gathered in the first and third weeks taking at least 3 days, (M5 and M6 mangoes take 2 days on average). The average daily production of M1 and M2 mangoes at the beginning of the season can range from 120-160 boxes (3,000-4,000 kg), which increases to 800-920 boxes (20,000-23,000 kg) at peak period. Whilst M3 and M4 mangoes produce between 140-180 boxes (3,500-4,500 kg) a day, increasing to 900-1,100 boxes (22,500-27,500 kg) at peak period. For M5 and M6 mangoes, the mangoes collected at the beginning of the season range from 120-140 boxes (3,000-3,500 kg), increasing to 700-800 boxes (17,500-20,000 kg) at peak period. 83% of the farmers are small-scale, so produce on average 40 boxes (1,000 kg) at peak period of the harvesting season.

Lack of refrigerated transport means the products are not moved in the correct way, which affects the quality of the products at the CP and final markets and reduces the final selling price. On average between 2-5% of the fruits were being damaged during the transportation between farms and the CP. This translated into an average loss of between 18 and 45 boxes (450-1,000 kg) of M1 and M2 mangoes per day (at peak harvesting period), leading to annual losses in the region of 10,000-27,000 kg per annum, out of 540,000 kg harvest resulting in a potential financial loss of 547,000 THB (£14,005) per season.

4.4.2 How Does the Transportation Work?

The process of getting product from farm to the CP starts when the farmer agreed the contract. The mangoes are then harvested and transported in standard container boxes (37 x 55.5 x 30.5 cm) or 25 kg on average, by a farmer owned vehicle (light pick-up truck) with maximum payload of 60 boxes (1,500 kg). At the HL social enterprise, pre-product processes are applied such as un-bagging, cleaning, grading, cutting, packing, and storing into the container box to make them ready for shipping out to the markets. When the products are ready to ship out, the HL's board members will arrange a vehicle from the Third-party logistics provider to move the products from the CP to the final markets. The interaction between farmers and HL social enterprise is shown in Figure 26.

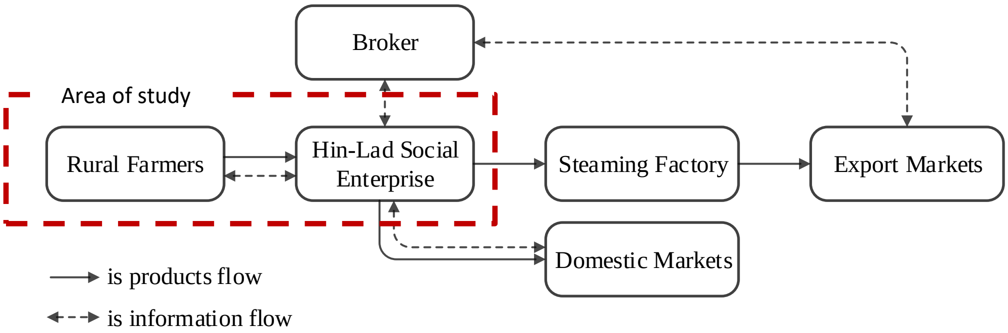


Figure 26 Interaction between farmers and HL social enterprise

The disadvantages of geographical barriers such as rivers and mountains, rural road networks, have been used to divide the 78 mango plantations into three zones, and these were used to describe the business-as-usual operation and develop more exclusive collaborative transportation scenarios. GIS application software "Google Earth 3D" was used to identify the farm locations and routes, allowing for travel distance and driving times between farms and the CP, as illustrated in

Figure 27. The zone number depends on how far it is from the CP, with 19% of the plantations located in zone 1 (farms that are <5 km from the CP), and 50% are in zone 2 (6-10 km away from the CP), and 31% are in zone 3 (>10 km away from the CP). The mean distance between the farm and the CP for zone 1 was 3.35 km (SD 1.12 km), some 10-15 minutes away. For zone 2 the mean distance was 7.06 km (SD 1.35 km), some 20-30 minutes away, while for zone 3 this was 15.24 km (SD 4.12 km), some 45-60 minutes away.

Figure 27 The 78 plantation locations by zone

Source: Google Earth 7.6 (2020)

The most common vehicles used by rural farmers were light pick-up trucks and Thai tractors (known as “E-Taen”), as show in Figure 28, to move their produce from the farm to the CP. Across these vehicles, the mean load capacity was found to be 60 boxes (1,500 kg), with the gross vehicle weight around 2,500 kg (DLT, 2018). The CO_2 emissions of these vehicles were 0.22 $kgCO_2$/tonne-km when fully loaded (TGO, 2019).

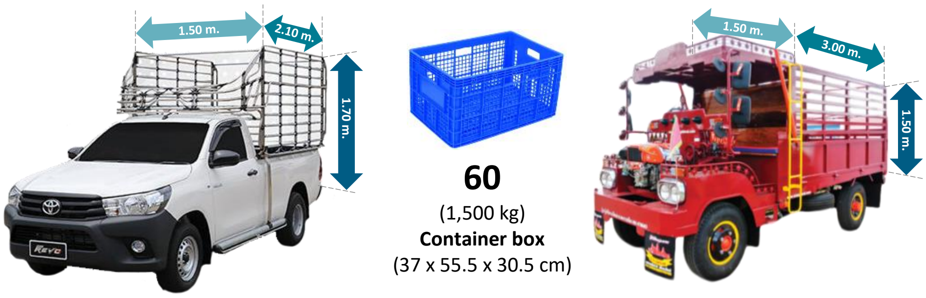


Figure 28 Light pick-up vehicles being used by rural farmers in Thailand

Source: Etanphimai (2016)

Eighty percent of the rural farmers owned a vehicle, which was used to move the product from their plantation to the CP, whilst the rest generally hired other farmers to move their product (the individual relationship between farmers). Based on the observed business-as-usual operation, the vehicles were used in multiple ways, for carrying agricultural products and non-farm related activities. Using the vehicles for non-farm activity is defined as being all those activities that go beyond farming and agricultural purposes. Thus, the cost of operating the vehicles was sensitive to the levels of utilisation and for the case study, these were based on their utilisation during the growing season only. Although the Thai tractor had a lower operating cost, it was generally used for on-farm/plantation and short distance travelling.

4.4.3 Vehicle Use: Time and Motion Study

Time and motion studies provide techniques to analyse an operation in detail and measure which activities relate to farming. Through studying at a specific period of time e.g. observed daily and weekly operations were used to understand a whole year of cultivation, it was possible to calculate how the vehicle owned by the rural farmers was used. The in-depth interviews were undertaken to gain more details based on their daily and weekly operations. Fieldwork showed that the members of HL agricultural social enterprise were mainly cultivating mangoes as their main economic crop, but cassava and rice were also grown (64% (n=49) of household income came from mango cultivation, cassava 20%, rice 6%, and the rest (11%) from non-agricultural sources). Table 10 shows the time spent in different farming activities. On average farmers spent 1,074 hours a year on their farming activities. This includes watering, fertilising, weeding, farm maintenance, harvesting, and delivering. However, the time spent varies from activity to activity. In addition, the rural farmer has diversified their agricultural production to include mango, cassava, and rice crops. The time spent on the activities related only to mango cultivation was found to be 822 hours on average or 77% of the total farming activities, 10% (109 hours) for rice cultivation, and 13% for cassava cultivation.

Table 10 Time spent on farming activities per annual derived from the in-depth interviews

Task	Duration (hours)	How often (days)	% of time spending
Mango crop	**822**	**156**	**76.5**
Watering mango	168	21	15.6
Tree maintenance, pruning, weeding	164	35	15.3
Fertilising, bio-Insecticide	284	68	26.4
CO_2 bagging	64	8	6.0
Harvesting, delivering, pre-processing product	142	24	13.2
Rice crop	**109**	**33**	**10.2**
Land preparation	16	2	1.5
Planting	8	2	0.7
Weeding	4	2	0.4
Water management	44	16	4.1
Fertilising, bio-Insecticide	32	10	3.0
Harvesting and delivering	6	1	0.6
Cassava crop	**143**	**40**	**13.3**

Land preparation	16	2	1.5
Planting	20	3	1.9
Tree maintenance, Weeding	46	19	4.3
Fertilising	39	12	3.6
Harvesting and delivering	22	4	2.1

The timetable as presented in Table 11 shows how long rural farmers reportedly spent on activities related to farming, and the vehicle used predominantly with all these activities over a one-week period. They spent 34 hours a week on average for their farming activities during the growing period between 5 June and 11 October 2017, while they spent 27 hours a week for their farming activities between 18 December to 4 June.

Table 11 Time spent on farming activities over one-week period between 17-23 July 2017

Time	MON	TUE	WED	THU	FRI	SAT	SUN
06:00-07:00		Fertiliser				Spraying liquid fertiliser	
07:00-08:00		Feeding for				For mango plantation	
08:00-09:00	Watering	Mango trees	Weeding	Rice Water			
09:00-10:00	Mango trees		For cassava	management			
10:00-11:00			plantation				
11:00-12:00							
12:00-13:00							
13:00-14:00	Watering						
14:00-15:00	Mango trees						
15:00-16:00							
16:00-17:00			Spraying Bio	Spraying Bio			
17:00-18:00			insecticide	insecticide			
18:00-19:00			Cassava plantation	Rice plantation			

Similarly, Table 12 shows the amount of time spent on activities related to farming during the harvesting season, over a one-week period from 19-25 March 2018. The rural farmers spent 21 hours (78%) on average on managing mango trees, harvesting and pre-processing (cleaning, grading, packing) every week, while the rest of the 6 hours were spent on cassava crop cultivation, such as weeding and spraying bio insecticide.

Table 12 Time spent on farming activities over one-week period between 19-25 March 2018

Time	MON	TUE	WED	THU	FRI	SAT	SUN
06:00-07:00						Spraying liquid	
07:00-08:00						Fertiliser for	
08:00-09:00	Mango trees	Harvesting	Weeding			Mango plantation	
09:00-10:00	management	M1 and M2	For cassava				
10:00-11:00		mangoes	plantation				
11:00-12:00		Moving to CP					
12:00-13:00							
13:00-14:00		Unbagging					
14:00-15:00		Cleaning					
15:00-16:00		Cutting					
16:00-17:00		Grading	Spraying Bio		Spraying Bio		

17:00-18:00	Packing	insecticide		insecticide
18:00-19:00		Cassava plantation		For mango

Table 13 shows the time spent on farming activities and was used to calculate how the vehicle was used for farming. Thus, the vehicle was used 420 times for farming activities in one year, of which 78% related to mango cultivation, 9% was for rice, and 13% for cassava cultivation. In addition, only 12% of the total vehicle trips were used for collecting and delivering mango from the farm to the CP in the harvesting period between 18 December 2017 and 4 June 2018.

Table 13 The average vehicles time used in relation to the annual farming activities

Task	**Vehicle used (No. used)**	**Travelled distance (km.)**	**Driving Time (hour)**	**How often (days)**	**% Vehicle used**
Mango crop	**330**	**521**	**26.1**	**156**	**77.8**
Watering mango	168	194.9	9.7	21	39.6
Tree maintenance, pruning, weeding	35	95.3	4.8	35	8.3
Fertilising, bio-Insecticide	68	78.9	3.9	68	16.0
CO_2 bagging	8	9.3	0.5	8	1.9
Harvesting, delivering, pre-processing product	51	142.6	7.1	24	12.0
Rice crop	**39**	**143**	**7.2**	**33**	**9.2**
Land preparation	2	6.2	0.3	2	0.5
Planting	4	12.4	0.6	2	0.9
Weeding	2	6.2	0.3	2	0.5
Water management	17	49.6	2.5	16	4.0
Fertilising, bio-Insecticide	10	31.0	1.6	10	2.4
Harvesting and delivering	4	37.6	1.9	1	0.9
Cassava crop	**55**	**164**	**8.2**	**40**	**13.00**
Land preparation	2	5.2	0.3	2	0.5
Planting	10	26.0	1.3	3	2.4
Tree maintenance, Weeding	19	49.4	2.5	19	4.5
Fertilising	12	31.2	1.6	12	2.8
Harvesting and delivering	12	52.2	2.6	4	2.8

4.4.4 Business-as-Usual Transportation Operations Based on HL's Social Enterprise

This section describes the business-as-usual transportation operation when rural farmers move their products from farms to the CP. The data were gathered over a 7-month period between 18 December 2017 and 4 June 2018, particularly the transport of M1 and M2 mangoes. The operating characteristics of 49 plantations when collecting and delivering M1 and M2 mangoes are presented in Table 14. Generally, the M1 and M2 mangoes were collected and delivered to the CP twice a month, encompassing an average of four-day's work, by using the light pick-up vehicle owned by the rural farmers. 22,256 boxes (547,000 kg) of M1 and M2 mangoes were collected from farms and delivered to the CP over a 7-month periods, from the middle of December to early of June, generating a total distance driven of 6,415.4 km or 20% of all farming activities, producing 1,536.5 $kgCO_2$/tonne-km, with a total transportation cost at 30,922 THB (£790). In addition, an average of 2-5% of produce was being lost during transit between farm and the CP, at a cost of 219,164 THB (£5,602). The total number of round-trip visits to the farms were 770 during the harvesting season, and the total loaded capacity was 46,200 container boxes, which resulted in a total of 23,944 empty boxes spaces without any load across the fleet.

Table 14 Summary of the BAU operations of M1 and M2 mango over 7-month operations

Harvesting	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
DEC	49	50	690	16440	443.5	22.2	328.8	6576	2137	8714	2310	89.2
JAN	98	101	1594	38360	891.0	44.6	767.2	15344	4294	19639	4466	184.6
FEB	98	135	4445	109602	1106.8	55.3	2192.0	43841	5334	49176	3655	279.0
MAR	98	166	6635	164354	1317.5	65.9	3287.1	65742	6350	72092	3325	354.8
APR	98	166	6635	164354	1317.5	65.9	3287.1	65742	6350	72092	3325	354.8
MAY	98	103	1801	43840	900.3	45.0	876.8	17536	4339	21876	4379	191.9
JUN	49	49	456	10960	438.8	21.9	219.2	4384	2114	6499	2484	82.3
Total	**558**	**770**	**22256**	**547910**	**6415.4**	**320.8**	**10958**	**219164**	**30922**	**250086**	**23944**	**1536.5**

where

VF_{inv} – number of vehicles involved

VF_{vis} – number of vehicles visit farm (round-trips)

Q_{box} – capacity loaded (boxes)

Q_{kg} – capacity loaded (kg)

D_{tv} – total distance travelled (km)

T_{dri} – total time driven (hour)

W_{avrw} – product waste during transit (kg)

C_{wst} – cost of product waste during transit (THB)

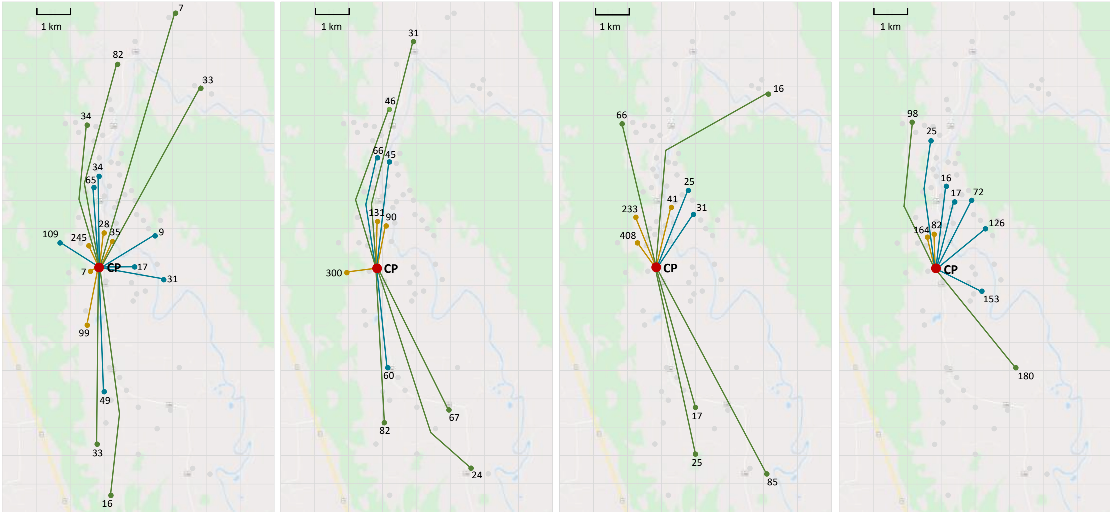
TC_{own} – total transportation cost with farmer's own vehicle (THB)

TC_{total} – total transportation cost associated with cost of product wastage (THB)

ER_{box} – empty box space (box)

EM_{CO2} – total CO2 emission ($kgCO_2$/tonne-km)

The 49 plantation locations in relation to the HL's consolidation point facility are shown in Figure 29. The distances travelled from farms have been colour coded according to the CP used, yellow lines representing farms that under 5 km from the CP, blue lines 5-10 km, and green line over 10 km from the CP. In addition, the time window opens for products to be dropped-off at the CP at 06.00am each day and finishes at 12.00pm. Farmers agree to a pre-arranged production schedule organised by the social enterprise, where harvesting times are managed to prevent over-supply to the CP.



(a) Day 1 (b) Day 2 (c) Day 3 (d) Day 4

Figure 29 Farm locations in relation to the consolidation point

22,256 boxes (547,000 kg) of M1 and M2 mangoes were collected and moved to the CP using the farmer's own vehicles with a load capacity of 60 boxes (1,500 kg). Table 15 served as the input data to create the collaborative transport scenarios, for simulating the alternative first-mile transport.

Table 15 BAU operations of 49 HL farmers using their own vehicle for moving produce over 7-month period.

Farmers	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farmer 01	12	165	4000	32.6	1.6	80	1600	157.3	1757.3	13.1	555	7.1
Farmer 02	12	195	4800	23.8	1.2	96	4800	114.5	5075.3	9.5	525	5.3
Farmer 03	12	186	4400	102.0	5.1	88	14400	491.6	14948.4	41.0	534	22.2
Farmer 04	17	539	13206	51.0	2.6	264	9600	245.8	10030.1	14.5	481	13.5
Farmer 06	20	900	22400	132.0	6.6	448	24000	636.2	25046.5	31.8	300	38.4
Farmer 09	19	778	19200	76.0	3.8	384	13680	366.3	14393.1	19.3	362	21.4
Farmer 11	17	486	12000	57.1	2.9	240	960	275.3	1253.8	16.2	534	14.3
Farmer 14	31	1446	36000	113.8	5.7	720	1920	548.4	2034.5	17.7	414	33.4
Farmer 15	23	965	24000	89.2	4.5	480	3760	430.1	4170.3	18.7	415	25.2
Farmer 16	46	2400	60000	217.1	10.9	1200	3840	1046.5	4356.9	22.8	360	64.9
Farmer 17	26	1378	34200	147.9	7.4	684	2000	713.1	2436.1	27.4	182	44.9
Farmer 19	12	100	2400	61.0	3.1	48	2560	293.8	3036.6	24.5	620	11.8
Farmer 21	14	389	9400	85.1	4.3	188	1760	410.3	2251.6	29.3	451	20.8
Farmer 23	14	389	9600	107.2	5.4	192	1440	516.9	1973.9	36.9	451	26.8
Farmer 25	12	200	5000	90.5	4.5	100	5760	436.1	6704.8	36.3	520	20.5
Farmer 26	12	265	6400	98.9	4.9	128	3840	476.6	4665.3	39.7	455	23.2
Farmer 30	12	150	3600	110.8	5.5	72	2000	533.9	2614.8	44.5	570	23.5
Farmer 33	17	581	14400	196.0	9.8	288	2640	944.8	3312.7	55.6	439	52.9
Farmer 34	14	389	9600	171.2	8.6	192	4800	825.3	6015.2	59.0	451	42.8
Farmer 36	12	200	5000	127.6	6.4	100	5282	614.8	5528.2	51.2	520	28.8
Farmer 37	12	275	6600	139.6	7.0	132	1760	672.7	2733.5	56.1	445	32.4
Farmer 39	17	492	12000	252.1	12.6	240	400	1215.2	1551.0	71.5	528	61.7
Farmer 40	12	186	4400	202.0	10.1	88	3520	973.5	3922.6	81.1	534	43.2
Farmer 42	12	46	1000	238.8	11.9	20	4800	1151.0	5679.2	95.9	674	40.7
Farmer 43	12	358	8800	83.5	4.2	176	960	402.6	1544.2	33.6	362	20.9

Farmers	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farmer 45	17	486	12000	182.4	9.1	240	2880	879.2	3394.2	51.7	534	45.6
Farmer 47	12	100	2400	121.2	6.1	48	1920	583.2	2655.7	48.7	620	23.4
Farmer 48	12	293	7200	106.7	5.3	144	4960	514.2	6523.4	42.9	427	25.5
Farmer 50	12	195	4800	152.6	7.6	96	880	735.7	1829.7	61.3	525	34.1
Farmer 51	17	500	12400	324.4	16.2	248	17722	1563.4	18354.7	92.0	520	82.5
Farmer 52	12	101	2200	197.0	9.9	44	400	949.7	488.5	79.1	619	37.3
Farmer 53	33	1777	44304	131.3	6.6	886	6400	633.1	6958.8	19.2	203	39.8
Farmer 54	12	46	1000	18.4	0.9	20	1440	88.5	2181.5	7.4	674	3.1
Farmer 56	17	646	16000	115.9	5.8	320	1360	558.8	2398.2	32.9	374	32.4
Farmer 57	12	150	3600	153.8	7.7	72	10560	741.5	11859.3	61.8	570	32.6
Farmer 58	12	146	3400	215.4	10.8	68	8960	1038.2	9596.2	86.3	574	44.9
Farmer 59	23	1069	26400	269.6	13.5	528	3920	1299.3	4741.9	56.5	311	78.3
Farmer 60	14	395	9800	170.5	8.5	196	7360	821.9	7937.0	58.7	445	43.0
Farmer 62	19	746	18400	119.7	6.0	368	1760	577.0	2092.6	30.4	394	33.4
Farmer 65	12	186	4400	69.0	3.5	88	480	332.6	876.2	27.7	534	15.0
Farmer 66	12	55	1200	82.2	4.1	24	880	396.2	1269.8	33.0	665	14.3
Farmer 67	12	101	2200	80.9	4.0	44	4160	389.8	4582.4	32.5	619	15.3
Farmer 68	14	425	10400	87.6	4.4	208	1440	422.4	1808.4	30.2	415	22.4
Farmer 69	12	150	3600	76.4	3.8	72	2400	368.4	2712.9	30.7	570	16.2
Farmer 71	12	246	6000	64.9	3.3	120	960	312.9	1284.5	26.1	474	14.9
Farmer 72	12	100	2400	67.3	3.4	48	880	324.5	2145.5	27.0	620	13.0
Farmer 73	12	101	2200	262.6	13.1	44	1920	1265.5	3150.8	105.5	619	49.8
Farmer 74	12	195	4800	255.4	12.8	96	5760	1230.8	6161.5	102.6	525	57.0
Farmer 78	17	589	14400	83.3	4.2	288	7680	401.5	8046.3	23.6	431	22.5
Total	**770**	**22256**	**547910**	**6415.4**	**320.8**	**10958**	**219164**	**30922**	**250086**	**-**	**23944**	**1536.5**

The data gathered at the peak period from 12-15 March 2018 is presented in

Table 16. This suggested that there were 49 light pick-up vehicles that operated 89 round trips to collect 3,753 boxes (93,112 kg) of M1 and M2 mangoes from 49 farms, which generated a total distance travelled of 698.4 km at a cost of 3,366 THB (£86) and produced 192.4 kgCO_2/tonne-km of CO_2 emissions. The 89 round trips operated with total loaded capacity of 1,500 boxes generating 546 empty box spaces without any loaded. The product wasted in transit was 1,862 kg at a cost of 37,245 THB (£952), based on the opportunity of lost selling cost (20 THB per kg).

Table 16 Summary of the BAU operations over between 12-15 March 2018

Day Operation	VF_{ini}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
Monday 12 Mar 2018	15	25	954	23698	191.3	9.6	473	9479	922	10401	546	52.4
Tuesday 13 Mar 2018	7	18	908	22610	92.5	4.6	452	9044	445	9490	172	27.5
Wednesday 14 Mar 2018	8	20	990	24636	177.1	8.9	492	9854	853	10708	210	51.7
Thursday 15 Mar 2018	19	26	901	22168	237.6	11.9	443	8867	1145	10012	659	60.7
Total	**49**	**89**	**3753**	**93112**	**698.4**	**34.9**	**1862**	**37245**	**3366**	**40611**	**1587**	**192.4**

The data were gathered during the off-peak period 18-21 December 2017, when around 3-7% of the total production was harvested. Table 17 shows that there were 49 light pick-up vehicles that operated 50 round trips to collect 690 boxes (16,440 kg) of M1 and M2 mangoes. In this period, they generated a total distance of 443.5 km at a total cost of 2,137 THB (£54) and produced 89.2

$kgCO_2$/tonne-km of CO_2 emission. The 50 round trips, with a total load capacity of 3,000 boxes, generated 2,310 empty box spaces without any loaded. The product waste during transit was 328 kg with a cost of 6,576 THB (£168). Thus, the overall cost was 8714 THB (£222) when the cost of product wastage during transport was considered.

Table 17 Summary of the BAU operations from 18-21 December 2017

Day Operation	VF_{ini}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
Monday 18 Dec 2017	15	15	177	4182	128.1	6.4	83	1673	617	2290	723	25.4
Tuesday 19 Dec 2017	7	8	163	3990	41.6	2.1	79	1596	200	1797	317	9.5
Wednesday 20 Dec 2017	8	8	178	4356	85.5	4.3	87	1742	412	2154	302	18.9
Thursday 21 Dec 2017	19	19	172	3912	188.3	9.4	78	1565	907	2473	968	35.4
Total	49	50	690	16440	443.5	22.2	328	6576	2137	8714	2310	89.2

Data collected suggested that an average of 2-5% of the fruits were being damaged during transit, so that they were being rejected by the onward transportation provider. This translated into an average loss of between 18-45 boxes of M1 and M2 mangoes, 450-1,000 kg per day (at peak harvesting period), leading to annual losses in the region of 10,000-27,000 kg a year out a harvest of 540,000 kg, resulting in a potential financial loss of 219,00 THB (£5,602) per season, and 547,000 THB (£14,005) in the worst-case (average 5% loss).

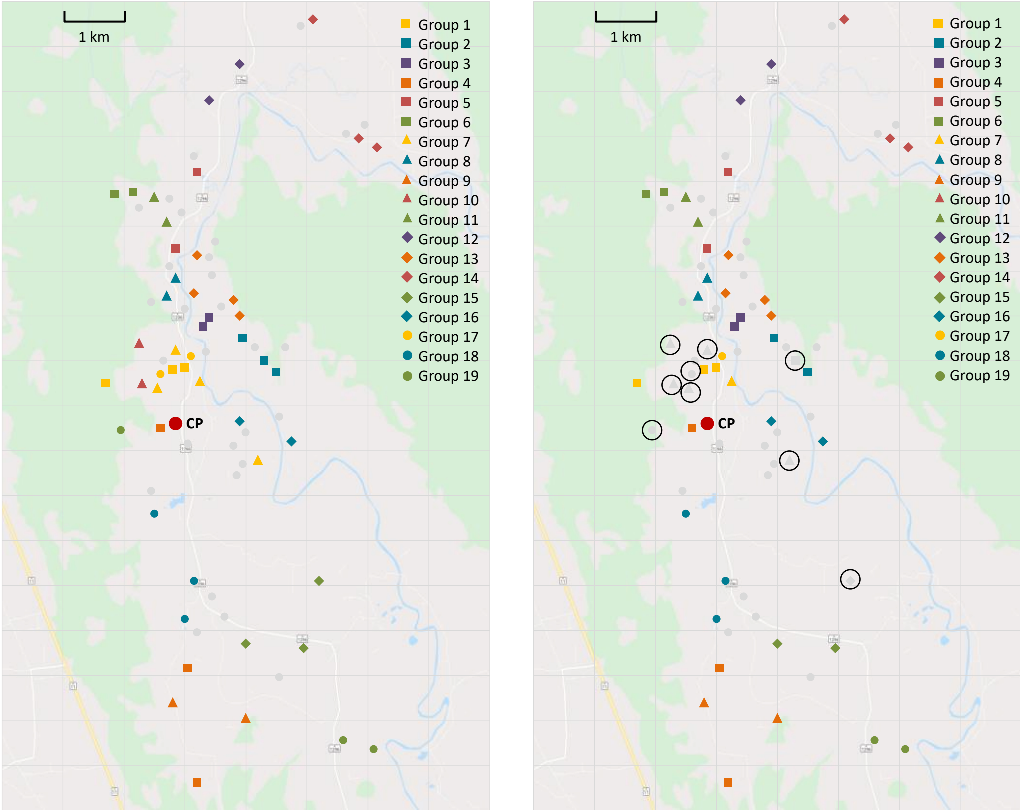
Chapter 5 Computational Results

This chapter used the CW saving algorithm to quantify the potential benefits of the proposed operating scenarios: (i) sharing vehicles through a farmer co-operative (section 5.1, and (ii) using a Third-party logistics provider's vehicle to make milk-round collections (section 5.2). Computational tests were performed based for the case of the M1 and M2 mango (the most valuable) over a 7-month period from 12 December 2017 to 04 June 2018, and key performance factors including vehicles visits to farms, distance travelled, driving times, total operating costs, empty box space, and CO_2 emissions. In addition, two developments were covered: a 'best-case' where all the farmers were willing to work together, and a 'worse-case', in which the large-scale farmers (who produce over 120 boxes per day) would not be willing to work together (with small-scale farmers) and would go it alone, sticking with their current transportation strategy.

5.1 Sharing Vehicles Through a Farmer Co-operative

This scenario looked at the merits of implementing a vehicle sharing scheme via a farmer co-operative where rural farmers work together. The CW saving algorithm was used to quantify a feasible set of vehicle routes that minimise the total travelling distances and the total number of vehicles visits to farms. According to the processes of algorithm implementation, as described in Section 3.5.3, the algorithm checks the demand of any given farm, and if the demand does not exceed the vehicle load capacity, then it merges the most convenient routes into a single route performed with the vehicle with greatest capacity and savings. Note that the maximum vehicle load capacity in the sharing vehicle scenario is 60 boxes (1,500 kg).

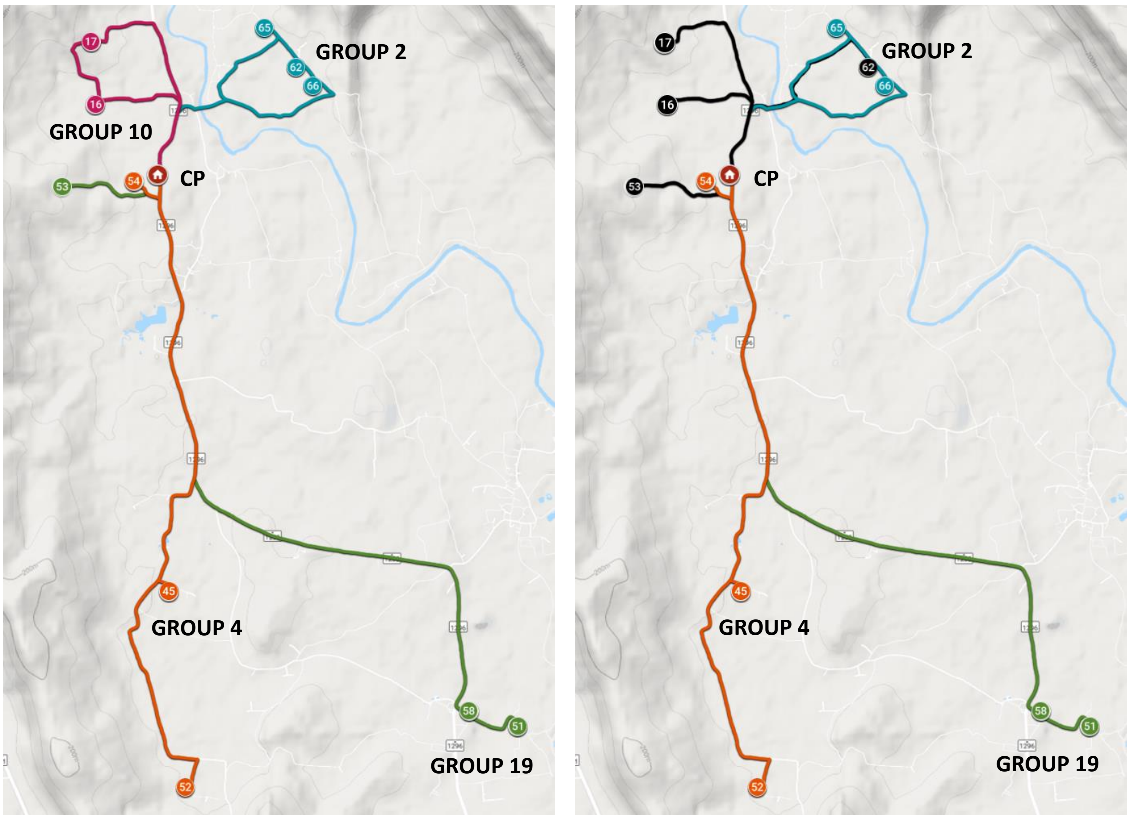
The specific sub-groups can be identified (who would share the vehicle with whom) based on the savings routes generated by the CW saving algorithm. This resulted in 19 sub-groups being identified, where 2-3 farmers work in the same group for moving their product by sharing the vehicle capacity, as shown in Figure 30 (a). However, in the worse-case, 9 out of 49 plantations were assumed to opt out of the collaboration. Figure 30(b) shows the farmers grouped under the vehicle sharing scenario without the large-scale farmers taking part (the plantation in the black circle were opted out). In addition, two or more sub-groups can feasibly be merged, depending on the transport need and quantity of the product to be moved. For example, sub-group 12 (route 39-40-*0*-39 collect) and sub-group 14 (route 73-74-42-*0*-73) can be merged into a single route (73-74-42-40-39-*0*-73) at the beginning of the season when the quantity of the product does not exceed the vehicle load capacity.



(a) grouping with large-scale farms (b) grouping without 9 large-scale farms (black circles)

Figure 30 the 19 sub-groups where the farmers are working together

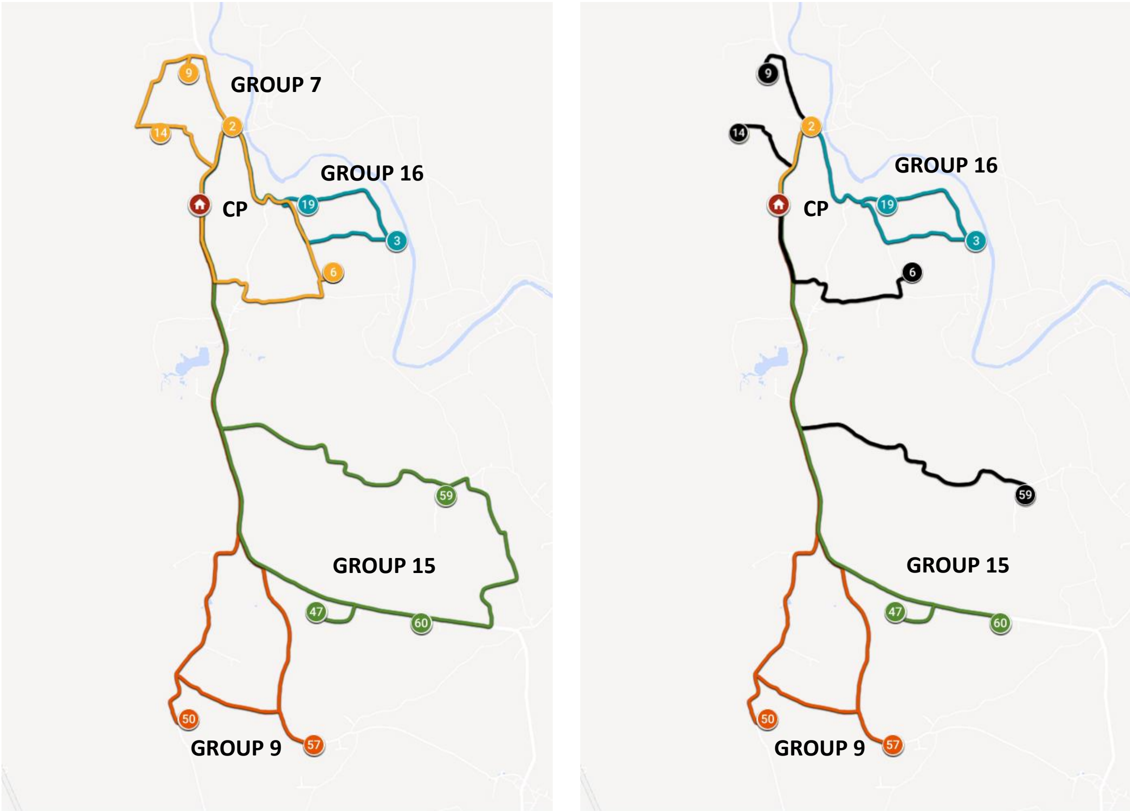
The rural farmers are put into specific sub-groups across the geographical area and then work together such as a vehicle bring shared by three rural farmers in sub-group for moving products from farm to the CP, e.g. farmers 65-62-66-0-65 (where *0* represents the consolidation point). In this case, it is assumed that farmer 65 shared his vehicle capacity with the other two, farmer 62 and farmer 66, to move the products, so farmer 65 used the vehicle load his product before going to pick-up the product at Farm 62 and Farm 66, then going to drop-off the product at the CP (*0*) before returning to his farm. Figure 30(a-b) were used to demonstrate the collection route of each sub-group, for more clearly collection routes the Figure 31 to Figure 36 were illustrated the collection routes for each sub-group of rural farmers.



(a) grouping with large-scale farms (b) grouping without large-scale farms (black circles)

Figure 31 Collection routes of sub-groups 2, 4, 10, and 19

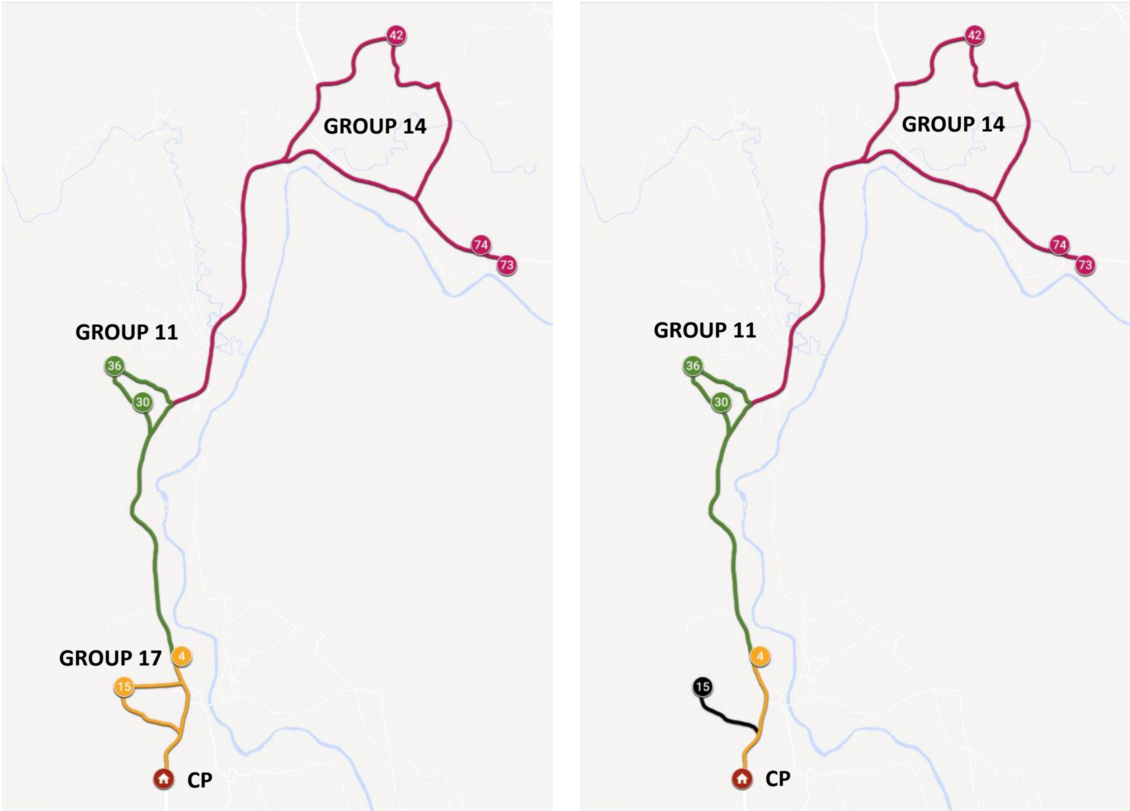
Figure 31(a) shows the sub-groups where rural farmers are sharing a vehicle scenario to move their product from farms to the HL's CP, indicated by the red circle. Bule circle indicate sub-group 2 stops where the farmer 65 shared his vehicle capacity going to pick-up the product at Farm 62 and Farm 66 (65-62-66-*0*-65), a distance travelled of 7.66 km. Orange circles indicate sub-group 4 stops (52-45-54-*0*-52) where farmer 52 being the main driving with a distance travelled of 18.03 km. Pink circles indicate sub-group 10 stops (16-17-*0*-16) where farmer 16 being the main driving, a distance travelled of 7.89 km. Green circles indicate sub-group 19 stops (58-51-53-*0*-58) where farmer 58 being the main driving, a distance travelled of 22.36 km. In Figure 31(b), the large-scale farmers were assumed to opt out of the collaboration scheme by sticking with their current operation. Black circles indicate these farmers 16, 17, 53, and 62.



(a) grouping with large-scale farms (b) grouping without large-scale farms (black circles)

Figure 32 Collection routes of sub-groups 7, 9, 15, and 16

Figure 32(a) shows the collection routes of sub-group 2, 7, 9, and 15. Blue circles indicate sub-group 16 stops (19-3-*0*-19) where farmer 19 being the main driving, a distance travelled of 8.06 km. Yellow circles indicate sub-group 7 stops (9-14-2-*0*-9) where farmer 9 being the main driving, a distance travelled of 5.76 km. Orange circles indicate sub-group 9 stops (50-57-*0*-50) where farmer 50 being the main driving, a distance travelled of 15.30 km. Green circles indicate sub-group 15 stops (47-60-59-*0*-47) where farmer 47 being the main driving, a distance travelled of 17.95 km. In Figure 32(b) the large-scale farmers are assumed to opt out, by sticking with their current operation. Black circles indicate these farmers 6, 9, 14, and 59.



(a) grouping with large-scale farms (b) grouping without large-scale farm (black circle)

Figure 33 Collection routes of sub-groups 11, 14, and 17

Figure 33(a) shows the collection routes of sub-groups 11, 14, and 17. Pink circles indicate sub-group 14 stops (farms 73-74-42-*0*-73) where farmer 73 being the main driving, a distance travelled of 25.66 km. Green circles indicate sub-group 11 stops (farms 36-30-*0*-36) where farmer 36 being the main driving, a distance travelled of 11.28 km. Yellow circles indicate sub-group 17 stops (farms 4-15-*0*-4) where farmer 4 being the main driving, a distance travelled of 4.78 km. Figure 33(b) shows the collection route of sub-group 17 when the large-scale farmer (farm 15) opted out of the collaboration scheme.

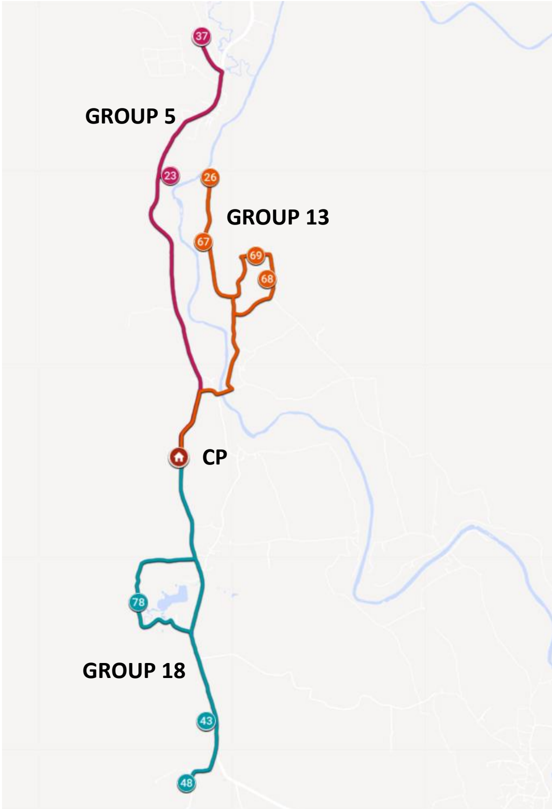


Figure 34 Collection routes of sub-groups 5, 13, and 18

Figure 34 shows the collection routes of sub-groups 5, 13, and 18. Pink circles indicate the sub-group 5 stops (farms 37-23-*0*-37) where farmer 37 being the main driving, a distance travelled of 12.04 km. Orange circles indicate sub-group 13 stops (farms 26-67-69-68-*0*-26) where farmer 26 being the main driving, a distance travelled of 11.37 km. Blue circles indicate sub-group 18 stops (farms 48-43-78-*0*-48) where farmer 48 being the main driving, a distance travelled of 11.55 km.

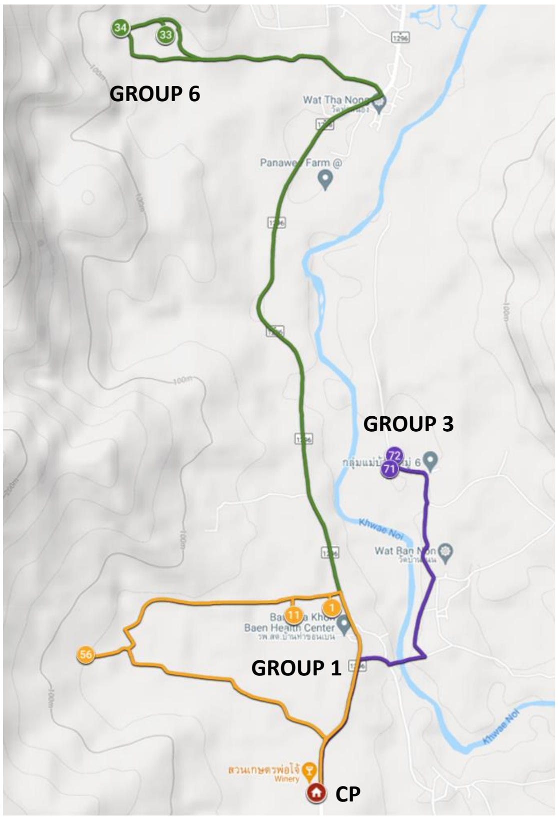


Figure 35 Collection routes of sub-groups 1, 3, and 6

Figure 35 shows the collection routes of sub-groups 1, 3, and 6. Yellow circles indicate sub-group 1 stops (farms 56-11-1-*0*-56) where farmer 56 being the main driving, a distance travelled of 6.95 km. Purple circles indicate sub-group 3 stops (farms 72-71-*0*-72) where 72 being the main driving, a distance travelled of 5.61 km. Green circles indicate sub-group 6 stops (farms 34-33-0-34) where farmer 34 being the main driving, a distance travelled of 12.33 km.

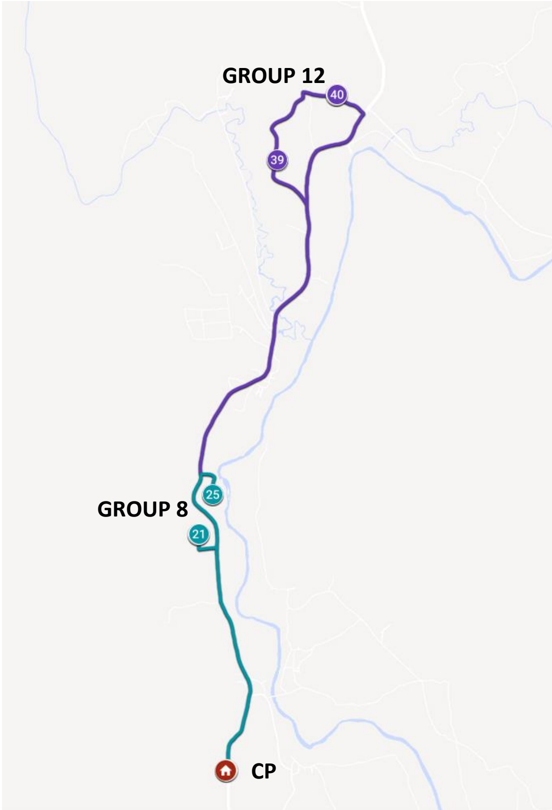


Figure 36 Collection routes of sub-groups 8 and 12

Figure 36 shows the collection routes of sub-groups 8 and 12. Blue circles indicate sub-group 8 stops (farms 25-21-*0*-25) where farmer 25 being the main driving, a distance travelled of 8.11 km. Purple circles indicate sub-group 12 stops (farms 40-39-*0*-40) where farmer 40 being the main driving, a distance travelled of 18.03 km.

Table 18 shows the potential routes plan data, for the 4-day operation from 12 March 2018 and 15 March 2018, that were determined by the CW saving algorithm when the rural farmers agreed to share their vehicle capacity. In addition, the 'worst-case' situation was also considered, where the large-scale farmers opted out of the collaboration and stuck with their current operation strategy, in this case, the large-scale farmer 6, 9, 14,15,16,17, 53, 59, and 62 who produced over 120 boxes of M1 and M2 mangoes.

The key results suggested that the sharing vehicle scenario by using CW saving algorithm, where all the farmers agree to share their vehicle load capacity and work together in Figure 30 sub-groups, reduced the number of vehicles needed by 16% (n=49) and 24% (n=89) on the vehicles visit to farms, with a 24% reduction in total distance travelled. This made a 24% reduction on the total transportation cost, but this reduced only 2% when the cost of product waste was also considered. In addition, vehicle sharing improved the vehicle utilisation by a reduction of 79% of empty box space (without any load), and a reduction of 24% on time spent on driving. In term of environmental benefit, the total CO_2 emissions was reduced by 17%.

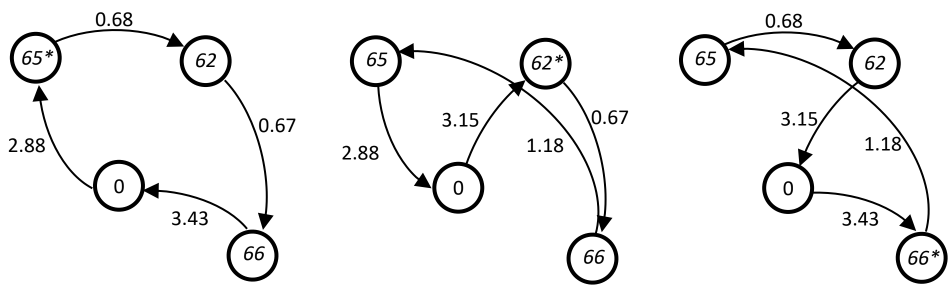
However, in the worst-case when large-scale farmer 6, 9, 14,15,16,17, 53, 59, and 62 opted out of the collaboration, the vehicle sharing scenario realised a 23% reduction on the total distance travelled. The number of vehicles needed gave a 16% reduction similar to the previous case, but the number of vehicles visit to farms was reduced by only 20% (4% lower compared with the best-case situation). These made a 23% reduction on the total transportation cost, and again 2% when the cost of product waste during transit was included. The sharing vehicle scenario increased the vehicle utilisation by reduced 15% of the total empty box space running, and the time spent driving by 23%. Also, the total CO_2 emissions reduced by 15% (2% behind the best-case), more details please find from the appendix B.

When using the VRP Spreadsheet Solver, the key results in Table 18 produced very similar results when compared to the CW saving algorithm. The number of vehicles involved reduced by 12%, and 19% on the vehicles visit to farms, with a 20% reduction in total distance travelled (698 to 559 km). In this case, the total transportation reduced by 20% from 3,366 (£86) THB to 2,695 THB (£68), and only 2% when the cost of product waste was also considered (when the product wastage rate was at 2%). In addition, the VRP spreadsheet solver improved the vehicle utilisation by reducing empty box space by 64% (from 1,587 to 567 boxes), and a reduction of 16% in the total CO_2 emissions (from 192 to 161 $kgCO_2$/tonne-km).

Table 18 The transportation routes from 12-15 March 2018 when farmers agree to share their vehicles

Collection routes between 12-15 March 2018	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
Business-as-Usual operations	**49**	**89**	**3753**	**93112**	**698.43**	**34.92**	**1862.24**	**37244.80**	**3366.43**	**40611.23**	**1587**	**192.40**
Sharing vehicle (best-case) (CW algorithm)	41	68	3753	93112	529.27	26.46	1862.24	37244.80	2551.08	39795.88	327	159.02
Net reduction (compared to BAU)	8	21	0	0	169.16	8.46	0	0	815.35	815.35	1260	33.38
	(16%)	**(24%)**	-	-	**(24%)**	**(24%)**	-	-	**(24%)**	**(2%)**	**(79%)**	**(17%)**
Sharing vehicle (worst-case) (CW algorithm)	41	71	3753	93112	539.28	26.96	1862.24	37244.80	2599.33	39844.13	507	162.86
Net reduction (compared to BAU)	8	18	0	0	159.15	7.96	0	0	767.10	767.10	1080	29.55
	(16%)	**(20%)**	-	-	**(23%)**	**(23%)**	-	-	**(23%)**	**(2%)**	**(68%)**	**(15%)**
Sharing vehicle (VRP solver)	43	72	3753	93112	559.15	27.96	1862.48	37244.80	2695.10	39933.70	567	161.44
Net reduction (compared to BAU)	6	17	0	0	139.28	6.96	0	0	2695.10	666.53	1020	30.96
	(12%)	(19%)	-	-	(20%)	(20%)	-	-	(20%)	(2%)	(64%)	(16%)

Although the optimal route plan given by the CW saving algorithm performed well, different contingency options must also be considered such as which farmer shares their vehicle and what happens when the vehicle is in for service and another farmer has to step to provide the transport? Figure 37 shows when different farmers are the main driver in sharing their vehicle capacity.



(a) farmer 65 (b) farmer 62 (c) farmer 66

Figure 37 The collection route for sub-group 2 (farms 62, 65, and 66) when a different farmer shares their vehicle capacity

Figure 37(a) shows the collection route of sub-group 2 when farmer 65 is the main driver sharing their vehicle with farmers 62 and 66 to move products from the farms to the CP. In this situation, 46 boxes (1,080 kg of M1 and M2 mangoes were collected), generating a total distance travelled of 7.66 km at a cost of 36.92 THB (£0.94), and producing 1.78 kgCO_2/tonne-km of CO_2 emission, and total driving time at 0.38 hour. However, when farmer 62 is the main driver sharing his vehicle, Figure 37(b), the total distance travelled was 7.88 km at a cost of 37.98 THB (£0.97) and producing 1.83 kgCO_2/tonne-km of CO_2 emission, with a total driving time of 0.39 hour. When farmer 66 is the main driver sharing his vehicle capacity, Figure 37(c), the total distance travelled was 8.44 km with a cost of 40.68 THB (£1.04) and producing 1.96 kgCO_2/tonne-km of CO_2, with a total driving time of 0.42 hour. Table 19 compare farmers sharing vehicles in different situations.

Table 19 The different options when the different farmers being main driver on 15 March 2018

Options	VF_{inv}	Q_{box}	D_{tv}	T_{dri}	TC_{own}	ER_{box}	EM_{CO2}
BAU scenario (farmers 62, 65, 66)	**3**	**46**	**18.90**	**0.94**	**91.10**	**134**	**3.90**
Farm 65* - Farm 62 - Farm 66 - CP - Farm 65	1	46	7.66	0.38	36.92	14	1.78
Net reduction (opt 1)	**2** (66%)	-	**11.24** (59%)	**0.56** (59%)	**54.18** (59%)	**120** (90%)	**2.11** (54%)
Farm 62* - Farm 66 - Farm 65 - CP - Farm 62	1	46	7.88	0.39	37.98	14	1.83
Net reduction (opt 2)	**2** (66%)	-	**11.02** (58%)	**0.55** (58%)	**53.12** (58%)	**120** (90%)	**2.07** (53%)
Farm 66* - Farm 65 - Farm 62 - CP - Farm 66	1	46	8.44	0.42	40.68	14	1.96
Net reduction (opt 3)	**2** (66%)	-	**10.46** (55%)	**0.52** (55%)	**50.42** (55%)	**120** (90%)	**1.94** (50%)

* The farmer who does the driving

Table 19 indicates that the driving time and the total CO_2 emission for the collection route varies with distance travelled, as a result for different farmers being the main driver and sequencing collections. In addition, the total transportation cost is slightly different between each option compared with the BAU scenario. This confirms that the CW saving algorithm is sufficient effective, even in the situation where the different farmers are driving. Although there is not must difference in terms of the transportation impacts from each farmer in the group being the main driver. However, the farmer who loads their products on the vehicle first (the driver) is always likely to sustain the most product damage because the mangoes will have been on the lorry for longer. The data from the group discussions shows that the rural farmers also concerned about the likely increased damaged that might be incurred to the farmer who loaded their product onto the vehicle first, once all the other was added on top of it. This is another key challenge that should be considered when implementing the collaborative transportation schemes.

When using the VRP Spreadsheet Solver, the key results in Table 20 suggested that the number of vehicles involved reduced by 36%, and 35% in term of vehicle visits to farms, with a 34% reduction in total distance travelled (from 6,415 to 4,206 km). If one looks at only the transportation cost, the result suggested that the cost was reduced by 34% (30,922 THB (£790) to 20,274THB (£518)), and reduced by only 4% when the cost of product wastage was also considered (at 2% of product wastage). In addition, vehicle sharing scenario when using the VRP Spreadsheet Solver improved the vehicle utilisation by reducing empty box space by 68% (from 23,944 to 7,744 boxes) and reducing CO2 emissions by 24% (from 1,537 to 1,161 kgCO2/tonne-km).

Table 20 gives a summary of the key results when farmers agreed to share the vehicle over the whole season (48 days operation). The first column specifies the different scenarios and proposed operating scenarios both best-case and worst-case scenarios, while the remaining columns indicate factors that used to quantify the potential benefits. These suggest that the scenario in which vehicles are shared through a farmer co-operative reduced the total distance travelled over the 48 days (7-month) period of operation between 18 December 2017 and 04 June 2018 by 36% (from 6,415 to 4,083 km), and the total CO_2 emissions by 28% (from 1,537 to 1,101 kgCO_2/tonne-km). The number of vehicles involved was reduced by 40%, and the number of vehicles visits to the farms by 41%, which reduced the total transportation cost by 36% from 30,922 THB (£790) to 19,681THB (£503). In addition, the total time spent on driving reduced by 36% (from 320 to 204 hours).

In addition, the sensitivity on how the benefits of each potential operating scenario will change with changes in the levels of product wastage as well as the cost savings of collaborative transport if changes in the levels of farmers joining in the collaboration scheme (see in section 3.3.2). The sensitivity analysis in Table 7 shows the benefits of using light pick-up vehicle (sharing vehicle scenario) when changing the levels of product wastage. The results suggested that the total cost was reduced by 8% when the product was damaged by 1%, and the total cost was reduced by 4% when the product wastage increased up to 2%, and by 2% and 1% when the product wastage rates were changed up to 5% and 10%, respectively.

In the worst-case scenario, where the large-scale farmers were not willing to co-operate, 9 out of 49 farmers (18%), who produced 51% of the M1 and M2 mangoes, were assumed to opt out. The vehicle sharing scenario realised a 35% reduction of the total distance travelled over the BAU (from 6,415 to 4,185 km) and 25% reduction in CO_2 emissions (from 1,537 to 1,159 kgCO_2/tonne-km). The number of vehicles needed was reduced by 39%, and 36% reduction in the number of vehicles visit to farms, making the reduction on overall transportation cost by 35% from 30,922 THB (£790) to 20,175 THB (£516). In addition, the time spent on driving reduced by 35% (from 320 to 209 hours).

When using the VRP Spreadsheet Solver, the key results in Table 20 suggested that the number of vehicles involved reduced by 36%, and 35% in term of vehicle visits to farms, with a 34% reduction in total distance travelled (from 6,415 to 4,206 km). If one looks at only the transportation cost, the result suggested that the cost was reduced by 34% (30,922 THB (£790) to 20,274THB (£518)), and reduced by only 4% when the cost of product wastage was also considered (at 2% of product wastage). In addition, vehicle sharing scenario when using the VRP Spreadsheet Solver improved the vehicle utilisation by reducing empty box space by 68% (from 23,944 to 7,744 boxes) and reducing CO_2 emissions by 24% (from 1,537 to 1,161 kgCO_2/tonne-km).

Table 20 Summary of vehicle sharing scenario in comparison to BAU over 48 days of operation

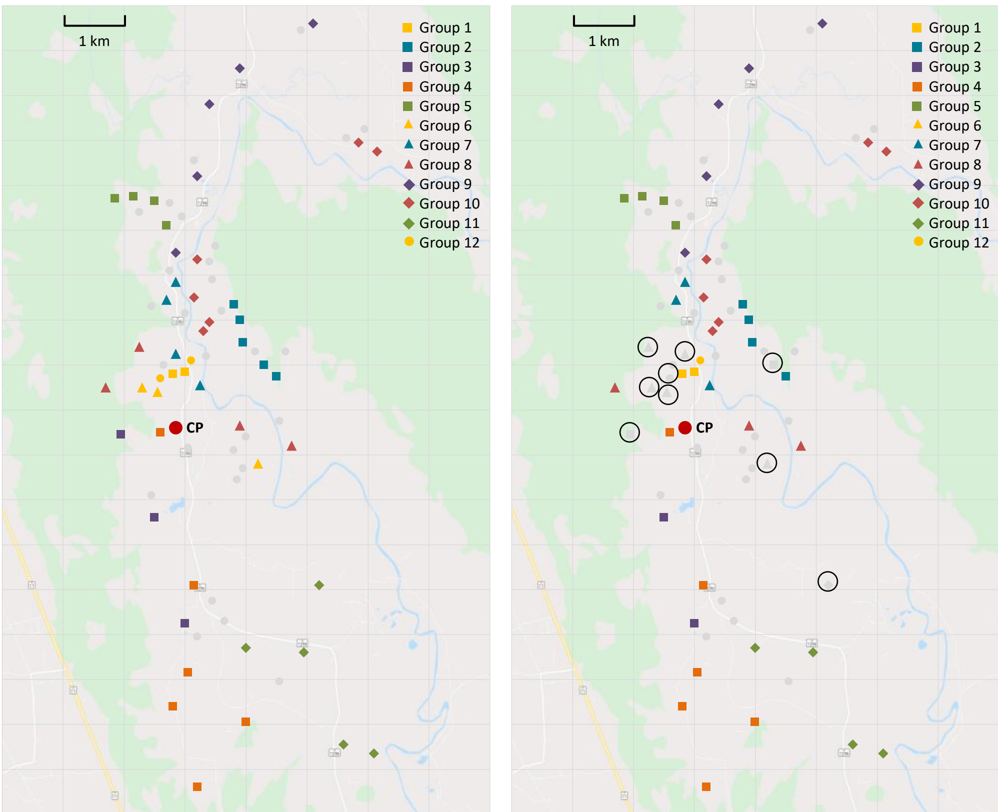
Scenario	VF_{inv}	VF_{vis}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}	CT_{min}
BAU	588	770	6415.38	320.77	10958	219164	30922	250086	23944	1537	
Sharing vehicle (Best-case)	355	459	4083.15	204.16	10958	219164	19681	238845	5284	1101	9.00
Net Reduction	**242** (41%)	**331** (40%)	**2332.23** (36%)	**6996.69** (36%)	**0** -	**0** -	**11241** (36%)	**11241** (4%)	**18660** (78%)	**436** (28%)	
Sharing vehicle (Worst-case)	358	492	4185.69	209.2	10958	219164	20175	239339	7264	1159	8.50
Net Reduction	**230** (39%)	**278** (36%)	**2229.69** (35%)	**111.48** (35%)	**0** -	**0** -	10747 (35%)	**10747** (4%)	**16680** (70%)	**378** (25%)	
Sharing vehicle (VRP solver)	376	500	4206.37	210.32	10958	219164	20274.70	239448.30	7744	1161	24.00
Net reduction	**213** **(36%)**	**270** **(35%)**	**2209.01** **(34%)**	**110.45** **(34%)**	**0** -	**0** -	**10647.43** **(34%)**	**10637.83** **(4%)**	**16200** **(68%)**	**375** **(24%)**	

The results of the case studied suggested that an operation where the vehicles are shared between groups of farmers when using CW saving algorithm clearly produced operational benefits by reducing the number of vehicle invloved and number of vehicles visit to farms, which is likely to reduce the total distance travelled and overall transportation cost, and also improve the vehicle utilisation by minimising the number of empty box space running. The results of the case study shows the potential environmental benefits of sharing vehicles by groups of farmers. However, using the farmer's own vehicles does not address the problem of product waste due to a lack of refrigeration. Therefore, a Third-party refrigerated vehicle making a milk-round collection was considered, and the results are presented in Section 5.2.

5.2 Third-Party Logistics Provider Making a Milk-round Collection

Section 3.3.2 described the case of using a Third-party logistics provider to make a milk-round collection. Three different cases were explored, with two different types of vehicles used and were evaluated against the BAU case to quantify any improvement in transportation efficiency and reduction in the product waste during transportation. These cases are: a light refrigerated vehicle, or a 20ft refrigerated vehicle are used separately, or both simultaneously on the same route. The vehicles in these potential operating scenarios have different maximum load capacities, where the light refrigerated vehicle has a mean load capacity of 100 boxes (2,500 kg), while the 20ft refrigerated vehicle has 200 boxes (5,000 kg).

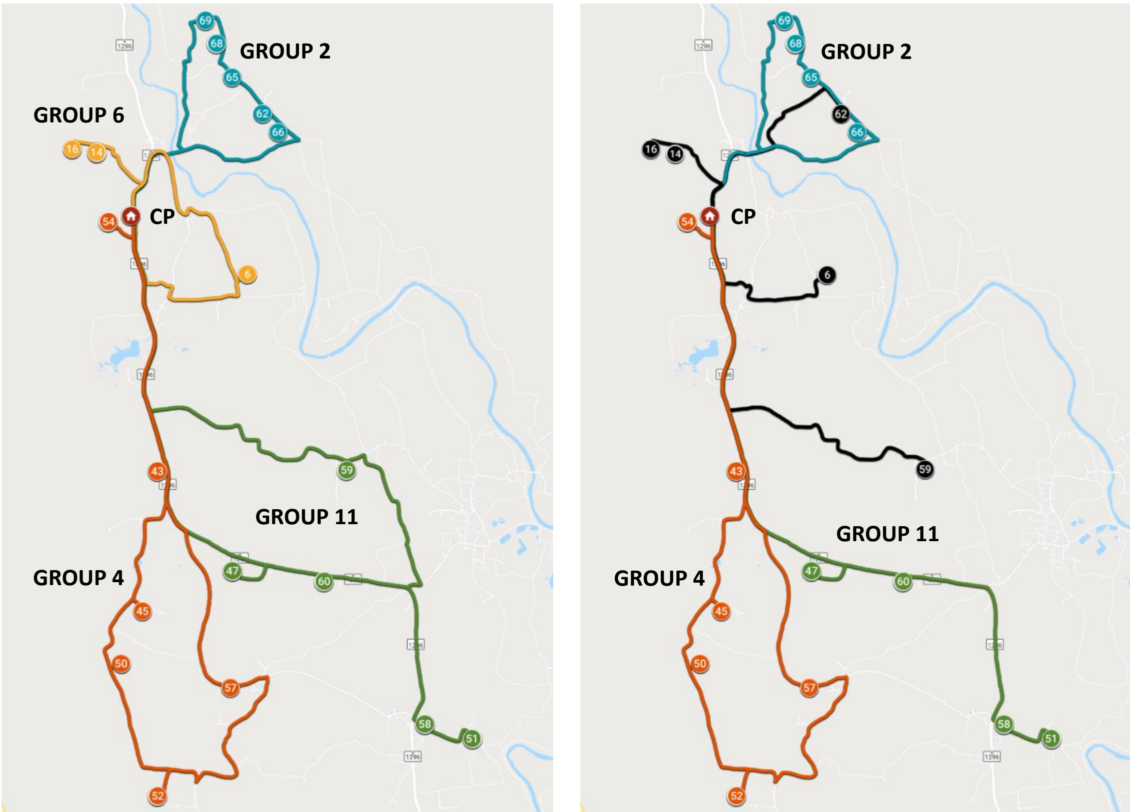
The rural farmers can be grouped into 12 sub-groups, as shown in Figure 38(a), while Figure 38(b) shows the farmer’s groups without 9 large-scale farms who opt out of the collaborations and stick with the current operation strategy. The rural farmers in the specific sub-groups were served by a Third-party refrigerated vehicle, where the products being collected from the rural farmers and dropped at the CP.



(a) grouping with large-scale farms (b) grouping without 9 large-scale farms

Figure 38 the 12 sub-groups served by Third-party refrigerated vehicles

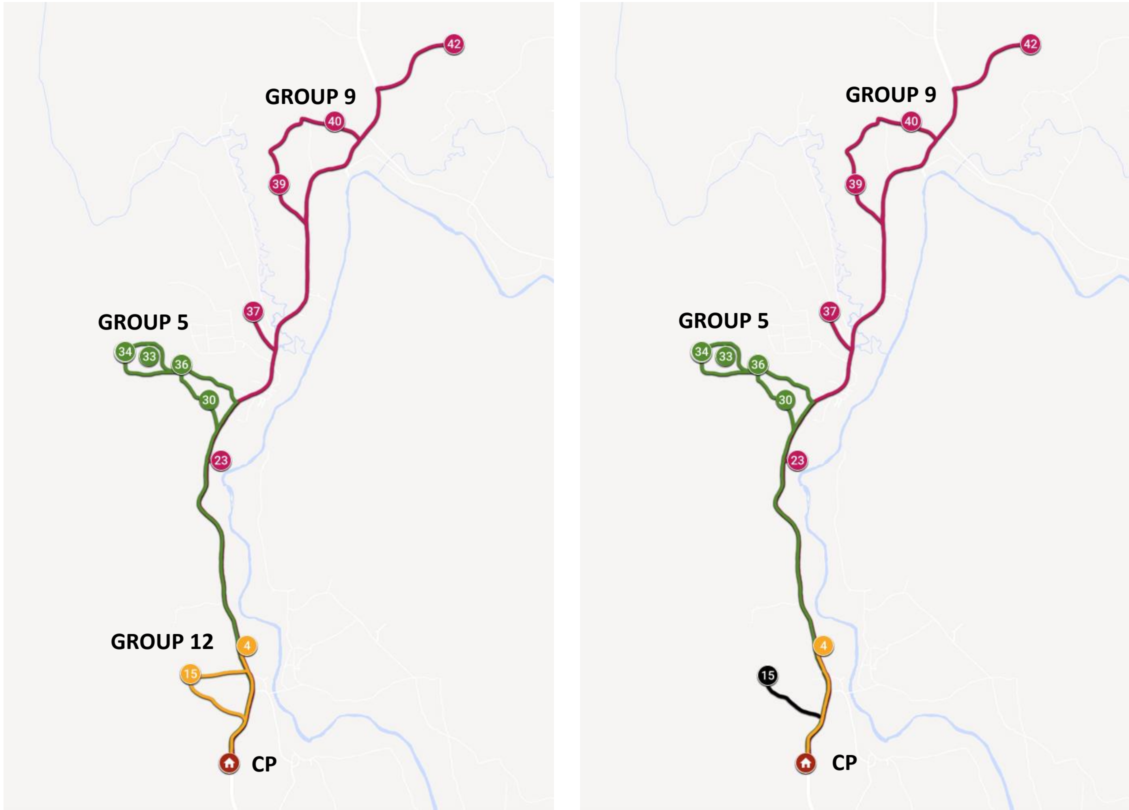
Appropriate light refrigerated and 20ft refrigerated vehicles, designed to transport perishable foods, were used to find a feasible set of vehicle routes that minimised the total travelling distances and the total number of vehicle visits to farms so that each farmer's demand was satisfied, as well as to address the problem of product waste during the transport. For example, a Third-party refrigerated vehicle would serve three farmers in sub-group *0*-65-62-66-*0*. In this case Third-party refrigerated vehicle was used to make milk-round collection, where the vehicle started from the CP going to pick-up the product at farms 65, 62, and 66 then returning to drop-off the product at the CP again.



(a) grouping with large-scale farms (b) grouping without large-scale farms (black circles)

Figure 39 Collection routes of sub-groups 2, 4, 6 and 11

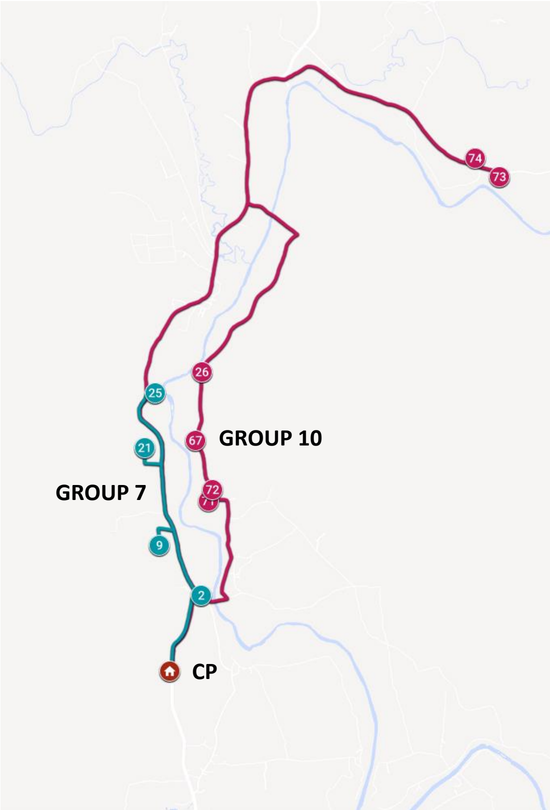
Figure 39(a) shows the collection routes of sub-groups 2, 4, 6 and 11. Blue circles indicate sub-group 2 stops (*0*-69-68-65-62-66-*0*), a distance travelled of 10.22 km. Yellow circles indicate sub-group 6 stops (*0*-16-14-6-*0*), a distance travelled of 11.28 km. Orange circles indicate sub-group 4 stops (*0*-57-52-50-45-43-54-*0*), a distance travelled of 20.32 km. Green circles indicate sub-group 11 stops (*0*-59-51-58-60-47-*0*), a distance travelled of 27.38 km. The black circles indicate the large-scale farmers 6, 14, 16, 59, and 62, who opted out of the collaboration as presented in Figure 39(b).

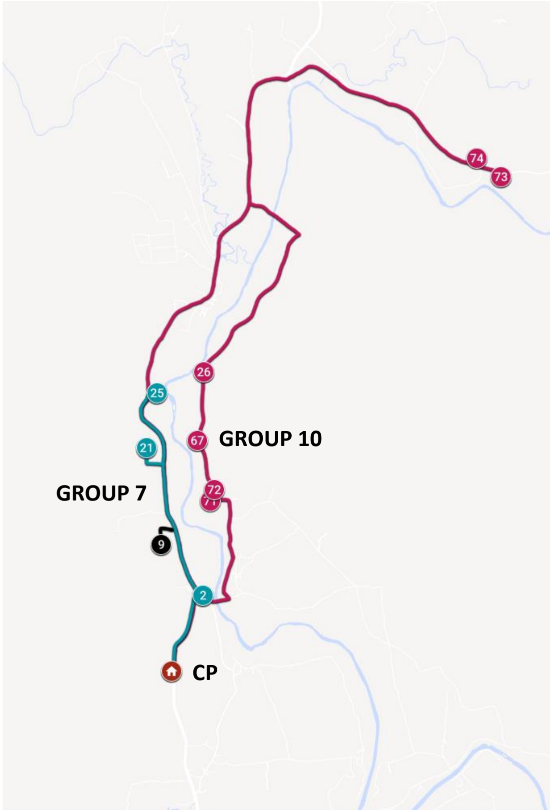


(a) grouping with large-scale farms (b) grouping without large-scale farms (black circles)

Figure 40 Collection routes of sub-groups 5, 9, and 12

Figure 40(a) shows the collection routes of sub-groups 5, 9, and 12. Pink circles indicate sub-group 9 stops (*0*-42-40-39-37-23-*0*), a distance travelled of 23.16 km. Green circles indicate sub-group 5 stops (*0*-36-34-33-30-*0*), a distance travelled of 12.88 km. Yellow circles indicate sub-group 12 stops (*0*-15-4-*0*), a distance travelled of 4.78 km. Figure 40(b) shows the sub-group of farmers without large-scale farmer 15.

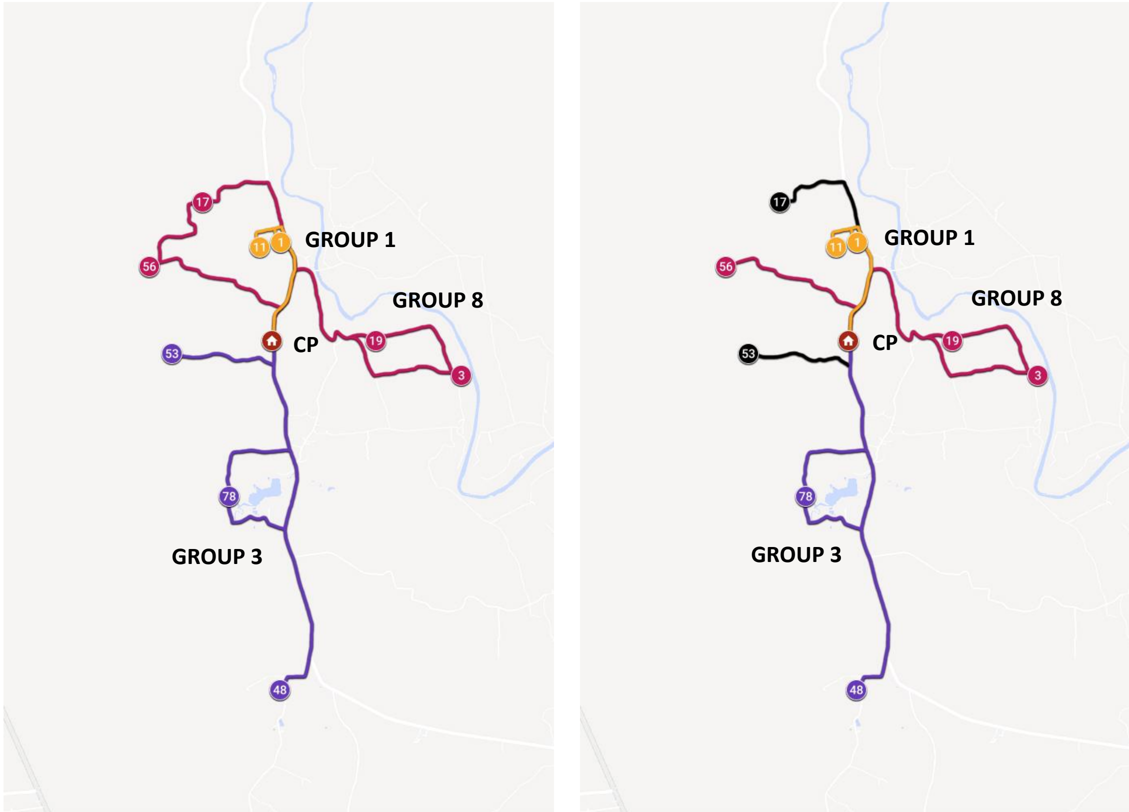




(a) grouping with large-scale farms (b) grouping without large-scale farms (black circles)

Figure 41 Collection routes of sub-groups 7, 10

Figure 41(a) shows the collection routes of sub-groups 7, and 10. Pink circles indicate sub-group 10 stops (*0*-74-74-26-67-72-71-*0*), a distance travelled of 28.48 km. Blue circles indicate sub-group 7 stops (*0*-25-21-9-2-*0*), a distance travelled of 9.10 km. Figure 41(b) shows sub-group 7 is (*0*-25-21-2-*0*), without the large-scale farmer 9 who opted out, with a distance travelled of 8.31 km.



(a) grouping with large-scale farms (b) grouping without large-scale farms (black circles)

Figure 42 Collection routes of sub-groups 1, 3, and 8

Figure 42(a) shows the collection routes of sub-groups 1, 3, and 8. Pink circles indicate sub-group 8 stops (*0*-56-17-19-3-*0*), a distance travelled of 15.84 km. Yellow circles indicate sub-group 1 stops (*0*-11-1-*0*), a distance travelled of 3.44 km. Purple circles indicate sub-group 3 stops (*0*-48-78-53-*0*), a distance travelled of 14.38 km. When the large-scale farmers farms 17 and 53 were opted out of the collaboration, the collection route in sub-group 8 shown in Figure 42(b) is (*0*-56-19-3-*0*), a distance travelled of 13.12 km. The collection route of sub-group 3 when only farmer 53 was opted out is (*0*-48-78-*0*), a distance travelled of 11.18 km.

5.2.1 Light Refrigerated Vehicle Milk-round Collections Scenario

Using a Third-party refrigerated vehicle to make milk-round collection, the CW saving algorithm was applied to find the optimal route plans on 12-15 March 2018. Table 21 shows that the implementation of this scenario reduced the distance travelled by 46%, with a 19% reduction in the total CO_2 emissions. In this case, 32 light refrigerated vehicles were used to collect 3,753 boxes of M1 and M2 mangoes, instead of using 49 light pick-up (farmer owned) vehicles. This realises a 35% reduction in the total number of vehicles needed and reduced the number of vehicle visits to farms by 53%. Although this scenario increased the transportation cost by 250%, from 3,366 THB (£86) to 11,782 THB (£301), but when the cost of product waste (the opportunity of lost sale) is taken into account, the cost is reduced by 71%. This assuming that the refrigerated vehicle produces the benefit in terms of saved product (the reduction of wastage), the rural farmers gained the additional revenue from selling those products. In addition, the vehicle utilisation improved with a 72% reduction on the empty box space running.

Addressing the worst-case situation, where 9 large-scale farmers opted out of the collaboration, 22 light refrigerated vehicles would be needed to serve the specific sub-groups without the large-scale farmers. Note that the products from the large-scale farms were moved by 9 light pick-up vehicles. Therefore, the number of vehicles needed was reduced by 37%, while the number of vehicles visit to farms reduced by 35%. This made a 35% reduction in the total distance travelled, and a 13% reduction in the total CO_2 emissions. The transportation cost increased by 168% from 3,366 THB (£86) to 9,035 THB (£230) but achieved a 30% reduction in the overall cost when the cost of product waste during transit was included. In addition, vehicle utilisation was improved with 73% reduction in the empty box space running when compared to the BAU scenario.

In addition, the key results in Table 21 suggested that when assigning a Third-party light refrigerated vehicle, the VRP Spreadsheet Solver produced very similar results compared to the CW saving algorithm. The number of vehicles involved was reduced by 29%, and 47% on the vehicle visits to farms, with a 44% reduction in total distance travelled (from 698 to 391 km). In this case, the total transportation increased by 288% from 3,366 THB (£86) to 13,055 THB (£333) if the product wastage rate was 0%. However, the benefit when assigning light refrigerated vehicle achieved a 60% reduction in the overall cost when the cost of product waste was also considered (at 2% from the product wastage rate). In addition, the VRP spreadsheet solver improve vehicle utilisation by reducing empty box space by 40% (from 1,587 to 947 boxes), and reducing CO_2 emissions by 12% (from 192 to 169 $kgCO_2$/tonne-km).

Table 21 The transportation routes from 12-15 March 2018 when using a Third-party light refrigerated vehicle to make a milk-round collection

Collection routes between 12-15 March 2018	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
Business-as-Usual operations	**49**	**89**	**3753**	**93112**	**698.43**	**34.92**	**1862.24**	**37244.80**	**3366.43**	**40611.23**	**1587**	**192.40**
Using light refrigerated vehicles (best-case)	32	42	3753	93112	376.78	18.84	0	0	11782.02	11782.02	447	155.94
Net reduction (compared to BAU)	17 **(35%)**	47 **(53%)**	0 -	0 -	321.65 **(46%)**	16.08 **(46%)**	1862.24 **(100%)**	37244.80 **(100%)**	8415.59 **(250%)**	28829.21 **(71%)**	1140 **(72%)**	36.46 **(19%)**
Using light refrigerated vehicles (worst-case)	31	58	3753	93112	452.19	22.61	968.04	19360.80	9035.79	28396.59	607	166.53
Net reduction (compared to BAU)	18 **(37%)**	31 **(35%)**	0 -	0 -	246.24 **(35%)**	12.31 **(35%)**	894.20 **(48%)**	17884.00 **(48%)**	5669.36 **(168%)**	12214.64 **(30%)**	980 **(62%)**	25.87 **(13%)**
Sharing vehicle (VRP solver)	35	47	3753	93112	391.52	19.58	0	0	13055.16	16055.16	947	169.42
Net reduction (compared to BAU)	**14** **(29%)**	**42** **(47%)**	**0** **-**	**0** **-**	**306.91** **(44%)**	**15.35** **(44%)**	**1862.24** **(100%)**	**37244.80** **(100%)**	**9688.73** **(288%)**	**24556.07** **(60%)**	**640** **(40%)**	**22.98** **(12%)**

Table 22 shows that the implementation of the Third-party light refrigerated vehicle milk-round collection over 48 days (7-month) operation reduced the total travelled distances by 51% (from 6,415 to 3,116 km) with a 22% reduction in the total CO_2 emissions (from 1,537 to 1,197 $kgCO_2$/tonne-km). The number of vehicles involved in the operation was reduced by 57%, and 63% reduction on the number of vehicles visit to farms (from 770 to 287 round trips). Although if focus only the transportation cost, the result suggested that the transportation cost increased by 206% from 30,922 THB (£790) to 94,768 THB (£2,422), when the product wastage rate at 0%. However, the products were moved in the correct way in BAU operations. This assuming that the reduction of wastage could benefit in terms of additional revenue from selling those products (based on the opportunity of lost sale, 20 THB per kg). Thus, the overall cost reduced by 62% when the cost of product wastage was factored in (at 2% of product wastage). In addition, assigning the Third-party light refrigerated vehicle improved the vehicle utilisation by reducing the number of empty box space running by 73%, as well as the overall time spent on driving was reduced by 51% (320 to 156 hours). The sensitivity analysis in Table 7 shown the benefits when assigning light refrigerated vehicle changes in the levels of product wastage. The results suggested that the total cost was reduced by 33% when the product damaged rate was at 1% and the total cost changed to 62% when the product wastage increased up to 2%, and the total cost increased to 84% and 92% when product wastage rates were changing up to 5% and 10%, respectively.

In the worst-case scenario, the total travelled distance was reduced by 43% (from 6,415 to 3,638 km), leading to a 21% reduction on the total CO_2 emissions (from 1,537 to 1,220 $kgCO_2$/tonne-km). In this case, the number of vehicles needed was reduced by 54% (from 588 to 273), and 47% (from 770 to 405) reduction on the number of vehicles visit to farms. In this case, the transportation cost increased from 30,922 THB (£790) to 70,078 THB (£1,791) but reduced 26% on the overall cost when the cost of product waste is included. In addition, empty box space running reduced by 64% and the time spent on driving was reduced by 43% (320 to 181 hours).

When using the VRP Spreadsheet Solver, the key results in Table 22 suggested that the number of vehicles involved reduced by 55%, and 62% on the vehicle visits to farms, with a 50% reduction in total distance travelled (from 6,415 to 3194 km). If one looks at only the transportation cost, the result suggested that the cost was increased by 246% from 30,922 THB (£790) to 107,011 THB (£2,735) but reduced by 57% in the overall cost when the cost of product wastage was also considered. In addition, assigning the light refrigerated vehicle when using VRP spreadsheet solver improve the vehicle utilisation by reduction of 53% of empty box space (from 23,944 to 11,244 boxes), and a reduction of 21% on the total CO_2 emissions (from1,537 to 1,211 $kgCO_2$/tonne-km).

Table 22 Summary of using a 3rd party light refrigerated vehicle to make milk-round collection scenario compared to the BAU over 48 days of operation

Scenario	VF_{inv}	VF_{vis}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}	CT_{min}
BAU	588	770	6415.38	320.77	10958	219164	30922	250086	23944	1537	
3rd light refrigerated vehicle (Best-case)	255	287	3116.41	155.82	0	0	94768	94768	6444	1197	7.40
Net Reduction	**333** (57%)	**483** (63%)	**3298.97** (51%)	**164.95** (51%)	**10958** (100%)	**219164** (100%)	**63846** (206%)	**155318** (62%)	**17500** (73%)	**340** (22%)	
3rd light refrigerated vehicle (Worst-case)	273	405	3638.03	181.90	5698	113962	70078	184040	8644	1220	8.00
Net Reduction	**315** (54%)	**365** (47%)	**2777.35** (43%)	**138.87** (43%)	**5260** (48%)	**105202** (48%)	**39156** (127%)	**66046** (26%)	**15300** (64%)	**317** (21%)	
Sharing vehicle (VRP solver)	266	291	3194.22	160.21	0	0	107011	107011	11244	1211	24.00
Net reduction	**323 (55%)**	**479 (62%)**	**3221.16 (50%)**	**160.56 (50%)**	**10958** (100%)	**219164** (100%)	**76088 (246%)**	**143075 (57%)**	**12700 (53%)**	**325 (21%)**	

The results suggest that a Third-party light refrigerated vehicle operation incurs environmental benefits from reduced CO_2 emissions and the total distance travelled, and also operational benefits from the reduced number of vehicles needed and vehicles visit farms, which is likely to improve vehicle utilisation. An advantage of this scenario is the appropriate vehicle for the collection of a perishable product such mangoes, and likely to reduce the product waste during transport.

5.2.2 20ft Refrigerated Vehicle Milk-round Collection Scenario

This case is similar to the previous one, but with a maximum load capacity at 200 boxes (5,000 kg). The 20ft refrigerated vehicle has the greatest load capacity and is the largest vehicle that can possibly access the plantations due to geographical barrier and the restricts road condition (rural road networks). Again, the CW saving algorithm was applied to find the optimal route plans on 12-15 March 2018.

Table 23 shows that the implementation of this scenario reduced the total distance travelled by 65%, with a 21% of the total CO_2 emissions. In this case, the 21 20ft refrigerated vehicles were used to collect 3,753 boxes of M1 and M2 mangoes, instead of using 49 light pick-up vehicles (farmer owned). This results in a 57% reduction in the number of vehicles needed and a 74% reduction in the number of vehicles visit to farms. Similarly with the previous scenario, the transportation cost increased by 203% over the BAU case, from 3,366 THB (£86) to 10,198 THB (£260). However, the refrigerated vehicle produces the benefit in terms of reduced product wastage, as well as the rural farmers could gained the additional revenue from selling those products at premium price grade. Thus, the overall cost was reduced 75% when the cost of product waste during transport was considered. Other advantage of refrigerated vehicle scenario was the likely reduction in product waste during the transportation, which in turn can gained additional revenue from selling those products at premium price grade. In addition, vehicle utilisation improved with a 47% reduction on the empty box space running, as and the time spent on driving reduced by 65% (34.92 to 22.61 hours).

Addressing the worst-case situation, without the 9 large-scale farmers, the total distance travelled reduced by 47%, with a 13% reduction in the total CO_2 emissions. Fourteen 20ft refrigerated vehicles were used to serve the sub-groups without 9 large-scale farmers, while the remaining of the produce from the large-scale farms were moved using their own 9 light pick-up vehicles. The reduction in the number of vehicles needed was 53%, while the saving was 44% on the total number of vehicles visit to farms (30% behind the best-case). The transportation cost increased by 133%, but when cost of product waste during transport is considered, the cost reduced by 33%. Vehicle utilisation was improved with 24% reduction in the empty box space running, and 47% reduction on time spent on driving.

Table 23 The transportation routes from 12-15 March 2018 when using a Third-party 20ft refrigerated vehicle to make a milk-round collection

Collection routes between 12-15 March 2018	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
Business-as-Usual operations	**49**	**89**	**3753**	**93112**	**698.43**	**34.92**	**1862.24**	**37244.80**	**3366.43**	**40611.23**	**1587**	**192.40**
Using 20ft refrigerated vehicles (best-case)	21	23	3753	93112	246.20	12.31	0	0	10198.86	10198.86	847	151.35
Net reduction (compared to BAU)	28 **(57%)**	66 **(74%)**	0 -	0 -	452.23 **(65%)**	22.61 **(65%)**	1862.24 **(100%)**	37244.80 **(100%)**	6832.43 **(203%)**	30412.37 **(75%)**	740 **(47%)**	41.06 **(21%)**
Using 20ft refrigerated vehicles (worst-case)	23	50	3753	93112	370.81	18.54	968.04	19360.80	7858.82	27219.62	1207	167.23
Net reduction (compared to BAU)	26 **(53%)**	39 **(44%)**	0 -	0 -	327.62 **(47%)**	16.38 **(47%)**	894.20 **(48%)**	17884.00 **(48%)**	4492.39 **(133%)**	13391.61 **(33%)**	380 **(24%)**	25.17 **(13%)**
Sharing vehicle (VRP solver)	22	25	3753	93112	252.47	13.01	0	0	11550.25	11550.25	1047	159.89
Net reduction (compared to BAU)	**27** **(55%)**	**64** **(72%)**	**0** **-**	**0** **-**	**445.96** **(64%)**	**21.91** **(63%)**	**1862.24** **(100%)**	**37244.80** **(100%)**	**8183.82** **(243%)**	**29060.98** **(72%)**	**540** **(34%)**	**32.51** **(17%)**

Table shows that the number of vehicles involved in the operation was reduced by 73% (from 588 to 159) and the number of vehicle visits to farms by 78% (from 770 to 166 round trips). This reduced the total distance travelled by 63% (from 6,415 to 2,353 km) and reduced the total CO_2 emissions by 16% (from 1,537 to 1286 kgCO_2/tonne-km). In this case, if look at only the transportation cost, the result suggested that the transportation cost was increased by 164% from 30,922 THB (£790) to 81,630 THB (£2,086) when product wastage was 0%. However, as the product does not move in the correct way and correct temperature in BAU operation. The reduction in wastage is such that the revenue gained back. Thus, when the cost of product waste was considered (at 2% of product wastage), the overall cost (transportation cost and the opportunity of lost sale) reduced by 67%. In addition, the empty box spaces were reduced by 54%, (from 23,944 to 10,944 boxes) and total time spent driving reduced 63%. The sensitivity analysis in Table 7 shows the benefits of assigning the 20ft refrigerated vehicle when different levels of product wastage are assumed. The results suggested that the total cost was reduced by 42% when the product damaged rate was at 1% and the total cost changed to 67% when the product wastage increased up to 2%, and the total cost increased to 86% and 93% when product wastage rates were changing up to 5% and 10%, respectively.

However, when 9 large-scale farmers were omitted from the scheme in the worst-case scenario, the number of vehicles involved in the operation were reduced by 62%, and the number of vehicles visit to farms by 54%, with a reduction in distance travelled by 51% (6,415 to 3,148 km), and the total CO_2 emissions by 16% (from 1,537 to 1,287 kgCO_2/tonne-km). In this case, the total transportation cost increase 114%, from 30,922 THB (£790) to 66,262 THB (£1,693) but reduced 28% on overall cost when the cost of product waste was included. In addition, vehicle utilisation improved by 38% reduction of empty box spaces, and 51% reduction on the driving time (from 320 to 157 hours).

When using the VRP Spreadsheet Solver, the key results in Table suggested that the number of vehicles involved was reduced by 71%, and 76% on the vehicle visits to farms, with a 60% reduction in total distance travelled (from 6,415 to 2,574 km). In this case, the total transportation increased by 184% (from 30,922 THB (£790) to 87,857 THB (£2,245)) when the product was not damaged (0% of product wastage rate). However, the reduction in wastage is such that the revenue gained back. Thus, when the cost of product waste was considered (at 2% of product wastage), the total cost was reduced by 65% (from 250,086 THB (£6,392) to 87,857 THB (£2,245)). In addition, assigning the 20ft refrigerated vehicle by using VRP Spreadsheet Solver improve the vehicle utilisation by reduction of 41% of empty box space (from 23,944 to 14,144 boxes), and a reduction of 14% on the total CO_2 emissions (from1,537 to 1,317 kgCO_2/tonne-km).

Table 24 Third-party 20ft refrigerated vehicle making a milk-round collection scenario in comparison to the BAU operations over 48 days of operations

Scenario	VF_{inv}	VF_{vis}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}	CT_{min}
BAU	588	770	6415.38	320.77	10958	219164	30922	250086	23944	1537	
3rd 20ft refrigerated vehicle (Best-case)	159	166	2353.49	117.67	0	0	81630	81630	10944	1286	7
Net Reduction	**429** (73%)	**604** (78%)	**4061.89** (63%)	**203.09** (63%)	**10958** (100%)	**219164** (100%)	**50708** (164%)	**168456** (67%)	**13000** (54%)	**251** (16%)	
3rd 20ft refrigerated vehicle (Worst-case)	222	354	3148.94	157.45	5698	113962	66262	180224	14944	1287	8
Net Reduction	**366** (62%)	**416** (54%)	**3266.44** (51%)	**163.32** (51%)	**5260** **(48%)**	**105202** **(48%)**	**35340** (114%)	**69862** **(28%)**	**9000** (38%)	**250** (16%)	
Sharing vehicle (VRP solver)	173	182	2574.63	121.73	0	0	87857	87857	14144	1317	24.00
Net reduction	**416** **(71%)**	**588** **(76%)**	**3840.75** **(60%)**	**199.04** **(62%)**	**10958** (100%)	**219164** (100%)	**56935** **(184%)**	**162228** **(65%)**	**9800** **(41%)**	**219** **(14%)**	

5.2.3 Mixture of Light and 20ft Refrigerated Vehicles

The modelling work suggested that some rounds using two light refrigerated vehicles could be merged to utilise one 20ft refrigerated vehicle (i.e. r_1 when $\{0, i_1, \ldots, i_n, j_1, \ldots, j_m, 0\}$ from Section 3.5.1. Perhaps, both light refrigerated and 20ft refrigerated vehicles could be assigned to make milk-rounds collections? For example, on Monday April 1, 2018, farmer 14 who produce 245 boxes of M1 and M2 mangoes generally required three light refrigerated vehicles for their operation, now can be merged to utilise one 20ft refrigerated vehicle and only one light refrigerated vehicle. In this operating scenario, the vehicles have maximum load capacity, with the light refrigerated vehicle being 100 boxes (2,500 kg), while the 20ft refrigerated vehicle holds 200 boxes (5,000 kg).

Table 24 shows the collection route on 12-15 March 2018 when assigning the mixture both light and 20ft refrigerated vehicles to make milk-round collections. The results show a reduction in the total distance travelled by 55%, with 21% reduction of the total CO_2 emissions. In this case, 20 light and 10 20ft refrigerated vehicles were used to collect 3,753 boxes of M1 and M2 mangoes, instead of using 49 light pick-up vehicles. The number of vehicles needed was reduced by 39%, and 65% reduction on number of vehicles visit to farms. In this case, the total transportation cost increased 253% from 3,366 THB (£86) to 11,886 THB (£303) when the product was not damaged (0% of product wastage rate). However, using the refrigerated vehicle could be saved the product and gained additional revenue from selling those products at the premium price grade. Therefore, the total cost was reduced by 71% over BAU case when the cost of product wastage was factored in (at 2% of product wastage rate). In addition, this case improved vehicle utilisation by a 72% reduction of empty box spaces, and a 55% reduction on time spent driving.

However, in the worst-case scenario, the total travelled distance was reduced by 41%, with a 16% reduction in the total CO_2 emissions. In this case, 14 light refrigerated and 4 20ft refrigerated vehicles were used to serve the sub-groups without 9 large-scale farmers. The rest products were moved by using 9 light pick-up vehicles (farmer owned). In this case, the total transportation cost increased by 140%, from 3,366 THB (£86) to 8,084 THB (£206), but the overall cost reduced 32% when the cost of product waste was considered. In addition, assigning mixture refrigerated vehicles improved the vehicle utilisation by a 62% reduction of the empty box spaces (10% behind the best-case), and 41% reduction on the time spent driving.

Table 24 The transportation routes from 12-15 March 2018 when using Third-party mixed (light and 20ft trucks) refrigerated vehicles

Collection routes between 12-15 March 2018	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
Business-as-Usual operations	**49**	**89**	**3753**	**93112**	**698.43**	**34.92**	**1862.24**	**37244.80**	**3366.43**	**40611.23**	**1587**	**192.40**
Using 20ft refrigerated vehicles (best-case)	30	31	3753	93112	312.33	15.62	0	0	11886.88	11886.88	447	**151.20**
Net reduction (compared to BAU)	**19 (39%)**	**58 (65%)**	**0 -**	**0 -**	**386.10 (55%)**	**19.31 (55%)**	**1862.24 (100%)**	**37244.80 (100%)**	**8520.45 (253%)**	**28724.35 (71%)**	**1140 (72%)**	**41.20 (21%)**
Using 20ft refrigerated vehicles (worst-case)	27	54	3753	93112	409.08	20.45	968.04	19360.80	8084.21	27445.01	607	**162.32**
Net reduction (compared to BAU)	**22 (45%)**	**35 (39%)**	**0 -**	**0 -**	**289.35 (41%)**	**14.47 (41%)**	**894.20 (48%)**	**17884.00 (48%)**	**4714.78 (140%)**	**13166.22 (32%)**	**980 (62%)**	**30.08 (16%)**
Sharing vehicle (VRP solver)	31	32	3753	93112	319.33	16.01	0	0	12586.44	12586.44	547	153.48
Net reduction (compared to BAU)	**18 (37%)**	**57 (64%)**	**0 -**	**0 -**	**379.10 (54%)**	**18.91 (54%)**	**1862.24 (100%)**	**37244.80 (100%)**	**9220.01 (274%)**	**28024.79 (69%)**	**1040 (66%)**	**38.92 (20%)**

Table 25 shows that the number of vehicles involved in this scenario were reduced by 62%, with a 70% reduction on the number of vehicles visit to farms, and the overall distance travelled reduced by 57%, with total CO_2 emissions down by 23% (from 1,537 to 1,176 $kgCO_2$/tonne-km). The transportation cost increased by 190%, from 30,922 THB (£790) to 89,526 THB (£2,288) when the product was not damaged (0% of product wastage rate). Using refrigerated vehicles could be saved the products during the transportation. Thus, the total cost seems to be reduced by 64% when the cost of product wastage was considered (2% of product wastage rate). In addition, using a mix of refrigerated vehicles improved vehicle utilisation by a 73% reduction in empty box spaces, and also by 57% on time spent driving. The sensitivity analysis in Table 7 shows the benefits of using Third-party mixed refrigerated vehicles when different the levels of product wastage are assumed. The results suggested that the total cost was reduced by 36% when the product damaged rate was at 1% and the total cost changed to 64% when the product wastage increased up to 2%, and the total cost increased to 85% and 92% when product wastage rates were changing up to 5% and 10%, respectively.

In the worst-case, the number of vehicles needed were reduced by 58%, and 51% on the total number of vehicles visit farms (from 770 to 378 round trips), producing a 48% reduction in total distance travelled, and 21% in total CO_2 emissions (from 1,537 to 1,219 $kgCO_2$/tonne-km). The transportation cost increased by 106%, from 30,922 THB (£790) to 63,729 THB (£1,629) but the overall cost reduced by 29% when the cost of product waste was considered. Also, vehicle utilisation increased by a 64% reduction in the empty box spaces, and 48% on time spent driving.

When using the VRP Spreadsheet Solver, the key results in Table 25 suggested that the number of vehicles involved reduced by 61%, and 70% on the vehicle visits to farms, with a 56% reduction in total distance travelled (from 6,415 to 2,794 km). If one looks at only the total transportation cost, the result suggested that the cost was increased by 200% from 30,922 THB (£790) to 92,875 THB (£2,374) when the product was not damaged. However, the benefit of assigning mixed refrigerated vehicle achieved a 63% reduction in the overall cost when the cost of product wastage (at 2% product wastage) was also considered (from 250,086 THB (£6,392) to 92,875 THB (£2,374). In addition, assigning mixed refrigerated vehicles with VRP spreadsheet solver improve the vehicle utilisation by reduction of 67% of empty box space (from 23,944 to 7,944 boxes), and a reduction of 22% on the total CO_2 emissions (from1,537 to 1,197 $kgCO_2$/tonne-km).

Table 25 Third-party mixed fleet vehicles making a milk-round collection scenario compared to the BAU operation

Scenario	VF_{inv}	VF_{vis}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}	CT_{min}
BAU	588	770	6415.38	320.77	10958	219164	30922	250086	23944	1537	
3rd mixed refrigerated vehicle (Best-case)	223	228	2776.88	138.84	0	0	89526	89526	6444	1176	8.00
Net Reduction	**365** (62%)	**542** (70%)	**3638.50** (57%)	**181.93** (57%)	**10958** (100%)	**219164** (100%)	**58604** (190%)	**160560** (64%)	**17500** (73%)	**361** (23%)	
3rd mixed refrigerated vehicle (Worst-case)	246	378	3362.38	168.12	5698	113962	63729	177691	8544	1225	8.00
Net Reduction	**342** (58%)	**392** (51%)	**3053.00** (48%)	**152.65** (48%)	**5260** (48%)	**105202** (48%)	**32807** (106%)	**72395** (29%)	**15400** (64%)	**312** (20%)	
Sharing vehicle (VRP solver)	229	229	2794.88	140.24	0	0	92875	92875	7944	1197.56	12.00
Net reduction	**359** **(61%)**	**539** **(70%)**	**3620.50** **(56%)**	**180.53** **(56%)**	**10958** (100%)	**219164** (100%)	**61953** **(200%)**	**157210** **(63%)**	**16000** **(67%)**	**338.96** **(22%)**	

The summary in Figure 43 shows that the sharing vehicles scenario produced operational benefits by reducing the number of vehicles needed and number of vehicles visit to farms by 40%, and also environmental benefits from reduced distance travelled by 36%, and CO_2 emissions by 28%. Together, these made a 36% reduction in the total transportation cost, but only 4% when the cost of product waste during transport was included.

The Third-party refrigerated vehicles, particularly using mixture refrigerated vehicles, can produce operational benefits, reducing the number of vehicles needed by 58% and the number of vehicles visit to farms by 51%, and environmental benefits from reduced distance travelled by 57%, and CO_2 emissions by 23%. Another important advantage is that refrigerated vehicles are appropriate to convey perishable products, such as mangoes. In this scenario, the transportation cost increased by 190%, but reduced by 64% when the cost of product waste during transport was included.

In addition, the VRP Spreadsheet Solver has been used for benchmark against the CW saving algorithm. The results suggested that the potential routes when using VRP Spreadsheet Solver produced very similar results with the CW saving algorithm. However, the operational and environmental benefits produced by VRP Spreadsheet Solver slightly lower when compared to the CW saving algorithm. In case of sharing vehicle, the VRP Spreadsheet Solver produced 5% behind the CW saving algorithm on the number of vehicles involved and number of vehicle visits to farm. In case of total distance travelled, and total transportation cost, the VRP Spreadsheet Solver generated 2% behind the CW saving algorithm.

Although the first scenario, where the farmers shared their vehicles, showed a significant reduction in the total transportation cost, using farmer's own vehicles does not address the problem of product waste due to lack of refrigeration. In this situation, the rural farmers lose out on potential income as product damaged during transport will attract a lower price and loads can be rejected. Therefore, using a Third-party vehicle to make a milk-round collection seemed to be an opportunity for the rural farmers. In addition, the results suggested that using the CW saving algorithm produced better operational and environmental benefits for the proposed logistics operating scenarios when compared to the VRP Spreadsheet Solver Excel based tool.

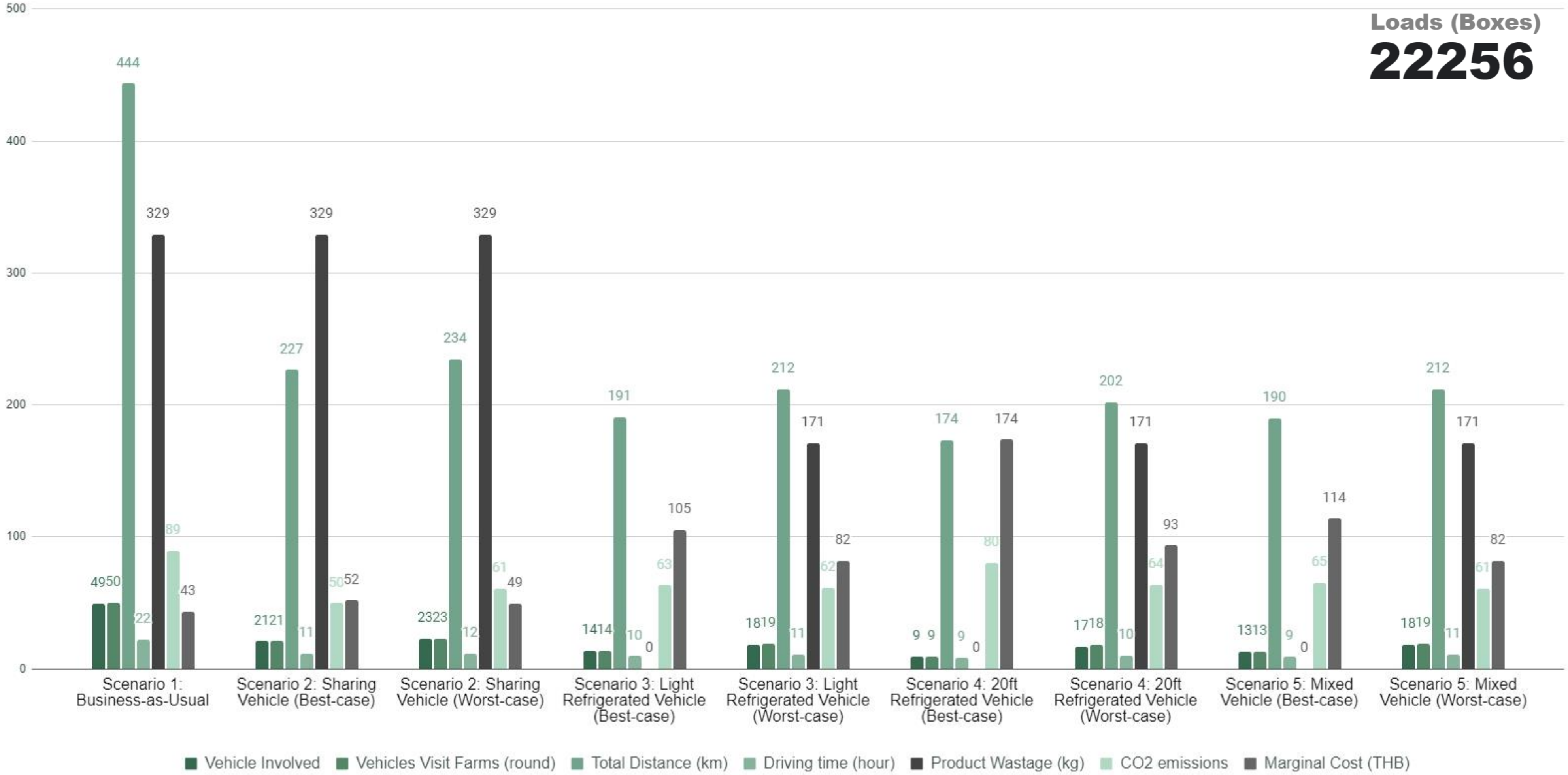


Figure 43 All ‘best-case’ and ‘worst-case’ scenarios over a 7-month period

5.3 Conclusions

This chapter explored the benefits of collaborative transport between a group of rural farmers, through two operating scenarios and two situations. In the first logistics operating scenario presented in 5.1, the results suggested that sharing vehicles through a farmer co-operative can produce operational benefits, reducing the number of vehicles needed by 41% with a 40% reduction in the number of vehicle visits to farms. These reduced total transportation cost by 36% over BAU operations, but by only 4% when the cost of product waste was included. Environmental benefits were reduced distance travelled by 36%, and reduced CO_2 emissions of 28%. Improve vehicle utilisation arose from reducing the empty box spaces by 78%.

In the worst-case situation, when the large-scale farmers opted out of the collaboration, the sharing vehicle scenario realised a 39% reduction in the number of vehicles needed and 36% on the number of vehicle visits to farms, producing a 35% reduction in transportation cost. Environmental benefits reduced distance travelled by 35% and CO_2 emissions by 25%.

In the second logistics operating scenario, the results suggested that using a Third-party mix of light refrigerated and 20ft refrigerated vehicles returns a better solution compared with using only one type of vehicle. The results presented in Section 5.2.3 clearly confirm that assigning the right fleet, of both light refrigerated and 20ft refrigerated vehicles, can produce operational benefits in terms of reduced the number of vehicles needed by 62%, and reducing the number of vehicle visits to farms by 70%. Although assigning a Third-party refrigerated vehicle increased the transportation cost by 190%, it seems to be lowered to 64% when the cost of product waste during transport was considered. In this case, the environmental benefits in terms of distance travelled was reduced by 57%, and emissions by 23%. The Third-party refrigerated vehicle is an appropriate vehicle for collection as it is likely to reduce the product waste during transport. Assigning right mixed fleet increased the vehicle utilisation from a 73% reduction in the empty box spaces running.

Chapter 6 Cost Allocation

Since the proposed transportation scheme of the coalition has been obtained on the proposed CW saving algorithm, the benefit arising from the collaboration can then be calculated by comparing the cost between BAU operations and collaborative cases. This chapter considers the cost allocation of a collaborative transportation, using computationally efficient cost allocation methods, to assist rural farmers manage that collaboration. Section 6.1 discusses the cost allocation methods applied to a case study to quantify how the transportation cost can split fairly between the farmers and quantifying the gained benefit. In section 6.2, the case study data are used to demonstrate how the transportation cost was fairly distributed among the group of rural farmers.

6.1 Cost Allocation Methods in Logistics Collaboration

When the transportation scheme with minimum cost was obtained in the previous chapter, the profit gained (cost saving) in the collaboration will now be allocated to individual participant farmers. Cost allocation is investigated using three different methods. Each method assigns a unique distribution (to the group of farmers) of the total transportation cost generated by the co-operative of all farmers. These are: proportional based on volume, stand-alone cost allocation, and the Shapley value methods all belongs to the co-operative game theory.

6.1.1 Proportional Methods

As mentioned in Section 3.4.1, the proportional method, based on volume or stand-alone cost allocation, are most frequently used in cost allocation (Frisk et al., 2010; Guajardo and Rönnqvist, 2016). A straightforward allocation is to distribute the total transportation cost $c(N)$ among the participant farmers according to a volume/demand quantity or a cost-weighted measure. The method allocates group costs to participants as a proportion of the costs that would have been individual incurred by each participant. For example, the overall transportation costs to deliver 6, 31, 9 boxes of M1 and M2 mangoes from farmers 62, 65, and 66 to the CP were 30.37, 27.72, and 30.02 THB, respectively. The purposed scenarios make the deliveries more effectively by combined the potential routes into one route, such as 65-62-66-*0*-65 (in this case, participant farmer 65 being the driver) which is likely to reduce the transportation cost to 36.92 THB (£0.94) for a round trip.

Under the proportional method, the transportation cost is charged according to the proportion of the cost/volume that would have been paid individually in the BAU scenario. Thus, the participant i's shared proportion (w_i) can be obtained following the Equation 3.14, where $c(\{i\})$ is equal to the actual transportation cost in BAU scenario when the participant farmer operates alone, and $\mathrm{c}(N)$ is the total transportation cost or volumes in the current operation. The method requires first the calculation of the proportionate share of transportation cost for each farmer on a stand-alone basis, and then applies each farmer's proportion toward the costs farmers are seeking to allocate. Then, the cost allocated to the participant farmers can be obtained following the Equation 3.15.

As an example, suppose farmers 62, 65, and 66, decide to join in a collaborative transportation agreement, and the transportation cost was 36.92 THB. The cost allocation results are displayed in Table 26, and show the value of $w_i(V)$ as the shared proportion of farmer i separately based on the volumes (farmers 62=13.04% 65=67.39% 66=19.57%), and $w_i(SA)$ as the shared proportion based on stand-alone operating cost (farmers 62=33.33% 65=30.42% 66=36.24%), based on Equation 3.14. The cost allocation to farmers 62, 65, and 66 is based on Equation 3.15 $y_i(V)$ (62=4.82 65=24.88 66=7.22), and $y_i(SA)$ (62=12.31 65=11.23 6=13.38).

Table 26 An example of cost allocation based on the proportional method when three farmers join in collaboration

Farmers	**Loads (box)**	**BAU cost (THB)**	$\boldsymbol{w_i(V)}$	$\boldsymbol{y_i(V)}$	$\boldsymbol{w_i(SA)}$	$\boldsymbol{y_i(SA)}$
Farmer $\{62\}$	6	30.37	13.04%	4.82	33.33%	12.31
Farmer $\{65\}$	31	27.72	67.39%	24.88	30.42%	11.23
Farmer $\{66\}$	9	33.02	19.57%	7.22	36.24%	13.38
Farmer $\{62, 65, 66\}$	**46**	**91.11**		**36.92**		**36.92**

where

$w_i(v)$ – participant i's shared proportion, based on volume (loads)

$w_i(SA)$ – participant i's shared proportion, based on stand-alone cost

$y_i(V)$ – the cost allocated, based on volume (loads)

$y_i(SA)$ – the cost allocated, based on stand-alone cost

The cost allocated to the participant farmers is based on the proportions of the loads and their stand-alone cost compared with the BAU scenario. However, it may provide allocations that are not seen as fair by all, as some farmers' plantations are located much further away from the CP than others, but if their loads are the same their cost will be similar.

6.1.2 Shapley Value Method

The Shapley value is one of the most popular cost allocation method used in co-operative games theory (Vanovermeire and Sörensen, 2014; Guajardo and Rönnqvist, 2016; Kolker, 2018). This method was applied as a mean to allocate the transportation cost in the collaborative transportation schemes. The method assigns a unique distribution among the participant farmers, as the average of the marginal contribution over all possible coalitions. The same with three farmers who do co-operate transport together shows the working of the Shapley value method. Table 27 lists all the subsets that include farmers 62, 65, and 66. In the first column 'S' gives the numbers of the subset, and the other columns the total cost of farmers, the transportation costs, and the saving costs.

Table 27 Example of three farmers co-operating

Subset in the coalition (S)	$\sum_{i \in S} C(\{i\})$	$C(s)$ **(THB.)**	$v(S)$ **(THB.)**
$\{62\}$	30.37	30.37	0
$\{65\}$	27.72	27.72	0
$\{66\}$	33.02	33.02	0
$\{62,65\}$	58.09	33.25	28.84
$\{62,66\}$	63.39	34.95	28.44
$\{65,66\}$	60.74	36.05	24.69
$\{62,65,66\}$	91.11	36.92	54.19

Thus, for farmer 62, based on Equation 3.20, the marginal contributions joining into subsets $\{62\}, \{62,65\}, \{62,66\}, \{62,65,66\}$ are equal 0, 28.84, 28.44, and 54.19 respectively. According to the sequence in which farmer 62 joins the coalition, the subset $\{62\}$ has two cases, which are $\{62,65,66\}$ and $\{62,66,65\}$ the subset $\{62, 65\}$ has one case $\{65,62,66\}$, the subset $\{62, 66\}$ also has one case $\{66,62,65\}$ and the subset $\{62,65,66\}$ has two cases, which are $\{65,66,62\}$ and $\{66,65,62\}$.

Table 28 shows the margin contribution of each farmer in all possible coalitions. The saving cost allocated to farmer 62 can be obtained based on the sum of all margin contributions divided by 6(3!). The identification of all the possible coalitions that a farmer may join with disparate sequences is the key to obtain the cost allocation. Thus, the cost savings allocated to farmers 62, 65, and 66 can be obtained from Equation 6.5 (δ_{62}=19.38, δ_{65}=17.51, and δ_{66}=17.31). Therefore, the cost of transportation for farmers 62, 65, and 66 were 10.99 THB, 10.21 THB, and 15.71 THB.

Table 28 Margin contribution of each participant farmer

Subset in the coalition (S)	$\varphi_{62}(v(S))$	$\varphi_{65}(v(S))$	$\varphi_{66}(v(S))$
$\{62,65,66\}$	0	28.84	25.35
$\{62,66,65\}$	0	25.75	28.44
$\{65,62,66\}$	28.84	0	25.35
$\{65,66,62\}$	29.50	0	24.69
$\{66,62,65\}$	28.44	25.75	0
$\{66,65,62\}$	29.50	24.69	0
Savings Cost	**19.38**	**17.51**	**17.31**

Take farmer 62 for example. When s is equal to 3, it indicates that there are three farmers after farmer 62 joining coalition S, so farmer 62 is the third one in coalition. In this case, the value of $(n-|s|)!\,(|s|-1)!$ is equal to 2 in Equation 3.21, which indicates that there are two kinds of sequences when farmer 62 joins in coalition S, which are $\{65,66,62\}$ and $\{66,65,62\}$, and the marginal contributions are equal to 29.50 in these two coalitions, based on equation 3.20.

When s is equal to 2, it indicates that there are three farmers after farmer 62 joining the coalition S, and farmer 62 is the second one to join the coalition. In this case, the value of $(n-|s|)!\,(|s|-1)!$, which indicates that there is only one kind of sequence when farmer 62 joins coalition S. However, the value of $\varphi_i\big(v(s)\big)$ also have two cases, which depends on the farmers in the coalition S. If the farmers in the coalition S are $\{62,65\}$, the value of $\varphi_i\big(v(s)\big)$ is equal to 28.84, while the value is 28.44 if the farmers are $\{62,66\}$. Finally, when s is equal to 1, it indicates that there is only one farmer after farmer 62 joining coalition S, and farmer 62 is the first one to join the coalition. In this case, the value of $(n-|s|)!\,(|s|-1)!$ is equal to 2, which indicates that there are two kinds of sequences when farmer 62 join the coalition S, i.e. $\{62,65,66\}$ and $\{62,66,65\}$. The margin contributions are equal to 0 in both of these coalitions, based on Equation 3.20.

The benefit gained in the collaboration depends on the gap between the cost in the collaborative and non-collaborative scenarios. The cost of the collaboration can be obtained based on the potential transportation routes using CW saving algorithm, while the cost of non-collaboration is the sum of each farmer's cost when operating alone. The grand coalition was generated based on the potential transportation routes, where each coalition had three farmers $\{62,65,66\}$ and the number of mangoes moved ranged from 21 to 166 container boxes, where the number varied between off-peak and peak periods of collection. It should be note that the light pick-up vehicle with a loaded capacity of 60 boxes would be moving 21, 31, 41, and 49 container boxes in only one vehicle, while 127 and 166 boxes required two and three vehicles, respectively.

Table 29 presents the results of transportation in different coalitions. The details of each coalition comprise the following: first column is a serial number of the coalition, S; (2) the number of the mangoes moved (n); (3) farmers in coalition (i); (4) the cost to farmer i in the BAU operations – non-collaboration case, $C(\{i\})$; (5) the cost of farmer i in the collaboration case, $C(s)$; (6) cost reduction ratio of farmer i; (7) number of mangoes moved by each farmer i; (8) the proportion of farmers' mangoes in coalition; (9) the number of vehicle needed in BAU operation, VF_{BAU}; (10) the number of vehicles needed in the collaborative, VF_C; (11) the reduction in vehicles, RV; (12) total non-collaborative cost, $\sum C(\{i\})$; (13) total collaboration cost of coalition, $\sum C(\{s\})$; (14) cost savings of coalition.

Table 29 The results of transportation in different coalitions.

Coalition (S)	Container boxes (n)	(i)	$C(\{i\})$	$C(s)$ (THB)	Cost saving of farmer (i)	Number of mangoes moved each farmer (boxes)	Proportion of farmers' mangoes	VF_{BAU}	VF_C	RV	$\sum C(\{i\})$ (THB)	$\sum C(\{s\})$ (THB)	Savings
1	21	62	30.37	10.99	64%	16	76.2%	3	1	66.7%	91.11	36.92	59.5%
		65	27.72	10.21	63%	4	19.0%						
		66	33.02	15.71	52%	1	4.8%						
2	31	62	30.37	10.99	64%	23	74.2%	3	1	66.7%	91.11	36.92	59.5%
		65	27.72	10.21	63%	6	19.4%						
		66	33.02	15.71	52%	2	6.5%						
3	41	62	30.37	10.99	64%	31	75.6%	3	1	66.7%	91.11	36.92	59.5%
		65	27.72	10.21	63%	8	19.5%						
		66	33.02	15.71	52%	2	4.9%						
4	49	62	30.37	10.99	64%	37	75.5%	3	1	66.7%	91.11	36.92	59.5%
		65	27.72	10.21	63%	9	18.4%						
		66	33.02	15.71	52%	3	6.1%						
5	127	62	60.74	32.55	46%	96	75.6%	4	2	50.0%	121.48	67.29	44.6%
		65	27.72	14.72	47%	24	18.9%						
		66	33.02	20.02	39%	7	5.5%						
6	166	62	91.11	52.80	42%	126	75.9%	5	3	40.0%	151.85	97.66	35.7%
		65	27.72	19.78	29%	31	18.7%						
		66	33.02	25.08	24%	9	5.4%						

At the level of the individual farmers, it can be seen that the cost to each farmer in each coalition reduces significantly, especially for farmer 62, and the cost reduction rates of different farmers are very different (see column cost saving of farmer i). The cost to the coalition decreases markedly with the benefit gain rates ranging from 35.7% to 59.5% (column savings).

Table 30 shows the benefit gain rates of the coalitions, including both sub-coalition $\{62,65\}$, $\{62,66\}$, $\{65,66\}$ and grand coalition $\{62,65,66\}$. It indicates that the grand coalition can always obtain the largest benefit in all possible coalitions (see column savings), which suggests an effective collaboration.

Table 30 The benefit gain rates of the coalitions.

Coalition (S)	Container boxes (n)	Subset in coalition	$\sum C(\{i\})$ (THB)	$\sum C(\{s\})$ (THB)	Savings
1	21	$\{62,65\}$	58.09	33.25	43%
		$\{62,66\}$	63.39	34.95	45%
		$\{65,66\}$	60.74	36.05	41%
		$\{62,65,66\}$	91.11	36.92	59%
2	31	$\{62,65\}$	58.09	33.25	43%
		$\{62,66\}$	63.39	34.95	45%
		$\{65,66\}$	60.74	36.05	41%
		$\{62,65,66\}$	91.11	36.92	59%
3	41	$\{62,65\}$	58.09	33.25	43%
		$\{62,66\}$	63.39	34.95	45%
		$\{65,66\}$	60.74	36.05	41%
		$\{62,65,66\}$	91.11	36.92	59%
4	49	$\{62,65\}$	58.09	33.25	43%
		$\{62,66\}$	63.39	34.95	45%
		$\{65,66\}$	60.74	36.05	41%
		$\{62,65,66\}$	91.11	36.92	59%
5	127	$\{62,65\}$	88.46	63.62	28%
		$\{62,66\}$	93.76	65.32	30%
		$\{65,66\}$	60.74	36.05	41%
		$\{62,65,66\}$	121.48	67.29	45%
6	166	$\{62,65\}$	118.83	93.99	21%
		$\{62,66\}$	124.13	95.69	23%
		$\{65,66\}$	60.74	36.05	41%
		$\{62,65,66\}$	151.85	97.66	36%

To guarantee the stability of the collaboration, the gained benefit must be allocated to the participant farmers fairly. The proposed Shapley value method distributes the benefit based on the marginal contributions of the participants, which can ensure the uniqueness of the allocation outcome. However, the outcome may not be stable, which means that the participant farmers may not accept the allocation because there is a subset S such that its participants will get more benefit. Therefore, the non-emptiness of the core in the coalition is supposed to be checked. Under this condition each participant is gained with an incentive to form the coalition. The rural farmers would gain the benefit from collaboration at least equal to their BAU operations or more benefit.

Table 31 presents the benefit allocated to individual farmers based on the Shapley value method. Column savings show the benefit gain rates of the participant farmers, and column average savings presents the average benefit of individual sub-coalitions are calculated to check the non-emptiness of the core in a grand coalition. Table 31 and Table 32 shows the benefit gained in sub-coalition and grand coalition. It can be seen that the total benefit gained in the grand coalition $\{62,65,66\}$ for the participant farmers is larger than that in any sub-coalition including $\{62,65\}$, $\{62,66\}$, $\{65,66\}$, which obtained from $\sum \boldsymbol{C}(\{\boldsymbol{i}\}) - \sum \boldsymbol{C}(\{\boldsymbol{s}\})$. Based on the constrains (3.17) and (3.18), it can be concluded that the core of each coalition is non-empty and the allocation outcome in each coalition can satisfy the quality of the stability. There is no sub-coalition of each grand coalition which has a better outcome for participants – farmers can accept the allocation outcome without bargaining.

Table 31 The results of benefit sharing.

Coalition (S)	Container boxes (n)	(S)	$C(\{i\})$ (THB)	$v\{62,65)$	$v\{62,66)$	$v\{65,66$	$v\{62,65,66)$	$v(S)$	Savings	Average savings
		62	30.37					19.38	63.8%	
1	21	65	27.72	24.84	28.44	24.69	54.19	17.51	63.2%	59.8%
		66	33.02					17.31	52.4%	
		62	30.37					19.38	63.8%	
2	31	65	27.72	24.84	28.44	24.69	54.19	17.51	63.2%	59.8%
		66	33.02					17.31	52.4%	
		62	30.37					19.38	63.8%	
3	41	65	27.72	24.84	28.44	24.69	54.19	17.51	63.2%	59.8%
		66	33.02					17.31	52.4%	
		62	30.37					19.38	63.8%	
4	49	65	27.72	24.84	28.44	24.69	54.19	17.51	63.2%	59.8%
		66	33.02					17.31	52.4%	
		62	60.74					19.38	31.9%	
5	127	65	27.72	24.84	28.44	24.69	54.19	17.51	63.2%	49.2%
		66	33.02					17.31	52.4%	
		62	91.11					19.38	21.3%	
6	166	65	27.72	24.84	28.44	24.69	54.19	17.51	63.2%	45.6%
		66	33.02					17.31	52.4%	

Table 32 The stability of the Shapley value allocation method.

Coalition (S)	$v\{62,65\}$	$v\{62,66\}$	$v\{65,66\}$	$v\{62,65,66\}$			**Stability**
				62	**65**	**66**	
1	24.84	28.44	24.69	19.38	17.51	17.31	Stability
2	24.84	28.44	24.69	19.38	17.51	17.31	Stability
3	24.84	28.44	24.69	19.38	17.51	17.31	Stability
4	24.84	28.44	24.69	19.38	17.51	17.31	Stability
5	24.84	28.44	24.69	19.38	17.51	17.31	Stability
6	24.84	28.44	24.69	19.38	17.51	17.31	Stability

In the next section, the cost allocation methods listed above will be used to demonstrate how the transportation cost of the various scenarios should be distributed among the group of rural farmers. The data have been taken from the collective logistics scenarios developed in the previous Section 5.1), where the farmers shared their vehicle.

6.2 Exploring Fairness in Cost Distribution

The results presented in Chapter 5 were used to quantify how the transportation cost of sharing vehicles through a farmer co-operative scenario could be distributed fairly among the group of rural farmers. This instance is used to evaluate the feasibility and effectiveness of cost allocation methods in order to achieve objective 3 and answer the research question: quantify the cost allocation.

6.2.1 Fairly Allocating System Costs between Rural Farmers

A key challenge in such a collaborative working arrangement is how to equitably distribute the logistics costs among the participants given that some farmers will have greater volumes to transport compared to others. The profit gained (cost saving shared) through collaboration will also vary depending on the variability in harvest loads from week to week and therefore the vehicle sharing scenario would be expected to involved farmers working with a range of neighbours over a given period.

To investigate these issues, three different cost allocation methods were used: (i) the proportional method based on volume or (ii) stand-alone cost (Nguyen, Dessouky and Toriello, 2014; Liu, 2016) and (iii) the Shapley value method, based co-operative game theory (Guajardo and Rönnqvist, 2016; Kolker, 2018; Shi *et al.*, 2020). Each method assigns a unique distribution of total transportation cost generated by the co-operative of all participant farmers.

The data used in this section have been taken from the collective logistics scenarios developed in the previous Section 5.1, 'sharing vehicle through a farmer co-operative scenario', involving the transportation of mangoes from 49 farms to the CP from 12-15 March 2018 (peak period collection). There is a relatively large difference in size between farms as shows in Table 33. The first column shows the number of collective routes for M1 and M2 mangoes, along with the routing and loading size (kg) of each route. The remaining columns shows the transportation details in terms of loads, distance travelled, product wastage during transport, driving time, total transportation cost, empty box space, and CO_2 emissions. The data shows that are 41 routes that take 68 round trips to collect 3,753 boxes (93,112 kg) of M1 and M2 mangoes over 4-day operations. This generated a total transportation cost of 2,551.08 (£65), a 24% reduction over the BAU scenario. This source data will be used to demonstrate how the transportation costs can be distributed fairly amongst the participant farmers by using the different cost allocation methods.

The feasible coalition considered in the Table 33 were all farmers as one coalition, considering the possibility of large-scale farmer operate separately with small-scale farmer coalition. The transportation cost of each specific route was calculated and fairly distributed to the farmers when they agree to collaborate as the example given in section 6.1.2. The rural farmers could benefit from some fairness standards such as based on the overall volumes or weight of the product being transported (Guajardo and Rönnqvist, 2016), or based on the principle of the more one brings to the coalition, the more one gets out of the division of the accumulated gains (Kolker, 2018).

Table 33 The collection routes when farmers agreed to share their vehicle, involving 49 plantations from 12-15 March 2018

	Collection routes	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
Sharing vehicle scenario on 12-15 March 2018													
Monday 12 March 2018													
1	Farm 2(816) - Farm 9(264) - Farm 14(120) - CP - Farm 2	1	1	49	1200	5.76	0.29	24.00	480.00	27.76	507.76	11	1.49
2	Farm 9(3000) - CP - Farm 9	1	2	120	3000	8.00	0.40	60.00	1200.00	38.56	1238.56	0	2.59
3	Farm14(6000) - CP - Farm 14	1	4	240	6000	14.68	0.73	120.00	2400.00	70.76	2470.76	0	4.75
4	Farm 21(1428) - CP - Farm 21	1	1	58	1428	6.08	0.30	28.56	571.20	29.31	600.51	2	1.87
5	Farm 25(850) - Farm 21(170) - CP - Farm 25	1	1	41	1020	8.11	0.41	20.40	408.00	39.09	447.09	19	2.24
6	Farm 30(612) - Farm 36(850) - CP - Farm 30	1	1	59	1462	11.28	0.56	29.24	584.80	54.37	639.17	1	3.55
7	Farm 33(1500) - CP - Farm 33	1	1	60	1500	11.53	0.58	30.00	600.00	55.57	655.57	0	3.73
8	Farm 33(948) - Farm 34(132) - CP - Farm 33	1	1	44	1080	12.33	0.62	21.60	432.00	59.43	491.43	16	3.60
9	Farm 34(1500) - CP - Farm 34	1	1	60	1500	12.23	0.61	30.00	600.00	58.95	658.95	0	3.95
10	Farm 43(1496) - CP - Farm 43	1	1	60	1496	6.96	0.35	29.92	598.40	33.55	631.95	0	2.24
11	Farm 45(1500) - CP - Farm 45	1	1	60	1500	10.73	0.54	30.00	600.00	51.72	651.72	0	3.47
12	Farm 45(540) - Farm 52(374) - Farm 54(170) - CP - Farm 45	1	1	45	1084	18.04	0.90	21.68	433.60	86.95	520.55	15	5.29
13	Farm 57(612) - Farm 50(816) - CP - Farm 57	1	1	58	1428	15.30	0.77	28.56	571.20	73.75	644.95	2	4.71
Tuesday 13 March 2018													
14	Farm 11(1500) - CP - Farm 11	1	1	60	1500	3.36	0.17	30.00	600.00	16.20	616.20	0	1.09
15	Farm 11(540) - Farm 1(680) - CP - Farm 11	1	1	50	1220	3.44	0.17	24.40	488.00	16.58	504.58	10	0.90
16	Farm 16(10200) - CP - Farm 16	1	7	408	10200	33.04	1.65	204.00	4080.00	159.25	4239.25	12	10.38
17	Farm 17(5814) - CP - Farm 17	1	4	233	5814	22.76	1.14	116.28	2325.60	109.70	2435.30	7	7.13
18	Farm 19(408) - Farm 3(748)- CP - Farm 19	1	1	48	1156	8.06	0.40	23.12	462.40	38.85	501.25	12	2.01
19	Farm 56(2720) - CP - Farm 56	1	2	109	2720	13.64	0.68	54.40	1088.00	65.74	1153.74	11	4.00
Wednesday 14 March 2018													
20	Farm 6(3808) - CP - Farm 6	1	3	153	3808	19.80	0.99	76.16	1523.20	95.44	1618.64	27	5.71
21	Farm 15(4080) - CP - Farm 15	1	3	164	4080	11.64	0.58	81.60	1632.00	56.10	1688.10	16	3.64
22	Farm 47(408) - Farm 60(166) - CP - Farm 47	1	1	24	574	13.88	0.69	11.48	229.60	66.90	296.50	36	3.03
23	Farm 51(1500) - CP - Farm 51	1	1	60	1500	19.08	0.95	30.00	600.00	91.97	691.97	0	6.17
24	Farm 53(7500) - CP - Farm 53	1	5	300	7500	19.90	1.00	150.00	3000.00	95.92	3095.92	0	6.43
25	Farm 58(578) - Farm 51(608) - CP - Farm 58	1	1	49	1186	19.16	0.96	23.72	474.40	92.35	566.75	11	4.90
26	Farm 59(4488) - CP - Farm 59	1	3	180	4488	35.16	1.76	89.76	1795.20	169.47	1964.67	0	11.34
27	Farm 60(1500) - CP - Farm 60	1	1	60	1500	12.18	0.61	30.00	600.00	58.71	658.71	0	3.94
Thursday 15 March 2018													
28	Farm 4(2244) - CP - Farm 4	1	2	90	2244	6.00	0.30	44.88	897.60	28.92	926.52	30	1.82
29	Farm 23(1500) - CP - Farm 23	1	1	60	1500	7.66	0.38	30.00	600.00	36.92	636.92	0	2.48

	Collection routes	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{wst}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
30	Farm 26(1088) - CP - Farm 26	1	1	45	1088	8.24	0.41	21.76	435.20	39.72	474.92	15	2.43
31	Farm 37(1122) - Farm 23(132) - CP - Farm 37	1	1	52	1254	12.04	0.60	25.08	501.60	58.03	559.63	8	3.25
32	Farm 39(1500) - CP - Farm 39	1	1	60	1500	14.83	0.74	30.00	600.00	71.48	671.48	0	4.79
33	Farm 40(748) - Farm 39(540) -CP - Farm 40	1	1	53	1288	18.03	0.90	25.76	515.20	86.90	602.10	7	5.00
34	Farm 48(1224) - CP - Farm 48	1	1	49	1224	8.89	0.44	24.48	489.60	42.85	532.45	11	2.34
35	Farm 62(3000) - CP - Farm 62	1	2	120	3000	12.60	0.63	60.00	1200.00	60.73	1260.73	0	4.07
36	Farm 65(748) - Farm 62(128) - Farm 66(204) - CP - Farm 65	1	1	46	1080	7.66	0.38	21.60	432.00	36.92	468.92	14	1.78
37	Farm 67(374) - Farm 69(612) Farm 68(408) - CP -Farm 67	1	1	58	1394	9.86	0.49	27.88	557.60	47.53	605.13	2	2.96
38	Farm 68(1360) - CP - Farm 68	1	1	55	1360	6.26	0.31	27.20	544.00	30.17	574.17	5	1.83
39	Farm 72(408) - Farm 71(1020) - CP - Farm 72	1	1	58	1428	5.61	0.28	28.56	571.20	27.04	598.24	2	1.73
40	Farm 73(374) - Farm 74(816) - Farm 42(170) - CP - Farm 73	1	1	56	1360	25.66	1.28	27.20	544.00	123.68	667.68	4	7.52
41	Farm 78(1428) - CP - Farm 78	1	2	99	2448	9.80	0.49	48.96	979.20	47.24	1026.44	21	2.86
	Total	**41**	**68**	**3753**	**93112**	**529.27**	**26.46**	**1862.24**	**37244.80**	**2551.08**	**39795.88**	**327**	**159.02**

A summary of the key results is presented in Table 34, with the column 'BAU cost' representing the rural farmers' cost of the current business-as-usual operation, along with the operating cost derived by the different cost allocation methods.

Table 34 Cos allocations and cost savings for each farmer generated by the proportional and the Shapley value methods compared to the BAU costs from 12-15 March 2018

Farmer	Loads (boxes)	BAU Transportation Cost (THB)	$y_i(V)$ (THB)	Saving (V)	$y_i(SA)$ (THB)	Saving (SA)	Shapley Value Cost (THB)	Saving (SV)
Farmer 01	28	13.11	9.29	29.18%	7.42	43.42%	6.75	48.51%
Farmer 02	33	9.54	18.70	-95.20%	5.70	40.31%	3.78	60.39%
Farmer 03	31	40.97	25.09	38.76%	24.32	40.65%	27.67	32.46%
Farmer 04	90	28.92	28.92	0.00%	28.92	0.00%	28.92	0.00%
Farmer 06	153	95.44	95.44	0.00%	95.44	0.00%	95.44	0.00%
Farmer 09	131	57.84	44.79	22.56%	50.07	13.44%	51.36	11.20%
Farmer 11	82	32.39	23.49	27.48%	25.36	21.71%	26.04	19.62%
Farmer 14	245	88.45	73.59	16.80%	81.32	8.06%	81.95	7.35%
Farmer 15	164	56.10	56.10	0.00%	56.10	0.00%	56.10	0.00%
Farmer 16	408	159.25	159.25	0.00%	159.25	0.00%	159.25	0.00%
Farmer 17	233	109.70	109.70	0.00%	109.70	0.00%	109.70	0.00%
Farmer 19	17	24.49	13.76	43.81%	14.53	40.65%	11.19	54.30%
Farmer 21	65	58.61	35.98	38.61%	46.76	20.23%	45.34	22.65%
Farmer 23	66	73.84	43.62	40.93%	59.97	18.79%	56.37	23.66%
Farmer 25	34	36.34	32.42	10.80%	21.64	40.46%	23.06	36.55%
Farmer 26	45	39.72	39.72	0.00%	39.72	0.00%	39.72	0.00%
Farmer 30	25	44.49	23.04	48.22%	25.27	43.20%	23.81	46.48%
Farmer 33	98	111.15	106.90	3.82%	84.41	24.05%	83.60	24.78%
Farmer 34	66	117.90	67.05	43.13%	89.54	24.05%	90.36	23.36%
Farmer 36	34	51.24	31.33	38.85%	29.10	43.20%	30.56	40.36%
Farmer 37	46	56.06	51.34	8.42%	34.99	37.58%	38.59	31.16%
Farmer 39	82	142.96	107.55	24.77%	112.19	21.53%	110.11	22.98%
Farmer 40	31	81.12	50.83	37.34%	46.20	43.05%	48.27	40.50%
Farmer 42	7	95.92	15.46	83.88%	39.03	59.31%	43.60	54.54%
Farmer 43	60	33.55	33.55	0.00%	33.55	0.00%	33.55	0.00%
Farmer 45	82	103.44	94.23	8.90%	84.25	18.55%	78.17	24.43%
Farmer 47	17	48.68	47.39	2.66%	30.33	37.70%	28.44	41.58%
Farmer 48	49	42.85	42.85	0.00%	42.85	0.00%	42.85	0.00%
Farmer 50	33	61.31	41.96	31.56%	36.73	40.09%	36.64	40.24%
Farmer 51	85	183.93	139.08	24.38%	139.55	24.13%	140.87	23.41%
Farmer 52	16	79.14	30.92	60.94%	49.78	37.10%	53.88	31.92%
Farmer 53	300	95.92	95.92	0.00%	95.92	0.00%	95.92	0.00%
Farmer 54	7	7.37	13.53	-83.41%	4.64	37.10%	6.62	10.23%
Farmer 56	109	65.74	65.74	0.00%	65.74	0.00%	65.74	0.00%
Farmer 57	25	61.79	31.79	48.56%	37.02	40.09%	37.12	39.93%
Farmer 58	24	86.52	45.23	47.72%	44.77	48.26%	43.45	49.78%
Farmer 59	180	169.47	169.47	0.00%	169.47	0.00%	169.47	0.00%
Farmer 60	67	117.42	78.22	33.38%	95.28	18.85%	97.18	17.24%
Farmer 62	126	91.10	65.55	28.05%	73.04	19.82%	72.24	20.70%
Farmer 65	31	27.72	24.88	10.22%	11.23	59.47%	10.73	61.28%
Farmer 66	9	33.02	7.22	78.12%	13.38	59.47%	14.68	55.54%
Farmer 67	16	32.49	13.11	59.64%	16.54	49.10%	17.02	47.61%
Farmer 68	72	60.35	44.10	26.92%	45.53	24.55%	45.45	24.68%
Farmer 69	25	30.70	20.49	33.28%	15.63	49.10%	15.23	50.40%

Farmer	Loads (boxes)	BAU Transportation Cost (THB)	$y_i(V)$ (THB)	Saving (V)	$y_i(SA)$ (THB)	Saving (SA)	Shapley Value Cost (THB)	Saving (SV)
Farmer 71	41	26.08	19.11	26.70%	13.27	49.09%	13.04	49.99%
Farmer 72	17	27.04	7.93	70.69%	13.77	49.09%	14.00	48.23%
Farmer 73	16	105.46	35.34	66.49%	42.91	59.31%	41.49	60.66%
Farmer 74	33	102.57	72.88	28.94%	41.74	59.31%	38.59	62.38%
Farmer 78	99	47.24	47.24	0.00%	47.24	0.00%	47.24	0.00%
Total	**3753**	**3366.43**	**2551.08**	**16.92%**	**2551.08**	**18.87%**	**2551.08**	**18.89%**

where,

V – the saving by proportional method, based on volume

SA – the saving by proportional method, based on stand-alone cost

SV – the saving by the Shapley value method

At the level of the individual farmers, it can be seen that the cost of each participant farmer reduces significantly, whichever method is chosen. However, the results highlight the fact that the operating cost reductions for each participant farmers resulting from the two mechanisms can be different due to the fact that the core of each instance includes multiple possible allocations and that different definitions of fairness can result in different core allocations. If an individual farmer can never save the collective any money, then that farmer does not get to share in any of the cost savings. In this case, farmers 4, 6, 15, 16, 17, 26, 43, 48, 53, 56, 59, and 78 pays the transportation, independent of the allocation method.

The proportional cost allocation based on volume (loads) is considered the simplest approach to splitting the transportation cost, based on the principle that the greater demand placed by an individual farmer, the greater their individual financial contribution to the collective. The different in savings for each farmer varies greatly, dependent on the volume moved, ranging from 2.7% to 83.9%, and averaging at 16.9% of the cost savings ($saving\ V$). The proportional method based on loads does not seem to be appropriate since at least two farmers 2 and 54 are worse of in this allocation as compared with the participant working alone. Although the cost allocation based on volume is easily to compute, no consideration is taken of the geographical collection of the demand points.

The proportion method based on the stand-alone cost seem to be fairer, where the transportation cost was based on the total common BAU cost used by each participant when operating separately. The fairness of this method can be verified the considering each participating as a separate entity to determine the cost allocation weights. The average cost savings obtained by the stand-alone cost method was 18.87% of the savings ($saving\ SA$), the difference in savings for each farmer ranging from 8.06% to 59.47%.

The Shapley value method made an attempt at fairness by averaging across all possible orders, which consider marginal cost and the dispersion degree of node (plantation location) in cost allocation. The average cost savings obtained by the Shapley value method was also found to be 18.89% of the savings ($saving\ SV$), the different in savings for each farmer ranging between 7.35% and 62.38%, where the savings are as equal as possible.

6.3 Overall Cost Savings for Rural Farmers

A key challenge in such a collaborative working arrangement is how to equitably distribute the logistics costs among the participants, given that some farmers will have greater volumes to transport than others. The profits gained (cost savings) through collaboration will also vary, depending on the variability in harvest loads from week to week, as presented in Section 6.2.1. This section shows how the transportation costs distribute fairly among the participant farmers over7-month operation.

A summary of the key results according to the different cost allocation concepts described is presented in Table 35. The columns describe the same terms as Table 34, but the data covers a 7-month period instead. The results show that the cost of each farmer reduces significantly compared with when they operate alone. The cost saving for each farmer generated by the two cost allocation mechanisms are different due to the multiple possible allocations and different definitions of fairness.

The proportional cost allocation method based on volume was used to split the transportation cost based on the volumes from the participant farmers. The fairness is based on the more volumes moved, the more costs they should pay. The number of boxes contributed by each farmer has a large impact on the cost allocations. The different in savings for each farmer ranged from -30.3% to 83.2%, with an average at 25.9% of the savings. Thus, the potential saving of the participant farmers varies greatly dependent on the volume of product moved, which seemed to be more benefit for small-scale farmers than others.

The proportion method based on the stand-alone cost also performed well, where the transportation cost is based on the BAU cost used by each participant farmer when operating alone. The average cost allocation obtained by this method was found at 29.6% of the savings, the different in savings for each farmer ranging from 1.4% to 64.0%. Compared with another method, such the Shapley value method, it behaved similarly.

The average cost allocation savings obtained by the Shapley value method found at 30.2%, the different in savings for each farmer ranging from 1.6% to 67.6% of the savings. The transportation cost was based on the average across all possible orders, considering marginal cost and the dispersion degree of the nodes (plantation location).

Table 35 Cost allocations and cost saving generated by proportional, and the Shapley value methods compared to the BAU over 7-month operations

Farmer	Loads (boxes)	BAU Transportation Cost (THB)	$y_i(V)$ (THB)	Saving (%)	$y_i(SA)$ (THB)	Saving (%)	Shapley Value Cost (THB)	Saving (%)
Farmer 01	165	157.32	107.37	31.75%	95.53	39.28%	73.71	53.15%
Farmer 02	195	114.52	156.99	-26.17%	67.78	40.82%	43.75	61.80%
Farmer 03	186	491.64	192.12	60.92%	286.32	41.76%	313.08	36.32%
Farmer 04	539	245.82	287.04	-16.77%	231.61	5.78%	217.92	11.35%
Farmer 06	900	636.24	570.93	10.26%	611.80	3.84%	616.83	3.05%
Farmer 09	778	366.32	341.29	6.83%	324.38	11.45%	328.06	10.44%
Farmer 11	486	275.32	262.17	4.78%	196.29	28.71%	163.28	40.70%
Farmer 14	1446	548.37	481.14	12.26%	509.89	7.02%	510.08	6.98%
Farmer 15	965	430.14	447.35	-4.00%	415.56	3.39%	410.30	4.61%
Farmer 16	2400	1046.52	977.09	6.63%	982.43	6.12%	996.04	4.82%
Farmer 17	1378	713.07	711.24	0.26%	703.27	1.37%	701.68	1.60%
Farmer 19	100	293.83	99.93	65.99%	169.72	42.24%	157.18	46.51%
Farmer 21	389	410.28	292.12	28.80%	283.19	30.98%	244.84	40.32%
Farmer 23	389	516.90	449.89	12.96%	366.70	29.06%	335.27	35.14%
Farmer 25	200	436.11	186.62	57.21%	258.00	40.84%	277.27	36.42%
Farmer 26	265	476.60	352.11	26.12%	325.16	31.78%	335.65	29.57%
Farmer 30	150	533.86	193.37	63.78%	227.32	57.42%	216.72	59.41%
Farmer 33	581	944.77	668.71	29.22%	645.16	31.71%	687.34	27.25%
Farmer 34	389	825.28	575.72	30.24%	521.55	36.80%	542.64	34.25%
Farmer 36	200	614.84	253.73	58.73%	261.80	57.42%	248.42	59.60%
Farmer 37	275	672.68	459.25	31.73%	370.88	44.87%	352.18	47.65%
Farmer 39	492	1215.17	747.71	38.47%	822.51	32.31%	863.95	28.90%
Farmer 40	186	973.45	563.68	42.09%	485.72	50.10%	457.39	53.01%
Farmer 42	46	1151.02	162.73	85.86%	413.97	64.03%	450.75	60.84%
Farmer 43	358	402.57	382.84	4.90%	281.49	30.08%	245.08	39.12%
Farmer 45	486	879.22	567.33	35.47%	654.19	25.59%	671.18	23.66%
Farmer 47	100	584.18	278.84	52.27%	267.63	54.19%	246.69	57.77%
Farmer 48	293	514.20	346.90	32.54%	383.54	25.41%	482.25	6.21%
Farmer 50	195	735.72	451.80	38.59%	347.57	52.76%	238.56	67.57%
Farmer 51	500	1563.42	985.24	36.98%	945.99	39.49%	975.00	37.64%
Farmer 52	101	949.73	264.80	72.12%	453.41	52.26%	571.25	39.85%
Farmer 53	1777	633.06	638.00	-0.78%	612.75	3.21%	619.81	2.09%
Farmer 54	46	88.50	115.29	-30.28%	47.35	46.50%	72.05	18.58%
Farmer 56	646	558.83	528.25	5.47%	444.61	20.44%	473.21	15.32%
Farmer 57	150	741.51	352.24	52.50%	350.30	52.76%	336.12	54.67%
Farmer 58	146	1038.23	367.14	64.64%	457.37	55.95%	455.14	56.16%
Farmer 59	1069	1299.28	1277.96	1.64%	1168.68	10.05%	1166.64	10.21%
Farmer 60	395	821.91	594.27	27.70%	604.69	26.43%	594.19	27.71%
Farmer 62	746	576.95	613.83	-6.39%	460.42	20.20%	452.21	21.62%
Farmer 65	186	332.58	224.18	32.59%	185.74	44.15%	147.98	55.51%
Farmer 66	55	396.20	66.63	83.18%	221.28	44.15%	175.45	55.72%
Farmer 67	101	389.84	139.04	64.33%	197.79	49.26%	185.10	52.52%
Farmer 68	425	422.42	312.87	25.93%	270.08	36.06%	288.46	31.71%
Farmer 69	150	368.44	201.19	45.39%	186.93	49.26%	188.62	48.81%
Farmer 71	246	312.91	174.98	44.08%	142.85	54.35%	130.44	58.31%
Farmer 72	100	324.48	70.35	78.32%	148.13	54.35%	141.96	56.25%
Farmer 73	101	1265.54	348.95	72.43%	455.16	64.03%	465.83	63.19%

Farmer	Loads (boxes)	BAU Transportation Cost (THB)	$y_i(V)$ (THB)	Saving (%)	$y_i(SA)$ (THB)	Saving (%)	Shapley Value Cost (THB)	Saving (%)
Farmer 74	195	1230.84	651.62	47.06%	442.67	64.03%	446.74	63.70%
Farmer 78	589	401.51	394.76	1.68%	373.64	6.94%	366.73	8.66%
Total	**22256**	**30922.13**	**19680.78**	**25.87%**	**19680.78**	**29.55%**	**19680.78**	**30.23%**

Figure 44 shows the cost saving have obviously improved significantly at the level of the individual farmers. However, the results indicate that the operating cost reductions for each participant farmer is different for the two methods. BAU Cost shows the total transportation cost of the participant farmers when currently operating on its own. The remaining line charts present the cost allocation from different cost allocation methods: proportional based on volume ($saving\ V$), proportional based on stand-alone cost ($savingSA$), and the Shapley value ($saving\ SV$).

According to proportional method based on volume, it is interesting to note that farmers such as 19, 42, 52, 54, 66, 67, 71 and 72 who have delivered just below 100 boxes over the 7-month period, received a huge amount of cost reduction averaging at 58.0% of the cost savings, while others reduced their average by 26.3%. In case of the large-scale farmers farms 6, 9, 14, 15, 16, 17, 53, 59, and 62, the cost seems to be slightly reduced with average cost savings of 2.5%. The reason for this is that the weights used to allocate the non-separable cost do not take into account each participant's individual cost and savings. Also, the different in savings for each participant farmer varies greatly, between -30.3% and 83.2% of the savings.

The cost allocations obtained by the Shapley value, and proportional based on stand-alone cost provides relatively stable results over the whole period and have a similar range of the cost saving. The cost saving obtained by the proportional based on stand-alone cost was found to be 29.6%, and 30.2% for the Shapley value method. In this case, it is interesting that the average cost savings among farms 19, 42, 52, 54, 66, 67, 71 and 72 (each under 100 boxes in 7-month) were found to be 48.6%, while others reduced their average by 31.9%. In case of the large-scale farmers 6, 9, 14, 15, 16, 17, 53, 59, and 62, the average cost saving is 7.3%.

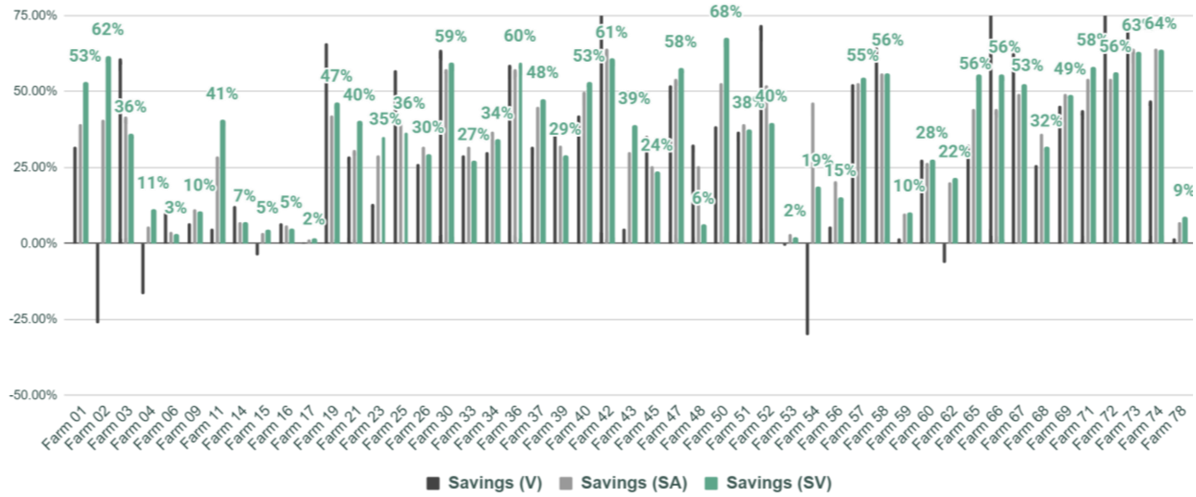


Figure 44 Summary of cost savings in the different cost allocation methods

where

$Saving\ (V)$ – cost savings generated by proportional method based on volume

$Saving\ (SA)$ – cost savings generated by proportional method based on stand-alone cost

$Saving\ (SV)$ – cost savings generated by the Shapley value

The two different cost allocation methods performed well. However, there is no concept that is completely fair, so the method that should be chosen depends on the preference of the participants. The total transportation cost for the coalition when the farmers co-operated together was 19,680.78 THB (£503) a week, a 36% reduction over the BAU scenario 30,922.13 THB (£790). The transportation cost allocation using the Shapley value produced the most equitable distribution of savings between the farmers after giving consideration of farmers' geographical locations, with a mean saving for each farmer of 30.2% over the BAU scenario. The mean savings of the proportional method based on volume was 25.9%, and 29.6% when based on the stand-alone cost.

6.4 Conclusion

This chapter explored how the transportation cost of a new logistics operating scenario could be fairly distributed to assist the rural farmers to manage their collaboration together. The case studies showed how the transportation costs could be distributed using the different cost allocation methods, the proportional and Shapley value methods. The profit gained in the collaboration depends on the gap between the cost in the collaborative and non-collaborative cases. The cost in the collaborative case was based on the transportation scheme given in Chapter 5, while the cost in the non-collaborative case was the sum of each participant farmer's cost when operating alone.

The key results presented in Section 6.3 suggested that cost allocation based on volume produced average cost savings of 25.9%, ranging from -30.3% to 83.2%, the fairness of this method being based on the principle of ‘more pay for more volumes. However, the cost allocation based on volume does not seem to be an appropriate since six farmers are worse off in this allocation compared with their operating alone.

The proportional method based on the stand-alone cost seems to be fairer, based on the weight for cost allocation by considering each participant of the cost object as a separate entity to determine the cost allocation weights. The cost allocation obtained by the stand-alone cost average at 29.6% of the savings, and the saving ranges from 1.4% to 64.0%

In addition, the Shapley value made things fairer by averaging across all possible orders, which considered the marginal cost and the dispersion degree of nodes (farm location) in cost allocation. The cost allocation obtained by the Shapley value averaged 30.2% of savings. The difference in savings for each farmer ranged between at 1.6% and 67.6%, where the savings are as equal as possible.

The results verified the effectiveness of the proposed cost allocation methods, where the transportation costs were distributed fairly among the rural farmers in the collaborative transportation scheme. The two different cost allocation methods – proportional and the Shapley value methods are performed well. However, the method that should be chosen depends on the preference of the participants. If the participants prefer to give the largest possible incentive for flexibility, because this is an important factor to lower the total coalition cost, then the Shapley value method is the best option. However, this method will not always be best in practice. It might be possible to use a cost allocation method that will be similar results but is easier to calculate such the proportional method. Then the proportional method based on volumes or stand-alone cost is clearly to be an option for cost allocation.

Chapter 7 Conclusion

According to the problem stated in section 1.2, rural farmers face losing out on the opportunity to access new lucrative markets, primarily because their logistics infrastructure cannot meet the standards required, which results in considerable product losses and ineffective cost. The Thai government has expressed a need to address this problem, to create a more inclusive operating environment for rural farmer, to ensure that they can remain competitive in the long term. The research therefore aimed to investigate the opportunities for improving the logistics of food supply chain associated with rural farmer, particularly for mango producers in Thailand.

This study has evaluated the financial and environmental implications of introducing shared vehicle collaborative working arrangements to aid rural farmers in Thailand, particularly in mango industry, stay competitive whist reducing their overall CO_2 emissions. Using a significant data set of historic production data, alongside farmer interviews and focus groups, the potential impacts of implementing a shared vehicle methodology were evaluated. In the first approach, farmers would group together and share the capacity of their own vehicles, while in the second a Third-party logistics provider would operate a collection vehicle fleet on behalf of the rural farmers.

7.1 Assessment of Objectives

The following sections present a summary of research results and discuss on the major findings of this research on the research objectives.

Identify business-as-usual food logistics and supply chain management in Thailand's rural agricultural sector, focusing on mango supply chain (Objective 1).

The study provided an overview of the current state of food logistics and supply chain management in Thailand's agricultural, particularly mango supply chain through the farmer organisation chain. The agri-food supply chain in Thailand has formerly relied on traditional markets, but are now transformed with more structured markets, such as supermarket chain. The rapid rise of supermarket chains is driven by change in customer preferences, increasing awareness of food safety, and environmental issues. Therefore, the main challenge for food producer particularly rural famers, is how to produce commodities that meet the specific requirements imposed by the major buyers in terms of quality at a reasonable price. The challenges have been mitigated by the development of specific strategies, such as farmer's organisations – both co-operative and social enterprise – to aid the rural farmers access more agricultural inputs and gain more power of negotiation. However, they are constrained by general assets, in particular the lack of an effective transportation system remains an obstacle for rural farmers to move their products in an efficient way at the correct temperature that comply with market requirements. The inefficient transportation affects the product quality directly, of which 2-5% are getting lost during the transport between farms and the CP, and then up to 5-10% when travelling from the CP to the final markets. Rural farmers are losing possible income due to the products not being moved in the correct way and at the correct temperature. The sampled data showed that product waste during transport between farms and the CP was 430 boxes (10,958 kg) over the harvesting season, with an average 18-45 boxes, 450-1,000 kg per day, resulting in a potential financial loss of 219,00 THB (£5,602) per season, and 547,000 THB (£14,005) in the worst-case (at average 5% loss). This is consistent with elsewhere in Thailand that 3-20% of agricultural products are being lost due to inefficient transportation operations during the post-harvest distribution phase (OAE, 2017). In addition, the Office of Agricultural Economics Thailand (2017) reported that agricultural products losses subsequently increase by 10-30% once at the distribution centre, and 5-15% at the supermarket store itself, which means that up to 65% of the initial product volume can be wasted if the overall logistics process is not effectively managed. Section 4.4.4 shows that the transportation cost was around 12% of the total financial losses from product waste.

Data was gathered during fieldwork from 49 farmers across the Phitsanilok province, Thailand, which were studied in detail to quantify the business-as-usual logistics operations. The data were used to understand how rural farmers currently work to move their produce from farm to the CP and provided a grasp of the key challenges and problems faced by rural farmers. The mangoes were generally collected and delivered to the consolidation point twice a month, with an average of four day’s work for each delivery, using a light pick-up vehicle (load capacity 60 boxes, 1,500 kg) owned by the rural farmers. The farmers agree to a pre-arranged production schedule organised by the social enterprise, harvesting times being managed to prevent over-supply at the consolidation point. The time window opens for rural farmers to drop-off their products at the consolidation point from 6 am each day and finishes at 12 noon. Pre-product processes are then applied, such as cleaning, grading, cutting, and packaging from 1 pm to 6 pm, to make the products ready to ship out in the late evening. This time window ensures that the products will reach the supermarket distribution centre in the early morning of the next day. In addition, the data gathered at the plantations was used to identify the farm locations and routes, and travel distance, and driving times between farms and consolidation point. The plantations can be partitioned into three zones by how far they are from the point of consolidation, of which 19% were located in zone 1 (<5 km on average from the CP), 50% in zone 2 (located 6-10 km away from CP) and 31% located in zone 3 (>10 km away from CP).

A total of 22,256 boxes (547,000 kg) of M1 and M2 mangoes were produced and collected from 49 plantations and delivered to the consolidation point over a 48-day (7-month) operation, between mid-December and early June, generating a total distance driven of 6,415.38 km, a total transportation cost of 30,922.13 THB (£790), and producing 1,536.52 $kgCO_2$/tonne-km of CO_2 emission. In addition, the data showed that, in the BAU situation, farmers use their own vehicles that were only partly filled, to the extent of 51% of the total capacity, with 23,944 empty box spaces still available, which also affects the operational and environmental aspects.

One key problem with the business-as-usual case was the lack of refrigerated transportation used to move the product effectively from farms to the consolidation point. Data collected during the fieldwork showed that on average 2-5% of the products were being damaged during transport and were being rejected by the onward transportation provider. This translated into an average loss of between 18-45 boxes of mangoes, 450-1000 kg per day, leading to annual losses of 219,00 THB (£5,602) per season, and 547,000 THB (£14,005) in the worst-case (at average 5% loss) following the premium grade price. Thus, the average product waste during transport for the individual farmer was found to be 223 kg, leading to financial loss of 4,472 THB (£114) for the individual. This data was used to develop more inclusive collaborative operating scenarios: sharing vehicle through a farmer co-operative and using a Third-party logistics provider vehicle to make a milk-round collection.

> *Determine how appropriate load consolidation would be undertaken for the collective transport of food products over the first mile from rural farmers to the consolidation point (Objective 2).*

The second research question addressed the need to create a more efficient operating environment for rural farmers by improving their transport efficiency and ensure that they remain competitive. Data was gathered on the production of mangoes and used to develop alternative operating scenarios using a range of collaborative logistics options. A novel partial collaborative transportation scheduling strategy was proposed based on two potential operating scenarios: integrating farmers' own vehicle, and Third-party refrigerated vehicles. This approach is of interest of the Thai government as a potential method for better managing the agricultural supply chain, where strategic alliances are built between group of farmers. Collaborative transportation is as a collaborative strategy used successfully to solve transportation problem, particularly in food supply chain (Bosona and Gebresenbet, 2011; Bosona *et al.*, 2013; Fikar and Leithner, 2020). They considered this collaborative strategy as an alternative logistics operating scenarios for food distribution, which returned operational and environmental benefits. Bosona *et al.* (2013) and Bosona and Gebresenbet (2011) suggested that the logistics operating scenario, where the collection and distribution were coordinated, can produce significant improvement by reducing distance vehicles travel, reducing the time driving, and reducing the number of vehicle involved. Burton and Ruediger (2016); Gansterer and Hartl (2020); Gansterer, Hartl and Wieser (2020) found that a cost saving of 20-30% could be generated by fleet collaboration. In addition, Wang *et al.* (2018a), Wang *et al.* (2018b) and Yao, Cheng and Song (2019) demonstrated that collaborative transportation can lead to significant emission reduction through reducing the number of delivery vehicle needed.

Therefore, the CW savings algorithm was found to be sufficiently effective since the routes where quite constrained with the volume capacity and no further local search was really needed to find good routes. The first scenario looked at the merits of implementing a vehicle sharing system via a farmer's co-operative, where rural farmers work together to improve transportation efficiency by maximising vehicle utilisation. In the second scenario, a refrigerated vehicle operated by a Third-party logistics provider would make scheduled collections from individual farmers as part of structured rounds, dropping consolidated loads at the drop-off point for onward collection for the final markets. In this scenario, three different cases were covered, where two different types of vehicles are used and the improvement in transportation efficiency analysed and the reduction in product waste during the transportation process. In addition, a 'best-case' was covered that saw all the farmers willing to share their vehicles and be the transport provider, whilst in the 'worst-case', the large-scale farmers would not be willing to share their vehicles and would go it alone, sticking to their current operation. It was noted that 81% of the rural farmers in the area of study are small-scale farmers who produce small volume of M1 and M2 mangoes, while the remaining 19% are large-scale farmers who produce over 120 boxes per day.

The key results covering the whole period of harvesting were presented in Section 5.1. These show that when farmers agree to share their own vehicles, the number of vehicles involved in the operation reduced by 41% and vehicles visit to farms reduced by 40% (from 770 to 459 round trips) over the BAU situation. This resulted in a reduction in transportation cost of 36% (from 30,922 THB to 19,680 THB), total distances travelled by 36% (6,415 km to 4,083 km), and 28% of CO_2 emissions (1,536 to 1,100 $kgCO_2$/tonne-km), as well as improving vehicle utilisation by reducing empty box spaces by 78% (23,944 to 5,284 boxes). However, when the cost of product waste during transport was considered, the cost was reduced only 4%. Even in the worst-case scenario, where 9 large-scale farmers were assumed to opt out of the collaboration, the vehicle sharing scenario realised a 39% reduction on the number of vehicles needed, and 36% (770 to 492 round trips) on number of vehicles visit to farms, 35% reduction of the total distance travelled (6,415 km to 4,186 km), and 25% reduction on CO_2 emissions (1,536 to 1,158 $kgCO_2$/tonne-km). The total transportation cost was reduced by 35% (30,922 THB to 20,175 THB) and a reduction of 70% (23,944 to 7,264 boxes) of empty box spaces. The results of the case study clearly show that an operation where vehicles are shared between farmers produced both operational and environmental benefits. Bosona *et al.* (2011) and Bosona and Gebresenbet (2011) investigated collaborative first-mile collection particularly in rural areas, and identified a logistics operating scenario where rural farmers co-operate in transportation can significantly reduce the driving distance by 88%, the number of vehicles needed by 48%, and improvement in vehicle utilisation by a reduction of 40% of the empty vehicle spaces. In addition, their study showed that the collaborative transport strategy among food producers could make positive improvements towards improving potential markets, logistics efficiency, and environmental issues.

However, using the farmers' own vehicles does not address the problem of product waste during transport due to a lack of refrigeration. Therefore, the refrigerated vehicle operated by a Third-party logistics provider to make a milk-round collection was investigated. The three different cases were explored using two different types of vehicles, and a mixture. The key results were presented in Section 5.2, and showed that using a Third-party logistics provider with a fleet of mixed light and 20ft refrigerated vehicles performed best when compared that only one type of refrigerated vehicle being used. The total distances travelled reduced by 57% (6,415 km to 2,776 km), the number of vehicles needed reduced by 62%, with a 70% reduction in the number of vehicles visit to farms (770 to 228 round trips). Although using Third-party refrigerated vehicles increased total transportation cost by 190% (30,922 THB to 89,525 THB), but this scenario produces benefit in terms of reduction wastage during transport, where the rural farmers could gain additional revenue from selling those products. Thus, the cost was reduced by 64% (250,086 THB to 89,525 THB), when the cost of product waste was considered. The product waste cost was based on the opportunity of lost sale (20 THB per kg). This logistics operating scenario improved the vehicle utilisation by reducing the empty box spaces by 73% (23,944 to 6,444 boxes). In addition, the total CO_2 emission was reduced by 23% (1,536 to 1,175 kgCO_2/tonne-km) over the BAU scenario. Even in the worst-case scenario, where the large-scale farmers are not willing to cooperate with others and stick to the current operation strategy, the number of vehicles needed was reduced by 58%, and vehicles visit to farms by 51% (770 to 378 round trips), while total distance travelled reduced by 48% (6,415 km to 3,362 km). Vehicle utilisation improved by reducing the empty box spaces by 64% (23,944 to 8,544 boxes). In this case, the transportation cost increased by 106%, but reduced by 29% when the cost of product waste during transport was considered. In addition, the total CO_2 emissions was reduced by 20% (1,536 to 1,224 kgCO_2/tonne-km) over the BAU operations.

Table 36 summarises the key results in the different logistics operating scenarios, sharing vehicle through farmer's co-operative, and using a Third-party refrigerated vehicle to make milk-round collections.

Table 36 Summary of the key results in the different logistics operating scenarios

Scenario	VF_{inv}	VF_{vis}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	ER_{box}	EM_{CO2}
BAU	588	770	6415.38	320.77	10958	219164	30922	250086	23944	1537
Sharing vehicle (Best-case)	355	459	4083.15	204.16	10958	219164	19681	238845	5284	1101
Net Reduction	**242**	**331**	**2332.23**	**6996.69**	**0**	**0**	**11241**	**11241**	**18660**	**436**
	(41%)	(40%)	(36%)	(36%)	-	-	(36%)	(4%)	(78%)	(28%)
Sharing vehicle (Worst-case)	358	492	4185.69	209.2	10958	219164	20175	239339	7264	1159
Net Reduction	**230**	**278**	**2229.69**	**111.48**	**0**	**0**	10747	**10747**	**16680**	**378**
	(39%)	(36%)	(35%)	(35%)	-	-	(35%)	(4%)	(70%)	(25%)
3rd light refrigerated vehicle (Best-case)	255	287	3116.41	155.82	0	0	94768	94768	6444	1197
Net Reduction	**333**	**483**	**3298.97**	**164.95**	**10958**	**219164**	**63846**	**155318**	**17500**	**340**
	(57%)	(63%)	(51%)	(51%)	(100%)	(100%)	(206%)	(62%)	(73%)	(22%)
3rd light refrigerated vehicle (Worst-case)	273	405	3638.03	181.90	5698	113962	70078	184040	8644	1220
Net Reduction	**315**	**365**	**2777.35**	**138.87**	**5260**	**105202**	**39156**	**66046**	**15300**	**317**
	(54%)	(47%)	(43%)	(43%)	(48%)	(48%)	(127%)	(26%)	(64%)	(21%)
3rd 20ft refrigerated vehicle (Best-case)	159	166	2353.49	117.67	0	0	81630	81630	10944	1286
Net Reduction	**429**	**604**	**4061.89**	**203.09**	**10958**	**219164**	**50708**	**168456**	**13000**	**251**
	(73%)	(78%)	(63%)	(63%)	(100%)	(100%)	(164%)	(67%)	(54%)	(16%)
3rd 20ft refrigerated vehicle (Worst-case)	222	354	3148.94	157.45	5698	113962	66262	180224	14944	1287
Net Reduction	**366**	**416**	**3266.44**	**163.32**	**5260**	**105202**	**35340**	**69862**	**9000**	**250**
	(62%)	(54%)	(51%)	(51%)	(48%)	(48%)	(114%)	(28%)	(38%)	(16%)
3rd mixed refrigerated vehicle (Best-case)	223	228	2776.88	138.84	0	0	89526	89526	6444	1176
Net Reduction	**365**	**542**	**3638.50**	**181.93**	**10958**	**219164**	**58604**	**160560**	**17500**	**361**
	(62%)	(70%)	(57%)	(57%)	(100%)	(100%)	(190%)	(64%)	(73%)	(23%)
3rd mixed refrigerated vehicle (Worst-case)	246	378	3362.38	168.12	5698	113962	63729	177691	8544	1225
Net Reduction	**342**	**392**	**3053.00**	**152.65**	**5260**	**105202**	**32807**	**72395**	**15400**	**312**
	(58%)	(51%)	(48%)	(48%)	(48%)	(48%)	(106%)	(29%)	(64%)	(20%)

Fikar and Leithner (2020) identified the benefits of collaborative transport with five different logistics operating scenarios, one of which was all delivery outsourced to a Third-party logistics provider. This produced operational benefits in terms of cost saving, distance driven, and vehicle involved. The results were similar to other collaborative operating scenarios, such as farmers collaborating to jointly deliver order, and food co-operatives collaborating to jointly collect orders. However, the study suggested that if the focus is on food quality, the farmers were advised to use a Third-party vehicle to deliver their product.

In summary, this research found that collaborative transportation both of farmer sharing vehicles through a farmer's co-operative and using Third-party refrigerated vehicles to make milk-round collections, performed well, and realised benefits. These logistics operating scenarios can produce operational benefits in terms of reduced number of vehicles needed, vehicles visit to farms, and probably reduced the transportation costs, as well as environmental benefits in terms reduced distance travelled and CO_2 emissions. A significant advantage of using a Third-party refrigerated vehicle as an appropriate vehicle for collection, is the likely reduction in product waste during transport. In addition, assigning the right fleet to routes increases the vehicle utilisation by reducing empty box spaces. The research finding contributes to progress in best practice – the collective transport of food products over the first-mile phase. This would allow rural farmers to understand the concept of collaborative transportation through the proposed logistics operating scenarios, as well as the operational and environmental benefits.

> *Quantify an accepted cost allocation for sharing the total transportation cost of such a new transportation scheme (Objective 3).*

An important aspect of the collaboration between rural famers is to decide on how to share the benefits and how the total transportation cost should be distributed in a fair way among them.

The two different concepts of cost allocation addressed here, the proportional and the Shapley value methods, were applied in Chapter 6 to demonstrate how the transportation cost can be distributed in a fair way among this specific group of rural farmers. In summary, it can be seen that the cost of each farmer reduces significantly compared to when they operate alone. However, the results highlight the fact that the operating cost reductions for each farmer resulting from the two mechanisms can be different. Section 2.6.2 described that each instance includes multiple possible allocations and that different definitions of fairness in each method can result in different cost allocation.

The proportional cost allocation based on volumes is a simple method that was used to split the transportation costs of the farmers. Its fairness is clearly based on the greater volumes moved, the greater costs the farmers should pay. Guajardo and Rönnqvist (2016) suggested that the fairness can be verify based on a principle of the overall volumes or weight of the product transported. Thus, the total number of boxes contributed by the participant has a large impact on the cost allocation. The results found that the difference in savings for each participant farmer ranging from -30.3% to 83.2% with an average at 25.9%. The proportional cost allocation based on volumes produce an unstable cost allocation since at least six farmers were worse off compared with the farmers working on their own. The cost allocation based on volume weights can also be considered as a simplest method that the farmers use to split transportation costs, and no consideration is taken to the geographical distribution of the collection points.

The cost allocations computed according to the proportional method based on the stand-alone cost and the Shapley value methods seems to be stable compared with the proportional cost allocation method based on volumes. In these cases, the savings does not become negative, and therefore the proportional method based on the stand-alone cost and the Shapley value methods must present a stable cost allocation. Frisk *et al.* (2010) demonstrated that the cost allocation computed according to the Shapley value provide a stable cost allocation, and the savings are as equal as possible.

The cost savings obtained by the stand-alone cost allocation method was found to be 29.6%, the different in savings for each farmer ranging from 1.4% to 64.0%. The Shapley value cost allocation method behaved very similarly, the average cost savings being slightly higher when compared to the proportional based on stand-alone cost method. The average cost savings obtained by the Shapley value was 30.2%, the different in savings for each participant farmer ranging from 1.6% to 67.6%. The transportation cost was based on the average across all possible orders, considering marginal costing and the dispersion degree of nodes (plantation location). Vanovermeire *et al.* (2014) and Kayikci (2020) mentioned that the Shapley value concept is the most commonly used in practice, where cost is distributed according to the weighted average of the marginal contributions of each participant in the coalition.

The experiment has quantified the effectiveness the cost allocations by distributing the transportation costs fairly among a group of rural farmers with a collaborative transportation scheme. The two different cost allocation methods performed well and produced very similar results. Lozano *et al.* (2013); Vanovermeire *et al.* (2014) Frisk *et al.* (2010)and Kayikci (2020) suggested that the cost allocation with the Shapley value method can achieve more cost savings for the participants than other methods. However, there is no concept that is fair to everyone, and the method should be chosen depending on the preference of the participants. If the farmers agree to give the largest possible incentive for flexibility, because this is an important factor to lower the total coalition cost, then the Shapley value method is the best option. However, this method not always be best in practices, and it might be possible to use a cost allocation method that will be behave with similar results but is easier to calculate, such as the proportional method based on stand-alone cost.

7.2 Challenges of Implementing

The key findings discussed in Chapter 5 were presented to the group of rural farmers involved in this research via group discussions. The set of questions listed in Appendix C.6 were used to determine how these proposed transportation schemes would work for the group of farmers, as well as the challenges they would encounter implementing them. The group discussions were carried out remotely (video call – LINE VDO call group) with the two groups of farmers (9 farmers out of 49 from the case study). The results suggested the participant farmers were interested in applying the proposed transportation schemes, particularly the vehicle sharing scenario through a farmer co-operative.

However, the participants were not interested in the scenario where a Third-party refrigerated vehicle was integrated, which resulted from their experiences when hiring the Third-party vehicles. Their experience of hiring a Third-party vehicle operator seems that it was not flexible for their operation, and the farmer had to sign an official contract with the Third-party logistics company, and sometimes even had to pay a deposit. The key issue was their belief that hiring a Third-party vehicle operator would be more costly compared with the BAU operations and is complicated. The results suggested that the overall cost would decrease and that they would gain additional revenue from the reduction of wastage during transportation, but this was not convincing enough for them.

The farmers were interested in applying the shared vehicle scenario by working together in a sub-group. They said the advantages of working together would be an opportunity to improve their transportation efficiency and reduce the cost of delivery, particularly for the small-scale farmers amongst them. The large-scale farmers stated that it would also eliminate the problem of insufficient vehicles, particularly during the high season of harvesting where they have to move their product multi-trips.

In contrast, some farmers believed that the cost reduction from the proposed transportation schemes would not benefit them as much as the subsidy from the Thai government on the selling price. For example, the price offered to farmers was to be raised through direct government purchase to levels about 15% above the prevailing market price per kilogram. In 2019, 7.6 billion THB has been spent under a government subsidy scheme designed to help the mango producers (National Statistical Office, 2018). However, most participants believed that farmers recognise that operational benefits of working together usually result from long-term established relationships. Notable is the different farm sizes as a principal characteristic of rural farmers. Their experiences of small farm size are that they usually generate a small quantity of products (who produced below 120 boxes per day), and this seems to be more suitable for their participation, whilst farmers who have large farm size (who produced over 120 boxes per day) seems to be strict with their current operation and would not be willing to share their vehicle. Participants also voiced concern about the likely increased damage that might be incurred to the farmer who loaded their product onto the vehicle first, once all the other stock was added on top of it. They raised some interesting issues that a collaborative agreement must be agreed to make this operating logistics concept work such as who will take responsibility for the damaged product, who will be doing the driving, and how the costs will be shared.

In addition, the different cost sharing mechanisms were presented to the farmers to identify their opinions on cost allocation. The results showed that the farmers understood the cost sharing systems, the proportional method based on volume seems to be the only method they have experienced. The farmer's experience was that the transportation cost, when hiring other farmers' vehicles, was based on the load volumes or the distance travelled between their farm and the drop-off destination. After being introduced to all cost allocation mechanisms and a description of how each method works, the Shapley value method gained more interest from the farmers. Different cases were discussed, such as farmers who produce small volumes (under 120 boxes per day), a plantation located far away from the consolidation point, and even farmers who produce large volumes (over 120 boxes per day) but whose plantation is adjacent to the consolidation point. The participants realised that the Shapley value method was a fair solution for distributing the transportation cost amongst the farmers when working together. However, the participants mentioned that it was difficult for them to use in practice due to the complicated calculation. They said that they preferred the proportional method based on volume since it is easy to calculate and clear to understand for them.

The results of this study suggest a need for educate and policies that facilitate the integration of small-scale farmers in the collaboration environment. It is expected that the collaborative transport concept will become more pronounced in the near future for the farmer in Thailand. This research findings associated with the small-scale farmers in agricultural co-operatives and social enterprises can provide useful inputs for famers and policy makers interested in promoting collaborative transport concept for small-scale farmers.

Future evolution of small-scale farmers coping with agri-food industry transformation particularly the standard requirements will have to examine their own selection whether they are appropriate in working alone. The farmers have to consider for a collaboration concept as the research findings suggested that when the farmers are working together can produce better benefits for both operational and environmental benefits compared with the farmers working on their own. As they cannot avoid the collaboration concept, they will have to adjust themselves so that they can survive in the industry.

7.3 Contribution

The main contribution of this research is an empirical illustration of the potential operating scenarios for effective collective transport in the first-mile stage to better serve for rural farmers, establishing horizontal coordinated relationships between them, in which all parties benefit. The situation when rural farmers co-operate is important in order to improve their transportation efficiency. These results provide an important source of knowledge that can be used for ensuring best practices, aimed at enhancing the rural farmers' capability to remain competitive. The potential operating scenarios have also been very useful for explaining the potential benefits and cost allocation in such a new transportation scheme. This research has assessed the different cost allocation mechanisms, and its results prove that collaboration can achieve greater cost savings for the farmers than operating alone. The role of cost allocation is to assist rural farmers manage their collaboration together.

In addition, the analysis framework and research findings presenting the results how a range of different collaborative transport as proposed logistics operating scenarios might benefit rural farmers. As mentioned in section 2.1.1 that there were four major economic fruits, durian, longan, mangosteen, and mango. Where the rural farmers who produce these products are very similar to the farmers who produce mango in terms of working together in the co-operative and/or social enterprise and the majority of them are small-scale farmers with an average farm size 25 rai[18] (4.04 hectares) per household. In term of production, durian was produced 1.1 million tons annually with average 1,395 tons per rai, while the small-scale farmer produces only 540 tons. Longan was produced 1.2 million tons with average 722 tons per rai, and small-scale farmer produces only 88 tons. While mangosteen was slightly lower when compared to other fruits, the product was produced 0.3 million tons with average 442 tons per rai, and small-scale farmer produces only 85 tons (National Statistical Office, 2018). In term of transportation, particularly at first-mile collection, the light pick-up vehicle (non-refrigerated vehicle with loading capacity at 60 boxes) was dominated and commonly used by the rural farmers for moving their products between farm and consolidation point. In the BAU operations, the rural farmers generally harvested and moved the product to the next state of production processes at the consolidation point with located in the same area of their production areas. In addition, the standard container box (size 37 x 55.5 x 30.5 cm) was primarily used to store and transport products similar to moving the mango.

Although product losses during transportation particularly first-mile collection seem to be a minor problem for rural farmers who produce durian, longan, or mangosteen (the product lost rate was similar to mango at 1-2% (OAE, 2017)), even the optimal temperature to be maintained during transport is between 15°C and 18°C for these products with recommended by the Thailand National Bureau of Agricultural Commodity and Food Standards. Because these products have a hard outer shell protecting the soft flesh inside and the price does not indicate from surface or colour as much as mango. However, a damaged product during transport such as product crack and inefficient transportation causes unnecessary costs and polluting emissions as same as in the mango supply

[18] 1 rai = 0.16 hectares

chain. In case of durian, the transportation cost during primary distribution phase between farm and consolidation point was found to be 6.1% of the overall cost, and the cost was increased to 34.46% when the cost product wastage during transport was considered (Nuannoi, 2019). While in case of longan, the transportation cost for moving product was found to be 10.2% of the total cost, and the cost was increased to 39.5% when the cost of product wastage was considered (Mimkrathok et al., 2016). Therefore, the computational results in Chapter 5 support the collaborative transportation concept, and these not only for the mango producers but also can be potential used for other spatial contexts and agricultural products.

7.4 Limitations

There is no reliable source of public statistics available from government offices on the production processes of individual rural farmers. The quantitative data from government sources are mainly historical production records, based on the overall production in the regions. Therefore, new primary data is required, obtained through in-depth interviews and focus group discussion with groups of rural farmers to yield quantitative data of each farm's production.

Because of time and budget constraints, this research could cover only three co-operatives and one social enterprise, and these had a relatively small sample size. This research was able to develop alternative logistics operating scenarios to compare with BAU only for a limited range of a group of farmers from the HL social enterprise.

GIS rural data were not generally available. Obtaining accurate routing information is vital for realistic simulation and scenario development. This is made more important where the geographical terrain is challenging, and secondary (rural) road systems are predominant. Finally, a group discussion, where the key findings were fed back to the rural farmers, could cover only a small group of farmers due to the COVID-19 situation. The research was able to discuss and receive some feedback only a limited range of farmers.

7.5 Further Work

It is recommended that a survey be conducted in other social enterprise schemes or other groups of farmers for comparison with the current results. The work needs extending to other food groups, such as fruits and vegetables that require temperature control, as well as products stored at ambient temperature. To facilitate collaborative logistics, various related legal and regulative settings need to be investigated in more detail. For example, issues to be resolved include insurance and liability, and who is responsible for lost or damaged products during transport. Studies focussing on social aspects and group decision-making are of interest to support successful and sustainable real-world implementations of collaborative transport among rural farmers. This is to help rural farmers make decisions whether they should co-operate together.

Appendix A Business-as-Usual Operations

A.1 Business-as-Usual Transportation Operations

The collected quantitative data of BAU operations over the 7-month period between 18 December 2017 and 4 June 2018 were used to creating a production and logistics database. This information was used to provide the base calculation, the transportation cost structure, distance travelled, time taken, utilised and space vehicle capacity, and CO_2 emissions in the BAU operations. A Table A-37 show the transportation routes, vehicle loading sizes, time operation, and distance travelled between 49 farms and the consolidation point (CP) in the current operation of M1 and M2 mangoes over 7-month operations. The collected data will be used to develop alternative logistics operating scenarios as demonstrated in Chapter 5.

Table A-37 The BAU transportation of M1 and M2 mangoes over 7-month operations from 18 December 2017 and 4 June 2018

Farmers	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farmer 01	12	165	4000	32.64	1.63	80	1600	157.32	1757.32	13.11	555	7.12
Farmer 02	12	195	4800	23.76	1.19	96	4800	114.52	5075.32	9.54	525	5.30
Farmer 03	12	186	4400	102.00	5.10	88	14400	491.64	14948.37	40.97	534	22.19
Farmer 04	17	539	13206	51.00	2.55	264	9600	245.82	10030.14	14.46	481	13.48
Farmer 06	20	900	22400	132.00	6.60	448	24000	636.24	25046.52	31.81	300	38.38
Farmer 09	19	778	19200	76.00	3.80	384	13680	366.32	14393.07	19.28	362	21.42
Farmer 11	17	486	12000	57.12	2.86	240	960	275.32	1253.83	16.20	534	14.27
Farmer 14	31	1446	36000	113.77	5.69	720	1920	548.37	2034.52	17.69	414	33.36
Farmer 15	23	965	24000	89.24	4.46	480	3760	430.14	4170.28	18.70	415	25.18
Farmer 16	46	2400	60000	217.12	10.86	1200	3840	1046.52	4356.90	22.75	360	64.90
Farmer 17	26	1378	34200	147.94	7.40	684	2000	713.07	2436.11	27.43	182	44.88
Farmer 19	12	100	2400	60.96	3.05	48	2560	293.83	3036.60	24.49	620	11.75
Farmer 21	14	389	9400	85.12	4.26	188	1760	410.28	2251.64	29.31	451	20.76
Farmer 23	14	389	9600	107.24	5.36	192	1440	516.90	1973.86	36.92	451	26.83
Farmer 25	12	200	5000	90.48	4.52	100	5760	436.11	6704.77	36.34	520	20.46
Farmer 26	12	265	6400	98.88	4.94	128	3840	476.60	4665.28	39.72	455	23.21
Farmer 30	12	150	3600	110.76	5.54	72	2000	533.86	2614.84	44.49	570	23.45
Farmer 33	17	581	14400	196.01	9.80	288	2640	944.77	3312.68	55.57	439	52.92
Farmer 34	14	389	9600	171.22	8.56	192	4800	825.28	6015.17	58.95	451	42.84
Farmer 36	12	200	5000	127.56	6.38	100	5282	614.84	5528.22	51.24	520	28.84
Farmer 37	12	275	6600	139.56	6.98	132	1760	672.68	2733.45	56.06	445	32.38
Farmer 39	17	492	12000	252.11	12.61	240	400	1215.17	1551.02	71.48	528	61.66
Farmer 40	12	186	4400	201.96	10.10	88	3520	973.45	3922.57	81.12	534	43.24
Farmer 42	12	46	1000	238.80	11.94	20	4800	1151.02	5679.22	95.92	674	40.71
Farmer 43	12	358	8800	83.52	4.18	176	960	402.57	1544.18	33.55	362	20.88
Farmer 45	17	486	12000	182.41	9.12	240	2880	879.22	3394.20	51.72	534	45.57
Farmer 47	12	100	2400	121.20	6.06	48	1920	583.18	2655.72	48.68	620	23.35
Farmer 48	12	293	7200	106.68	5.33	144	4960	514.20	6523.42	42.85	427	25.51
Farmer 50	12	195	4800	152.64	7.63	96	880	735.72	1829.73	61.31	525	34.08
Farmer 51	17	500	12400	324.36	16.22	248	17722	1563.42	18354.66	91.97	520	82.45
Farmer 52	12	101	2200	197.04	9.85	44	400	949.73	488.50	79.14	619	37.34
Farmer 53	33	1777	44304	131.34	6.57	886	6400	633.06	6958.83	19.18	203	39.77
Farmer 54	12	46	1000	18.36	0.92	20	1440	88.50	2181.51	7.37	674	3.13
Farmer 56	17	646	16000	115.94	5.80	320	1360	558.83	2398.23	32.87	374	32.38
Farmer 57	12	150	3600	153.84	7.69	72	10560	741.51	11859.28	61.79	570	32.57
Farmer 58	12	146	3400	215.40	10.77	68	8960	1038.23	9596.24	86.32	574	44.92

Appendix A

Farmers	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farmer 59	23	1069	26400	269.56	13.48	528	3920	1299.28	4741.91	56.49	311	78.30
Farmer 60	14	395	9800	170.52	8.53	196	7360	821.91	7936.95	58.71	445	43.01
Farmer 62	19	746	18400	119.70	5.99	368	1760	576.95	2092.58	30.37	394	33.37
Farmer 65	12	186	4400	69.00	3.45	88	480	332.58	876.20	27.72	534	15.01
Farmer 66	12	55	1200	82.20	4.11	24	880	396.20	1269.84	33.02	665	14.27
Farmer 67	12	101	2200	80.88	4.04	44	4160	389.84	4582.42	32.49	619	15.33
Farmer 68	14	425	10400	87.64	4.38	208	1440	422.42	1808.44	30.17	415	22.44
Farmer 69	12	150	3600	76.44	3.82	72	2400	368.44	2712.91	30.70	570	16.18
Farmer 71	12	246	6000	64.92	3.25	120	960	312.91	1284.48	26.08	474	14.91
Farmer 72	12	100	2400	67.32	3.37	48	880	324.48	2145.54	27.04	620	12.97
Farmer 73	12	101	2200	262.56	13.13	44	1920	1265.54	3150.84	105.46	619	49.75
Farmer 74	12	195	4800	255.36	12.77	96	5760	1230.84	6161.51	102.57	525	57.01
Farmer 78	17	589	14400	83.30	4.17	288	7680	401.51	8046.32	23.62	431	22.51
Total	**770**	**22256**	**547910**	**6415.38**	**320.77**	**10958**	**219164**	**30922**	**250086**	**-**	**23944**	**1536.52**

Appendix B CW Savings Computation Results

B.1 Sharing Vehicles Through a Farmer Co-operative

The first scenario looked at the merits of implementing a vehicle sharing system via a farmer's co-operative where the light pick-up vehicle used by the rural farmers were shared to improve transportation efficiency by maximising vehicle utilisation. Two situations were considered where the 'best-case' saw all the farmers willing to share their vehicles as presented in Table B-38, whilst in the 'worst-case' the large-scale farmers would not be willing to share their vehicle as presented in Table B-39.

Table B-38 The results of sharing vehicle scenario when farmers agreed to share their vehicle capacity from12-15 March 2018 (best-case situation)

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farm 2(816) - Farm 9(264) - Farm 14(120) - CP - Farm 2	1	1	49	1200	5.76	0.29	24.00	480.00	27.76	507.76	27.76	11	1.49
Farm 9(3000) - CP - Farm 9	1	2	120	3000	8.00	0.40	60.00	1200.00	38.56	1238.56	19.28	0	2.59
Farm14(6000) - CP - Farm 14	1	4	240	6000	14.68	0.73	120.00	2400.00	70.76	2470.76	17.69	0	4.75
Farm 21(1428) - CP - Farm 21	1	1	58	1428	6.08	0.30	28.56	571.20	29.31	600.51	29.31	2	1.87
Farm 25(850) - Farm 21(170) - CP - Farm 25	1	1	41	1020	8.11	0.41	20.40	408.00	39.09	447.09	39.09	19	2.24
Farm 30(612) - Farm 36(850) - CP - Farm 30	1	1	59	1462	11.28	0.56	29.24	584.80	54.37	639.17	54.37	1	3.55
Farm 33(1500) - CP - Farm 33	1	1	60	1500	11.53	0.58	30.00	600.00	55.57	655.57	55.57	0	3.73
Farm 33(948) - Farm 34(132) - CP - Farm 33	1	1	44	1080	12.33	0.62	21.60	432.00	59.43	491.43	59.43	16	3.60
Farm 34(1500) - CP - Farm 34	1	1	60	1500	12.23	0.61	30.00	600.00	58.95	658.95	58.95	0	3.95
Farm 43(1496) - CP - Farm 43	1	1	60	1496	6.96	0.35	29.92	598.40	33.55	631.95	33.55	0	2.24
Farm 45(1500) - CP - Farm 45	1	1	60	1500	10.73	0.54	30.00	600.00	51.72	651.72	51.72	0	3.47
Farm 45(540) - Farm 52(374) - Farm 54(170) - CP - Farm 45	1	1	45	1084	18.04	0.90	21.68	433.60	86.95	520.55	86.95	15	5.29
Farm 57(612) - Farm 50(816) - CP - Farm 57	1	1	58	1428	15.30	0.77	28.56	571.20	73.75	644.95	73.75	2	4.71
Farm 11(1500) - CP - Farm 11	1	1	60	1500	3.36	0.17	30.00	600.00	16.20	616.20	16.20	0	1.09
Farm 11(540) - Farm 1(680) - CP - Farm 11	1	1	50	1220	3.44	0.17	24.40	488.00	16.58	504.58	16.58	10	0.90
Farm 16(10200) - CP - Farm 16	1	7	408	10200	33.04	1.65	204.00	4080.00	159.25	4239.25	22.75	12	10.38
Farm 17(5814) - CP - Farm 17	1	4	233	5814	22.76	1.14	116.28	2325.60	109.70	2435.30	27.43	7	7.13
Farm 19(408) - Farm 3(748)- CP - Farm 19	1	1	48	1156	8.06	0.40	23.12	462.40	38.85	501.25	38.85	12	2.01
Farm 56(2720) - CP - Farm 56	1	2	109	2720	13.64	0.68	54.40	1088.00	65.74	1153.74	32.87	11	4.00
Farm 6(3808) - CP - Farm 6	1	3	153	3808	19.80	0.99	76.16	1523.20	95.44	1618.64	31.81	27	5.71
Farm 15(4080) - CP - Farm 15	1	3	164	4080	11.64	0.58	81.60	1632.00	56.10	1688.10	18.70	16	3.64
Farm 47(408) - Farm 60(166) - CP - Farm 47	1	1	24	574	13.88	0.69	11.48	229.60	66.90	296.50	66.90	36	3.03
Farm 51(1500) - CP - Farm 51	1	1	60	1500	19.08	0.95	30.00	600.00	91.97	691.97	91.97	0	6.17
Farm 53(7500) - CP - Farm 53	1	5	300	7500	19.90	1.00	150.00	3000.00	95.92	3095.92	19.18	0	6.43
Farm 58(578) - Farm 51(608) - CP - Farm 58	1	1	49	1186	19.16	0.96	23.72	474.40	92.35	566.75	92.35	11	4.90
Farm 59(4488) - CP - Farm 59	1	3	180	4488	35.16	1.76	89.76	1795.20	169.47	1964.67	56.49	0	11.34
Farm 60(1500) - CP - Farm 60	1	1	60	1500	12.18	0.61	30.00	600.00	58.71	658.71	58.71	0	3.94
Farm 4(2244) - CP - Farm 4	1	2	90	2244	6.00	0.30	44.88	897.60	28.92	926.52	14.46	30	1.82
Farm 23(1500) - CP - Farm 23	1	1	60	1500	7.66	0.38	30.00	600.00	36.92	636.92	36.92	0	2.48
Farm 26(1088) - CP - Farm 26	1	1	45	1088	8.24	0.41	21.76	435.20	39.72	474.92	39.72	15	2.43
Farm 37(1122) - Farm 23(132) - CP - Farm 37	1	1	52	1254	12.04	0.60	25.08	501.60	58.03	559.63	58.03	8	3.25
Farm 39(1500) - CP - Farm 39	1	1	60	1500	14.83	0.74	30.00	600.00	71.48	671.48	71.48	0	4.79
Farm 40(748) - Farm 39(540) -CP - Farm 40	1	1	53	1288	18.03	0.90	25.76	515.20	86.90	602.10	86.90	7	5.00
Farm 48(1224) - CP - Farm 48	1	1	49	1224	8.89	0.44	24.48	489.60	42.85	532.45	42.85	11	2.34

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farm 62(3000) - CP - Farm 62	1	2	120	3000	12.60	0.63	60.00	1200.00	60.73	1260.73	30.37	0	4.07
Farm 65(748) - Farm 62(128) - Farm 66(204) - CP - Farm 65	1	1	46	1080	7.66	0.38	21.60	432.00	36.92	468.92	36.92	14	1.78
Farm 67(374) - Farm 69(612) Farm 68(408) - CP -Farm 67	1	1	58	1394	9.86	0.49	27.88	557.60	47.53	605.13	47.53	2	2.96
Farm 68(1360) - CP - Farm 68	1	1	55	1360	6.26	0.31	27.20	544.00	30.17	574.17	30.17	5	1.83
Farm 72(408) - Farm 71(1020) - CP - Farm 72	1	1	58	1428	5.61	0.28	28.56	571.20	27.04	598.24	27.04	2	1.73
Farm 73(374) - Farm 74(816) - Farm 42(170) - CP - Farm 73	1	1	56	1360	25.66	1.28	27.20	544.00	123.68	667.68	123.68	4	7.52
Farm 78(2448) - CP - Farm 78	1	2	99	2448	9.80	0.49	48.96	979.20	47.24	1026.44	23.62	21	2.86
Total	**41**	**68**	**3753**	**93112**	**529.27**	**26.46**	**1862.24**	**37244.80**	**2551.08**	**39795.88**	**45.56**	**327**	**159.02**

Table B-39 The results of sharing vehicle scenario when farmers agreed to share their vehicle capacity from 12-15 March 2018 (worst-case situation)

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farm 2(816) - CP - Farm 2	1	1	33	816	1.98	0.10	16.32	326.40	9.54	335.94	9.54	27	0.52
Farm 9(3264) - CP - Farm 9	1	3	131	3264	12.00	0.60	65.28	1305.60	57.84	1363.44	19.28	49	3.41
Farm14(6120) - CP - Farm 14	1	5	245	6120	18.35	0.92	122.40	2448.00	88.45	2536.45	17.69	55	5.65
Farm 21(1428) - CP - Farm 21	1	1	58	1428	6.08	0.30	28.56	571.20	29.31	600.51	29.31	2	1.87
Farm 25(850) - Farm 21(170) - CP - Farm 25	1	1	41	1020	8.11	0.41	20.40	408.00	39.09	447.09	39.09	19	2.37
Farm 30(612) - Farm 36(850) - CP - Farm 30	1	1	59	1462	11.28	0.56	29.24	584.80	54.37	639.17	54.37	1	3.55
Farm 33(1500) - CP - Farm 33	1	1	60	1500	11.53	0.58	30.00	600.00	55.57	655.57	55.57	0	3.73
Farm 33(948) - Farm 34(132) - CP - Farm 33	1	1	44	1080	12.33	0.62	21.60	432.00	59.43	491.43	59.43	16	3.71
Farm 34(1500) - CP - Farm 34	1	1	60	1500	12.23	0.61	30.00	600.00	58.95	658.95	58.95	0	3.95
Farm 43(1496) - CP - Farm 43	1	1	60	1496	6.96	0.35	29.92	598.40	33.55	631.95	33.55	0	2.24
Farm 45(1500) - CP - Farm 45	1	1	60	1500	10.73	0.54	30.00	600.00	51.72	651.72	51.72	0	3.47
Farm 45(540) - Farm 52(374) - Farm 54(170) - CP - Farm 45	1	1	45	1084	18.04	0.90	21.68	433.60	86.95	520.55	86.95	15	5.44
Farm 57(612) - Farm 50(816) - CP - Farm 57	1	1	58	1428	15.30	0.77	28.56	571.20	73.75	644.95	73.75	2	4.71
Farm 11(1500) - CP - Farm 11	1	1	60	1500	3.36	0.17	30.00	600.00	16.20	616.20	16.20	0	1.09
Farm 11(540) - Farm 1(680) - CP - Farm 11	1	1	50	1220	3.44	0.17	24.40	488.00	16.58	504.58	16.58	10	0.90
Farm 16(10200) - CP - Farm 16	1	7	408	10200	33.04	1.65	204.00	4080.00	159.25	4239.25	22.75	12	10.38
Farm 17(5814) - CP - Farm 17	1	4	233	5814	22.76	1.14	116.28	2325.60	109.70	2435.30	27.43	7	7.13
Farm 19(408) - Farm 3(748)- CP - Farm 19	1	1	48	1156	8.06	0.40	23.12	462.40	38.85	501.25	38.85	12	2.01
Farm 56(2720) - CP - Farm 56	1	2	109	2720	13.64	0.68	54.40	1088.00	65.74	1153.74	32.87	11	4.00
Farm 6(3808) - CP - Farm 6	1	3	153	3808	19.80	0.99	76.16	1523.20	95.44	1618.64	31.81	27	6.01
Farm 15(4080) - CP - Farm 15	1	3	164	4080	11.64	0.58	81.60	1632.00	56.10	1688.10	18.70	16	3.68

Appendix B

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farm 47(408) - Farm 60(166) - CP - Farm 47	1	1	24	574	13.88	0.69	11.48	229.60	66.90	296.50	66.90	36	3.66
Farm 51(1500) - CP - Farm 51	1	1	60	1500	19.08	0.95	30.00	600.00	91.97	691.97	91.97	0	6.17
Farm 53(7500) - CP - Farm 53	1	5	300	7500	19.90	1.00	150.00	3000.00	95.92	3095.92	19.18	0	6.43
Farm 58(578) - Farm 51(608) - CP - Farm 58	1	1	49	1186	19.16	0.96	23.72	474.40	92.35	566.75	92.35	11	4.90
Farm 59(4488) - CP - Farm 59	1	3	180	4488	35.16	1.76	89.76	1795.20	169.47	1964.67	56.49	0	11.34
Farm 60(1500) - CP - Farm 60	1	1	60	1500	12.18	0.61	30.00	600.00	58.71	658.71	58.71	0	3.94
Farm 4(2244) - CP - Farm 4	1	2	90	2244	6.00	0.30	44.88	897.60	28.92	926.52	14.46	30	1.86
Farm 23(1500) - CP - Farm 23	1	1	60	1500	7.66	0.38	30.00	600.00	36.92	636.92	36.92	0	2.48
Farm 26(1088) - CP - Farm 26	1	1	45	1088	8.24	0.41	21.76	435.20	39.72	474.92	39.72	15	2.49
Farm 37(1122) - Farm 23(132) - CP - Farm 37	1	1	52	1254	12.04	0.60	25.08	501.60	58.03	559.63	58.03	8	3.25
Farm 39(1500) - CP - Farm 39	1	1	60	1500	14.83	0.74	30.00	600.00	71.48	671.48	71.48	0	4.79
Farm 40(748) - Farm 39(540) -CP - Farm 40	1	1	53	1288	18.03	0.90	25.76	515.20	86.90	602.10	86.90	7	5.00
Farm 48(1224) - CP - Farm 48	1	1	49	1224	8.89	0.44	24.48	489.60	42.85	532.45	42.85	11	2.34
Farm 62(3128) - CP - Farm 62	1	3	126	3128	18.90	0.95	62.56	1251.20	91.10	1342.30	30.37	54	5.37
Farm 65(748) - Farm 66(204) - CP - Farm 65	1	1	40	952	7.48	0.37	19.04	380.80	36.05	416.85	36.05	20	2.12
Farm 67(374) - Farm 69(612) Farm 68(408) - CP -Farm 67	1	1	58	1394	9.86	0.49	27.88	557.60	47.53	605.13	47.53	2	2.96
Farm 68(1360) - CP - Farm 68	1	1	55	1360	6.26	0.31	27.20	544.00	30.17	574.17	30.17	5	1.83
Farm 72(408) - Farm 71(1020) - CP - Farm 72	1	1	58	1428	5.61	0.28	28.56	571.20	27.04	598.24	27.04	2	1.73
Farm 73(374) - Farm 74(816) - Farm 42(170) - CP - Farm 73	1	1	56	1360	25.66	1.28	27.20	544.00	123.68	667.68	123.68	4	7.52
Farm 78(2448) - CP - Farm 78	1	2	99	2448	9.80	0.49	48.96	979.20	47.24	1026.44	23.62	21	2.86
Total	**41**	**71**	**3753**	**93112**	**539.28**	**26.96**	**1862.24**	**37244.80**	**2599.33**	**39844.13**	**45.09**	**507**	**162.86**

B.2 Third-party Refrigerated Fleets Making Milk-round Collection

This scenario, the study explores the three different cases, where two different types of vehicles are used and analyses the improvement in transportation efficiency and reduction in the product waste during the transportation process. These scenarios arise from the fact that only one of the vehicle types is used (two scenarios) or both are used simultaneously in the same routing plan.

B.2.1 Light Refrigerated Vehicles

Table B-40 show the results when the light refrigerated vehicles operated by the 3PL provider were used to make milk-round collections in the 'best-case' situation where all the rural farmers are willing to cooperate. While the results in the 'worst-case' situation where the large-scale farmers were assumed to opt out of the collaborations as presented in Table B-41.

Table B-40 The results of assigning the light refrigerated vehicles to make a milk-round collections from 12-15 March 2018 (best-case situation)

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
CP - Farm 9(2500) - CP	1	1	100	2500	4.00	0.20	0.00	0.00	308.17	308.17	30.88	0	1.84
CP - Farm 14(6120) - CP	1	3	245	6120	11.01	0.55	0.00	0.00	362.29	362.29	85.00	55	4.77
CP - Farm 25(850) - Farm 21(1598) - CP	1	1	99	2448	8.11	0.41	0.00	0.00	339.90	339.90	62.61	1	3.65
CP - Farm 33(2448) - CP	1	1	98	2448	11.53	0.58	0.00	0.00	366.30	366.30	89.01	2	5.18
CP - Farm 36(850) - Farm 30(612) - Farm 9(764) - CP	1	1	90	2226	12.08	0.60	0.00	0.00	370.55	370.55	93.26	10	4.94
CP - Farm 34(1632) - Farm 2(816) - CP	1	1	99	2448	12.42	0.62	0.00	0.00	373.17	373.17	95.88	1	5.58
CP - Farm 43(1496) - CP	1	1	60	1496	6.96	0.35	0.00	0.00	331.02	331.02	53.73	40	2.51
CP - Farm 45(2040) - CP	1	1	82	2040	10.73	0.54	0.00	0.00	360.13	360.13	82.84	18	4.02
CP - Farm 54(170) - Farm 57(612) - Farm 52(374) - Farm 50(816) - CP	1	1	81	1972	19.63	0.98	0.00	0.00	428.83	428.83	151.54	19	7.11
CP - Farm 1(680) - Farm 19(408) - Farm 3(748) - CP	1	1	76	1836	8.99	0.45	0.00	0.00	346.69	346.69	69.40	24	3.03
CP - Farm 11(2040) - CP	1	1	82	2040	3.36	0.17	0.00	0.00	303.23	303.23	25.94	18	1.26
CP - Farm 16(10000) - CP	1	4	400	10000	18.88	0.94	0.00	0.00	423.04	423.04	145.75	0	8.67
CP - Farm 16(200) - Farm 17(814) - Farm 56(220) - CP	1	1	50	1234	12.19	0.61	0.00	0.00	371.40	371.40	94.11	50	5.12
CP - Farm 17(5000) - CP	1	2	200	5000	11.38	0.57	0.00	0.00	365.14	365.14	87.85	0	5.22
CP - Farm 56(2500) - CP	1	1	100	2500	6.82	0.34	0.00	0.00	329.94	329.94	52.65	0	3.13
CP - Farm 6(2500) - CP	1	1	100	2500	6.60	0.33	0.00	0.00	328.24	328.24	50.95	0	3.03
CP - Farm 15(4080) - CP	1	2	164	4080	7.76	0.39	0.00	0.00	337.20	337.20	59.91	36	3.26
CP - Farm 51(2108) - CP	1	1	85	2108	19.08	0.95	0.00	0.00	424.59	424.59	147.30	15	7.38
CP - Farm 53(7500) - CP	1	3	300	7500	11.94	0.60	0.00	0.00	369.47	369.47	92.18	0	5.48
CP - Farm 58(578) - Farm 47(408) - Farm 6(1308) - CP	1	1	94	2294	23.32	1.17	0.00	0.00	457.32	457.32	180.03	6	9.82
CP - Farm 59(4488) - CP	1	2	180	4488	23.44	1.17	0.00	0.00	458.25	458.25	180.96	20	9.66
CP - Farm 60(1666) - CP	1	1	67	1666	12.18	0.61	0.00	0.00	371.32	371.32	94.03	33	4.88
CP - Farm 4(2244) - CP	1	1	90	2244	3.00	0.15	0.00	0.00	300.45	300.45	23.16	10	1.24
CP - Farm 26(1088) - Farm 48(1224) - CP	1	1	94	2312	17.06	0.85	0.00	0.00	408.99	408.99	131.70	6	7.24
CP - Farm 39(2040) - CP	1	1	82	2040	14.83	0.74	0.00	0.00	391.78	391.78	114.49	18	5.55
CP - Farm 23(1632) - CP	1	1	66	1632	7.66	0.38	0.00	0.00	336.43	336.43	59.14	34	3.01
CP - Farm 62(2500) - CP	1	1	100	2500	6.30	0.32	0.00	0.00	325.93	325.93	48.64	0	2.89
CP - Farm 66(204) - Farm 65(748) - Farm 37(1122) - CP	1	1	86	2074	17.32	0.87	0.00	0.00	411.00	411.00	133.71	14	6.60
CP - Farm 68(1768) - Farm 69(612) - CP	1	1	97	2380	7.99	0.40	0.00	0.00	338.97	338.97	61.68	3	3.49
CP - Farm 67(374) - Farm 72(408) - Farm 71(1020) - Farm 62(628) - CP	1	1	100	2430	9.00	0.45	0.00	0.00	346.77	346.77	69.48	0	4.02
CP - Farm 74(816) - Farm 73(374) - Farm 42(170) - Farm 40(748) - CP	1	1	87	2108	26.31	1.32	0.00	0.00	480.40	480.40	203.11	13	10.18
CP - Farm 78(2448) - CP	1	1	99	2448	4.90	0.25	0.00	0.00	315.12	315.12	37.83	1	2.20
Total	**32**	**42**	**3753**	**93112**	**376.78**	**18.84**	**0**	**0**	**11782.02**	**11782.02**	**90.90**	**447**	**155.94**

Table B-41 The results of assigning the light refrigerated vehicles to make a milk-round collections from 12-15 March 2018 (worst-case situation)

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farm 9(3264) - CP - Farm 9	1	3	131	3264	12.00	0.60	65.28	1305.60	57.84	1363.44	57.84	49	3.41
Farm14(6120) - CP - Farm 14	1	5	245	6120	18.35	0.92	122.40	2448.00	88.45	2536.45	88.45	55	5.65
CP - Farm 25(850) - Farm 21(1598) - CP	1	1	99	2448	8.11	0.41	0.00	0.00	339.90	339.90	62.61	1	3.65
CP - Farm 33(2448) - CP	1	1	98	2448	11.53	0.58	0.00	0.00	366.30	366.30	89.01	2	5.18
CP - Farm 36(850) - Farm 30(612) - CP	1	1	59	1462	11.28	0.56	0.00	0.00	364.37	364.37	87.08	41	3.97
CP - Farm 34(1632) - Farm 2(816) - CP	1	1	99	2448	12.42	0.62	0.00	0.00	373.17	373.17	95.88	1	5.58
CP - Farm 43(1496) - CP	1	1	60	1496	6.96	0.35	0.00	0.00	331.02	331.02	53.73	40	2.51
CP - Farm 45(2040) - CP	1	1	82	2040	10.73	0.54	0.00	0.00	360.13	360.13	82.84	18	4.02
CP - Farm 54(170) - Farm 57(612) - Farm 52(374) - Farm 50(816) - CP	1	1	81	1972	19.63	0.98	0.00	0.00	428.83	428.83	151.54	19	7.11
CP - Farm 11(2040) - CP	1	1	82	2040	3.36	0.17	0.00	0.00	303.23	303.23	25.94	18	1.26
Farm 16(10200) - CP - Farm 16	1	7	408	10200	33.04	1.65	204.00	4080.00	159.25	4239.25	22.75	12	10.38
Farm 17(5814) - CP - Farm 17	1	4	233	5814	22.76	1.14	116.28	2325.60	109.70	2435.30	109.70	7	7.13
CP - Farm 56(2500) - CP	1	1	100	2500	6.82	0.34	0.00	0.00	329.94	329.94	52.65	0	3.13
CP - Farm 56(220) - Farm 1(680) - Farm 19(408) - Farm 3(748) - CP	1	1	85	2056	13.09	0.65	0.00	0.00	378.34	378.34	101.05	15	4.94
Farm 6(3808) - CP - Farm 6	1	3	153	3808	19.80	0.99	76.16	1523.20	95.44	1618.64	95.44	27	6.01
Farm 15(4080) - CP - Farm 15	1	3	164	4080	11.64	0.58	81.60	1632.00	56.10	1688.10	56.10	16	3.64
CP - Farm 51(2108) - CP	1	1	85	2108	19.08	0.95	0.00	0.00	424.59	424.59	147.30	15	7.38
Farm 53(7500) - CP - Farm 53	1	5	300	7500	19.90	1.00	150.00	3000.00	95.92	3095.92	95.92	0	8.08
CP - Farm 58(578) - Farm 47(408) - CP	1	1	41	986	19.65	0.98	0.00	0.00	428.99	428.99	151.70	59	6.59
Farm 59(4488) - CP - Farm 59	1	3	180	4488	35.16	1.76	89.76	1795.20	169.47	1964.67	169.47	0	14.24
CP - Farm 60(1666) - CP	1	1	67	1666	12.18	0.61	0.00	0.00	371.32	371.32	94.03	33	4.88
CP - Farm 4(2244) - CP	1	1	90	2244	3.00	0.15	0.00	0.00	300.45	300.45	23.16	10	1.24
CP - Farm 26(1088) - Farm 48(1224) - CP	1	1	94	2312	17.06	0.85	0.00	0.00	408.99	408.99	131.70	6	7.24
CP - Farm 39(2040) - CP	1	1	82	2040	14.83	0.74	0.00	0.00	391.78	391.78	114.49	18	5.55
CP - Farm 23(1632) - CP	1	1	66	1632	7.66	0.38	0.00	0.00	336.43	336.43	59.14	34	3.01
Farm 62(3128) - CP - Farm 62	1	3	126	3128	18.90	0.95	62.56	1251.20	91.10	1342.30	91.10	54	5.37
CP - Farm 66(204) - Farm 65(748) - Farm 37(1122) - CP	1	1	86	2074	17.32	0.87	0.00	0.00	411.00	411.00	133.71	14	6.60
CP - Farm 68(1768) - Farm 69(612) - CP	1	1	97	2380	7.99	0.40	0.00	0.00	338.97	338.97	61.68	3	3.49
CP -Farm 67(374) - Farm 72(408) - Farm 71(1020) - CP	1	1	74	1802	6.73	0.34	0.00	0.00	329.25	329.25	51.96	26	2.92
CP - Farm 74(816) - Farm 73(374) - Farm 42(170) - Farm 40(748) - CP	1	1	87	2108	26.31	1.32	0.00	0.00	480.40	480.40	203.11	13	10.18
CP - Farm 78(2448) - CP	1	1	99	2448	4.90	0.25	0.00	0.00	315.12	315.12	37.83	1	2.20
Total	**31**	**58**	**3753**	**93112**	**452.19**	**22.61**	**968.04**	**19360.80**	**9035.79**	**28396.59**	**90.29**	**607**	**166.53**

B.2.2 20ft Refrigerated Vehicles

Table B-42 show the results when the 20ft refrigerated vehicles operated by the 3PL provider were used to make milk-round collections in the 'best-case' situation where all the rural farmers are willing to cooperate. While the results in the 'worst-case' situation where the large-scale farmers were assumed to opt out of the collaborations as presented in Table B-43.

Table B-42 The results of assigning the 20ft refrigerated vehicles to make a milk-round collections from 12-15 March 2018 (best-case situation)

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
CP - Farm 14(5000) - CP	1	1	200	5000	3.67	0.18	0.00	0.00	413.10	413.10	33.07	0	2.59
CP - Farm 14(1120) - Farm 9(3264) - CP	1	1	176	4384	5.57	0.28	0.00	0.00	430.22	430.22	50.19	24	3.45
CP - Farm 34(1632) - Farm 25(850) - Farm 21(1598) - Farm 2(816) - CP	1	1	198	4896	13.76	0.69	0.00	0.00	504.01	504.01	123.98	2	9.51
CP - Farm 36(850) - Farm 33(2448) - Farm 30(612) - CP	1	1	157	3910	12.18	0.61	0.00	0.00	489.77	489.77	109.74	43	6.72
CP - Farm 43(1496) - CP	1	1	60	1496	6.96	0.35	0.00	0.00	442.74	442.74	62.71	140	2.81
CP - Farm 54(170) - Farm 57(612) - Farm 52(374) - Farm 50(816) - Farm 45(2040) - CP	1	1	163	4012	19.96	1.00	0.00	0.00	559.87	559.87	179.84	37	11.30
CP - Farm 11(2040) - Farm 1(680) - Farm 19(408) - Farm 3(748) - CP	1	1	158	3876	9.71	0.49	0.00	0.00	467.49	467.49	87.46	42	5.31
CP - Farm 16(10000) - CP	1	2	400	10000	9.44	0.47	0.00	0.00	465.08	465.08	85.05	0	6.66
CP - Farm 16(200) - Farm 17(814) - Farm 56(2720) - CP	1	1	150	3734	12.19	0.61	0.00	0.00	489.86	489.86	109.83	50	8.38
CP - Farm 17(5000) - CP	1	1	200	5000	5.69	0.28	0.00	0.00	431.30	431.30	51.27	0	4.01
CP - Farm 15(4080) - CP	1	1	164	4080	3.88	0.19	0.00	0.00	414.99	414.99	34.96	36	2.23
CP - Farm 51(2108) - Farm 60(1666) - CP	1	1	152	3774	19.24	0.96	0.00	0.00	553.38	553.38	173.35	48	10.25
CP - Farm 53(7500) - CP	1	2	300	7500	7.96	0.40	0.00	0.00	451.75	451.75	71.72	100	5.49
CP - Farm 58(578) - Farm 47(408) - Farm 6(3808) - CP	1	1	194	4794	23.32	1.17	0.00	0.00	590.14	590.14	210.11	6	15.77
CP - Farm 59(4488) - CP	1	1	180	4488	11.72	0.59	0.00	0.00	485.63	485.63	105.60	20	7.42
CP - Farm 4(2244) - CP	1	1	90	2244	3.00	0.15	0.00	0.00	407.06	407.06	27.03	110	1.82
CP - Farm 26(1088) - Farm 48(1224) - Farm 78(2448) - CP	1	1	193	4760	19.36	0.97	0.00	0.00	554.46	554.46	174.43	7	13.00
CP - Farm 37(1122) - Farm 23(1632) - CP	1	1	112	2754	12.04	0.60	0.00	0.00	488.51	488.51	108.48	88	6.10
CP -Farm 67(374) - Farm 72(408) - Farm 71(1020) - Farm 62(3128) - CP	1	1	200	4930	9.00	0.45	0.00	0.00	461.12	461.12	81.09	0	6.26
CP - Farm 69(612) - Farm 68(1768) - Farm 65(748) - Farm 66(204) - CP	1	1	137	3332	10.04	0.50	0.00	0.00	470.49	470.49	90.46	63	6.16
CP - Farm 74(816) - Farm 73(374) - Farm 42(170) - Farm 40(748) - Farm 39(2040) - CP	1	1	169	4148	27.51	1.38	0.00	0.00	627.90	627.90	247.87	31	16.10
Total	**21**	**23**	**3753**	**93112**	**246.20**	**12.31**	**0**	**0**	**10198.86**	**10198.86**	**105.63**	**847**	**151.35**

Table B-43 The results of assigning the 20ft refrigerated vehicles to make a milk-round collections from 12-15 March 2018 (worst-case situation)

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farm 9(3264) - CP - Farm 9	1	3	131	3264	12.00	0.60	65.28	1305.60	57.84	1363.44	57.84	49	3.41
Farm14(6120) - CP - Farm 14	1	5	245	6120	18.35	0.92	122.40	2448.00	88.45	2536.45	88.45	55	5.65
CP - Farm 25(850) - Farm 21(1598) - Farm 2(816) - CP	1	1	132	3264	8.31	0.42	0.00	0.00	454.90	454.90	74.87	68	4.99
CP - Farm 33(2448) - CP	1	1	98	2448	11.53	0.58	0.00	0.00	483.92	483.92	103.89	102	7.62
CP - Farm 36(850) - Farm 34(1632) - Farm 30(612) - CP	1	1	125	3094	12.88	0.64	0.00	0.00	496.08	496.08	116.05	75	7.34
CP - Farm 45(2040) - CP	1	1	82	2040	10.73	0.54	0.00	0.00	476.71	476.71	96.68	118	5.91
CP - Farm 57(612) - Farm 52(374) - Farm 50(816) - Farm 43(1496) - Farm 54(170) - CP	1	1	141	3468	19.99	1.00	0.00	0.00	560.14	560.14	180.11	59	12.76
Farm 16(10200) - CP - Farm 16	1	7	408	10200	33.04	1.65	204.00	4080.00	159.25	4239.25	159.25	12	10.38
Farm 17(5814) - CP - Farm 17	1	4	233	5814	22.76	1.14	116.28	2325.60	109.70	2435.30	109.70	7	7.13
CP - Farm 11(2040) - Farm 1(680) - CP	1	1	110	2720	3.44	0.17	0.00	0.00	411.02	411.02	30.99	90	1.72
CP - Farm 56(2720) - Farm 3(748) - Farm 19(408) - CP	1	1	157	3876	12.68	0.63	0.00	0.00	494.28	494.28	114.25	43	6.93
Farm 6(3808) - CP - Farm 6	1	3	153	3808	19.80	0.99	76.16	1523.20	95.44	1618.64	95.44	27	6.01
Farm 15(4080) - CP - Farm 15	1	3	164	4080	11.64	0.58	81.60	1632.00	56.10	1688.10	56.10	16	3.68
Farm 53(7500) - CP - Farm 53	1	5	300	7500	19.90	1.00	150.00	3000.00	95.92	3095.92	95.92	0	6.43
CP - Farm 60(1666) - Farm 51(2108) - Farm 58(578) - Farm 47(408)	1	1	193	4760	21.02	1.05	0.00	0.00	569.42	569.42	189.39	7	14.12
Farm 59(4488) - CP - Farm 59	1	3	180	4488	35.16	1.76	89.76	1795.20	169.47	1964.67	169.47	0	11.34
CP - Farm 4(2244) - CP	1	1	90	2244	3.00	0.15	0.00	0.00	407.06	407.06	27.03	110	1.82
CP - Farm 26(1088) - Farm 48(1224) - Farm 78(2448) - CP	1	1	193	4760	19.36	0.97	0.00	0.00	554.46	554.46	174.43	7	13.00
CP - Farm 37(1122) - Farm 23(1632) - CP	1	1	112	2754	12.04	0.60	0.00	0.00	488.51	488.51	108.48	88	6.10
Farm 62(3128) - CP - Farm 62	1	3	126	3128	18.90	0.95	62.56	1251.20	91.10	1342.30	91.10	54	5.37
CP -Farm 67(374) - Farm 72(408) - Farm 71(1020) - CP	1	1	74	1802	6.73	0.34	0.00	0.00	440.67	440.67	60.64	126	3.27
CP - Farm 69(612) - Farm 68(1768) - Farm 65(748) - Farm 66(204) - CP	1	1	137	3332	10.04	0.50	0.00	0.00	470.49	470.49	90.46	63	6.16
CP - Farm 74(816) - Farm 73(374) - Farm 42(170) - Farm 40(748) - Farm 39(2040) - CP	1	1	169	4148	27.51	1.38	0.00	0.00	627.90	627.90	247.87	31	16.10
Total	**23**	**50**	**3753**	**93112**	**370.81**	**18.54**	**968.04**	**19360.80**	**7858.82**	**27219.62**	**110.37**	**1207**	**167.23**

B.2.3 Mixed Refrigerated Vehicles

Table B-44 show the results when the mixed refrigerated vehicles operated by the 3PL provider were used to make milk-round collections in the 'best-case' situation where all the rural farmers are willing to cooperate. While the results in the 'worst-case' situation where the large-scale farmers were assumed to opt out of the collaborations as presented in Table B-45.

Table B-44 The results of assigning the mixed refrigerated vehicles to make a milk-round collections from 12-15 March 2018 (best-case situation)

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
CP - Farm 9(2500) - CP	1	1	100	2500	4.00	0.20	0.00	0.00	308.17	308.17	30.88	0	1.84
CP - Farm 14(5000) - CP	1	1	200	5000	3.67	0.18	0.00	0.00	413.10	413.10	33.07	0	2.59
CP - Farm 14(1120) - CP	1	1	45	1120	3.67	0.18	0.00	0.00	305.62	305.62	28.33	55	1.40
CP - Farm 33(2448) - CP	1	1	98	2448	11.53	0.58	0.00	0.00	366.30	366.30	89.01	2	5.18
CP - Farm 36(850) - Farm 30(612) - Farm 9(764) - CP	1	1	90	2226	12.08	0.60	0.00	0.00	370.55	370.55	93.26	10	4.94
CP - Farm 34(1632) - Farm 25(850) - Farm 21(1598) - Farm 2(816) - CP	1	1	198	4896	13.76	0.69	0.00	0.00	504.01	504.01	123.98	2	9.51
CP - Farm 43(1496) - CP	1	1	60	1496	6.96	0.35	0.00	0.00	331.02	331.02	53.73	40	2.51
CP - Farm 54(170) - Farm 57(612) - Farm 52(374) - Farm 50(816) - Farm 45(2040) - CP	1	1	163	4012	19.96	1.00	0.00	0.00	559.87	559.87	179.84	37	11.30
CP - Farm 1(680) - Farm 19(408) - Farm 3(748) - CP	1	1	76	1836	8.99	0.45	0.00	0.00	346.69	346.69	69.40	24	3.03
CP - Farm 11(2040) - CP	1	1	82	2040	3.36	0.17	0.00	0.00	303.23	303.23	25.94	18	1.26
CP - Farm 16(10000) - CP	1	2	400	10000	9.44	0.47	0.00	0.00	465.08	465.08	85.05	0	6.66
CP - Farm 16(200) - Farm 17(814) - Farm 56(220) - CP	1	1	50	1234	12.19	0.61	0.00	0.00	371.40	371.40	94.11	50	5.12
CP - Farm 17(5000) - CP	1	1	200	5000	5.69	0.28	0.00	0.00	431.30	431.30	51.27	0	4.01
CP - Farm 56(2500) - CP	1	1	100	2500	6.82	0.34	0.00	0.00	329.94	329.94	52.65	0	3.13
CP - Farm 6(2500) - CP	1	1	100	2500	6.60	0.33	0.00	0.00	328.24	328.24	50.95	0	3.03
CP - Farm 15(4080) - CP	1	1	164	4080	3.88	0.19	0.00	0.00	414.99	414.99	34.96	36	2.23
CP - Farm 51(2108) - CP	1	1	85	2108	19.08	0.95	0.00	0.00	424.59	424.59	147.30	15	7.38
CP - Farm 53(5000) - CP	1	1	200	5000	3.98	0.20	0.00	0.00	415.89	415.89	35.86	0	2.81
CP - Farm 53(2500) - CP	1	1	100	2500	3.98	0.20	0.00	0.00	308.02	308.02	30.73	0	1.83
CP - Farm 58(578) - Farm 47(408) - Farm 6(1308) - CP	1	1	94	2294	23.32	1.17	0.00	0.00	457.32	457.32	180.03	6	9.82
CP - Farm 59(4488) - CP	1	1	180	4488	11.72	0.59	0.00	0.00	485.63	485.63	105.60	20	7.42
CP - Farm 60(1666) - CP	1	1	67	1666	12.18	0.61	0.00	0.00	371.32	371.32	94.03	33	4.88
CP - Farm 4(2244) - CP	1	1	90	2244	3.00	0.15	0.00	0.00	300.45	300.45	23.16	10	1.24
CP - Farm 26(1088) - Farm 48(1224) - Farm 78(2448) - CP	1	1	193	4760	19.36	0.97	0.00	0.00	554.46	554.46	174.43	7	13.00
CP - Farm 39(2040) - CP	1	1	82	2040	14.83	0.74	0.00	0.00	391.78	391.78	114.49	18	5.55
CP - Farm 23(1632) - CP	1	1	66	1632	7.66	0.38	0.00	0.00	336.43	336.43	59.14	34	3.01
CP - Farm 66(204) - Farm 65(748) - Farm 37(1122) - CP	1	1	86	2074	17.32	0.87	0.00	0.00	411.00	411.00	133.71	14	6.60
CP - Farm 68(1768) - Farm 69(612) - CP	1	1	97	2380	7.99	0.40	0.00	0.00	338.97	338.97	61.68	3	3.49
CP -Farm 67(374) - Farm 72(408) - Farm 71(1020) - Farm 62(3128) - CP	1	1	200	4930	9.00	0.45	0.00	0.00	461.12	461.12	81.09	0	6.26
CP - Farm 74(816) - Farm 73(374) - Farm 42(170) - Farm 40(748) - CP	1	1	87	2108	26.31	1.32	0.00	0.00	480.40	480.40	203.11	13	10.18
Total	**30**	**31**	**3753**	**93112**	**312.33**	**15.62**	**0**	**0**	**11886.88**	**11886.88**	**84.69**	**447**	**151.20**

Table B-45 The results of assigning the mixed refrigerated vehicles to make a milk-round collections from 12-15 March 2018 (worst-case situation)

Collection routes and loading size	VF_{inv}	VF_{vis}	Q_{box}	Q_{kg}	D_{tv}	T_{dri}	W_{avrw}	C_{waste}	TC_{own}	TC_{total}	MC	ER_{box}	EM_{CO2}
Farm 9(3264) - CP - Farm 9	1	3	131	3264	12.00	0.60	65.28	1305.60	57.84	1363.44	57.84	49	3.41
Farm14(6120) - CP - Farm 14	1	5	245	6120	18.35	0.92	122.40	2448.00	88.45	2536.45	88.45	55	5.65
CP - Farm 25(850) - Farm 21(1598) - Farm 2(816) - CP	1	1	132	3264	8.31	0.42	0.00	0.00	454.90	454.90	74.87	68	4.99
CP - Farm 33(2448) - CP	1	1	98	2448	11.53	0.58	0.00	0.00	366.30	366.30	89.01	2	5.18
CP - Farm 36(850) - Farm 34(1632) - Farm 30(612) - CP	1	1	125	3094	12.88	0.64	0.00	0.00	496.08	496.08	116.05	75	7.34
CP - Farm 43(1496) - CP	1	1	60	1496	6.96	0.35	0.00	0.00	331.02	331.02	53.73	40	2.51
CP - Farm 45(2040) - CP	1	1	82	2040	10.73	0.54	0.00	0.00	360.13	360.13	82.84	18	4.02
CP - Farm 54(170) - Farm 57(612) - Farm 52(374) - Farm 50(816) - CP	1	1	81	1972	19.63	0.98	0.00	0.00	428.83	428.83	151.54	19	7.11
Farm 16(10200) - CP - Farm 16	1	7	408	10200	33.04	1.65	204.00	4080.00	159.25	4239.25	159.25	12	10.38
Farm 17(5814) - CP - Farm 17	1	4	233	5814	22.76	1.14	116.28	2325.60	109.70	2435.30	109.70	7	7.13
CP - Farm 11(2040) - CP	1	1	82	2040	3.36	0.17	0.00	0.00	303.23	303.23	25.94	18	1.26
CP - Farm 56(2500) - CP	1	1	100	2500	6.82	0.34	0.00	0.00	329.94	329.94	52.65	0	3.13
CP - Farm 56(220) - Farm 1(680) - Farm 19(408) - Farm 3(748) - CP	1	1	85	2056	13.09	0.65	0.00	0.00	378.34	378.34	101.05	15	4.94
Farm 6(3808) - CP - Farm 6	1	3	153	3808	19.80	0.99	76.16	1523.20	95.44	1618.64	95.44	27	6.32
Farm 15(4080) - CP - Farm 15	1	3	164	4080	11.64	0.58	81.60	1632.00	56.10	1688.10	56.10	16	3.83
Farm 53(7500) - CP - Farm 53	1	5	300	7500	19.90	1.00	150.00	3000.00	95.92	3095.92	95.92	0	7.12
Farm 59(4488) - CP - Farm 59	1	3	180	4488	35.16	1.76	89.76	1795.20	169.47	1964.67	169.47	0	12.56
CP - Farm 60(1666) - Farm 51(2108) - Farm 58(578) - Farm 47(408)	1	1	193	4760	21.02	1.05	0.00	0.00	569.42	569.42	189.39	7	14.12
CP - Farm 4(2244) - CP	1	1	90	2244	3.00	0.15	0.00	0.00	300.45	300.45	23.16	10	1.24
CP - Farm 26(1088) - Farm 48(1224) - Farm 78(2448) - CP	1	1	193	4760	19.36	0.97	0.00	0.00	554.46	554.46	174.43	7	13.00
CP - Farm 39(2040) - CP	1	1	82	2040	14.83	0.74	0.00	0.00	391.78	391.78	114.49	18	5.55
CP - Farm 23(1632) - CP	1	1	66	1632	7.66	0.38	0.00	0.00	336.43	336.43	59.14	34	3.01
Farm 62(3128) - CP - Farm 62	1	3	126	3128	18.90	0.95	62.56	1251.20	91.10	1342.30	91.10	54	5.37
CP - Farm 66(204) - Farm 65(748) - Farm 37(1122) - CP	1	1	86	2074	17.32	0.87	0.00	0.00	411.00	411.00	133.71	14	6.60
CP - Farm 68(1768) - Farm 69(612) - CP	1	1	97	2380	7.99	0.40	0.00	0.00	338.97	338.97	61.68	3	3.49
CP -Farm 67(374) - Farm 72(408) - Farm 71(1020) - CP	1	1	74	1802	6.73	0.34	0.00	0.00	329.25	329.25	51.96	26	2.92
CP - Farm 74(816) - Farm 73(374) - Farm 42(170) - Farm 40(748) - CP	1	1	87	2108	26.31	1.32	0.00	0.00	480.40	480.40	203.11	13	10.18
Total	**27**	**54**	**3753**	**93112**	**409.08**	**20.45**	**968.04**	**19360.80**	**8084.21**	**27445.01**	**99.33**	**607**	**162.32**

Appendix C Semi-Structured Questionnaires

C.1 Simi-structured Interviews with the Government Departments

Organisation information

1. Could you please describe some general information about your organisation? *(vision, mission, goals, specific projects)*.
    1.1. What do you specifically doing in the agriculture, particularly with the rural farmers? *(programs, projects, where, how many farmers are involved)*.
    1.2. Could you please describe your organisation involvement in food collective and the ways in which you work with rural farmers?

The development of agriculture

2. Could you please describe the current situation and the development of Thailand's agriculture? *(market mechanisms, distribution channels, market trends).*
    2.1. What have been the main changes in market structure of agriculture sector over the past 5 years, which has been the biggest challenges?
    2.2. How have the distribution channels of agri-food products been changed? *(from direct selling channels to more complex of intermediaries).*
    2.3. How has the management of rural farmers change recently? *(indicating any structural change and reform initiatives in recent years, farming licensing, and certification).*
    2.4. Which are the major buyers/export regions and how have they changes? *(fewer standard requirements in traditional markets, while high in supermarkets)*.
    2.5. How have the working and licensing conditions related to food production changes?
3. How have different market mechanisms systems affect rural farmers? *(such as the traditional markets and supermarkets)*.
    3.1. Are we see a move away from independent selling? *(individual farmers are getting involved in co-operative, or other group for selling products).*
4. What do you perceive to be the advantages and disadvantages for rural farmers of dealing with upcoming markets? *(the formalised procurement systems with high standard quality, quantity and delivery)*.
    4.1. What of you observed have been the key problems for rural farmers in working with supermarkets?

5. What do you understand to be the main requirements placed on rural farmers in terms of working with supermarket procurement system? *(in term of quality, quantity, financial, meeting requirements)*.
    5.1. Do you know about farmer exclusion, which resulted from the high standard requirements?

Government support and social scheme

6. What do you think would be most effective for helping rural farmers when dealing with new market mechanism requirements? *(such as setting up collective centre, collaborative working, as well as legislation support)*.
    6.1. Are there ongoing agricultural extension programs (agricultural assistance programs) or any specific plans do you have in the near further to support agri-food business sector, particularly rural farmers?
    6.2. If yes, could you please describe what and how programs will be delivered in this area to assist rural farmers?
    6.3. If no, are there any extension programs provided or operated privately (private companies) initiated?
7. Could you please describe the history of social schemes (such as co-operative and social enterprises)?
    7.1. How do they work? What types of government support are provided?
    7.2. How accessible are farmers to these initiative programs?
8. In your opinion, what are the advantages and disadvantages of collaborative working as co-operative and social enterprise?
    8.1. What are the potential benefits of collaborative working?
    8.2. What are the major constraints facing the co-operatives and rural farmers?

Food control and standard requirements

9. Are there any data that farmers, co-operative and other stakeholders in agriculture are mandated to provided/submit to the government or related organisations?
10. How you deal with the food control management for assuring food safety and quality?
    10.1. What are the accreditation systems have been used for monitoring and managing food transactions to ensure food safety to achieve market opportunities?
    10.2. What are the problems regarding food control management, particularly rural farmers?
11. What steps have been undertaken to encourage farmers to complete with government regulations? (positive way – incentive, training or negative way – penalty).

C.2 Simi-structured Interviews with the Retail Companies

Organisation information

1. Could you please describe some general information about your organisation?
    1.1. What is your organisation specifically doing in the agri-food industry?
2. What are the various products that the company is involved with?
    2.1. What kind of fresh fruits do you buy/sell? When each product off market?
    2.2. What do you thank would be the most potential product?
    2.3. Please describe the market share for conventional, organic, pesticide-safe, and perfect products.
    2.4. Please describe the market trends for agricultural products *(market share, demand, trend, customer requirements).*

Purchasing and delivering management

3. Please describe the main sources of agri-food (fresh fruits) supply to your company? *(such as brokers, wholesalers, farmer co-operative, farmer direct sell, and import).*
4. What criteria do you use to choose the suppliers? *(quality, quantity, delivery, prices, logistics, transaction costs, and times).*
    4.1. Does your supplier have to qualify for a “preferred contractor”? If so, could you please describe the qualification procedure?
    4.2. Do farmers have to go through some kind of qualification procedure?
    4.3. Are there any criteria or specific requirements for agri-food suppliers?
    4.4. If am a new farmer, how can I began selling products through supermarket?
5. Could you please describe how the procurement activity has been setting up?
    5.1. How often the procurement has been setting up?
    5.2. Could you please describe the processes of getting products from your suppliers? How do the purchase ordering placed?
    5.3. Have you had set up standard ordering processes (food transaction) that both parties (buyer and seller) can easily understand and follow?
    5.4. How long does it take for getting products after made purchase contract?
    5.5. Please describe the main difficulties faced in procuring agri-food products, particularly with rural farmers.
6. Have you had any contract so far with your suppliers regarding trade activity?
    6.1. What type of contract do you regularly use in your trading? *(please describe term and condition such how long is the contract for, food safety, price agreement, regularly of supply, any requirements).*

6.2. Do you run any contract schemes (contract farming) directly with your supplier? If so, please describe.

7. Please describe the grading and quality control system you currently used?
    7.1. What quality processes have you had to adopted?
    7.2. How much of supplier's product is typically rejected after grading?
    7.3. How did you handle with rejected shipment?
    7.4. What is the basic for your setting buying price?
8. How do you maintain the quality of your products when it moves to your stores?
    8.1. What are the accreditation systems currently used for monitoring and managing food transactions to ensure food safety to achieve market opportunities?
    8.2. What are the problems regarding food control management, particularly with rural food producers?
9. How is transport arranged?
    9.1. How is the product distributed geographically to various stores?
    9.2. Did you currently manage transportation activity on your own? If so, please describe.
    9.3. If no, who is responsible for this activity to move products?
10. Please identify each point in the transportation system where the product undergone movement from farms to distribution centre and various stores.
    10.1. Are there any problems incurred while transport?
11. What sort of value-added activity do you expect your suppliers to perform?
12. How suppliers or farmers engage with the current procurement system?

Food control and data requirements

13. Please describe your business relationship with your major suppliers/farmers?
    13.1. Are there any support programs/services have been provided to your suppliers, particularly rural food producers?
    13.2. Are there any regular meetings with your suppliers, factory (farm) visit to see how their business operate?
    13.3. Have you had shared any market information with your suppliers?
14. What information have you had provided to your suppliers?
15. In contrast, are there any data that suppliers or farmers are mandated to provide to your organisation? *(production, processes, transportation, others).*
16. What steps have been undertaken to encourage supplier/rural food producers to compete with organisation regulations? *(positive way – incentive or negative way – penalty)*.
17. Could you please describe the current processes and related costs of getting products associated with rural food transaction processes?

18. What are the desired further vision for food production, as well as distribution processes?
    18.1. What recommendations do you have for construction best practice operation to make food traction more effective and enhance the competitiveness of rural farmers?

The development of agricultural market

19. Could you please describe the current situation and the development of Thailand's agri-food industry? *(market mechanisms, distribution channels, market trends).*
    19.1. What have been the main changes in market structure of agriculture sector over the past 5 years?
    19.2. How have the distribution channels of agri-food products been changed?
    19.3. Does consumption pattern (customer concern about food safety, quality) effect to your business, and how you deal with these issues?
    19.4. How has the management of your suppliers, farmers change recently?
20. What do you perceive to be the advantages and disadvantages for rural food producers of dealing with supermarkets?
    20.1. What of you observed have been the key problems for rural farmers in working with supermarkets?
    20.2. In your opinion, what factors are necessary for farmers to gain more access to the modern trade markets?
    20.3. Do you have any ideas to help rural farmers to get more access to supermarkets?
21. Are there ongoing or specific programs do you have in the near future to support your suppliers and aid rural food producers?
    21.1. What programs will be delivered in this area to assist suppliers or farmers? How accessible are farmers to these initiated programs, what qualifications do they need?

C.3 Simi-structured Interviews with the Farmer Organisations

Organisation information

1. Could you please describe some general information about your organisation?
    1.1. How has this co-operative been setting up?
    1.2. Could you please describe your organisation involvement in food collective and the ways in which you work with rural farmers?
    1.3. How is the co-operative positioned in its industry? Is it progressing or declining?
2. Is co-operative owned and controlled by current members who use its services?
    2.1. Are member farmers engaged with the co-operative's operation and services?
    2.2. Could you please describe how does it work?
    2.3. How many member farmers does co-operative have currently?
3. How do individual farmers sign up to join the co-operative?
    3.1. Are there any costs or specific requirements for joining the co-operative?
    3.2. What are the rules once they are in?
4. Are there any data that farmers are mandated to provide to the co-operative once they are in? Could you please specify? *(such as production process, land management, financial)*.
    4.1. What information legally farmers have to provide?
    4.2. What information are you currently received?
    4.3. How frequency do they need to provide the information?
5. What information have you had provided to your members?
    5.1. What information sharing, rules on data sharing? What the problems and challenges faced regarding data sharing?
6. Please elaborate on the kind of agricultural service the co-operative provides for its members.
    6.1. How co-operative's services benefit the member farmers? *(agricultural inputs, storage, transportation, packaging, machinery service, market information, marketing)*.
7. Are those services handled within the structure of the co-operative?
    7.1. Are some of the service carried out by other firms? *(such as transportation activity carry out by 3^rd^ party)*.
8. Are there any rural services which are not provided by the organisation, but should be there or are provided by other actors?
9. Please identify and describe linkages, relationships with other organisations? *(such as public and private sectors)*.
    9.1. Do you work together with other partnerships in term of productions?
    9.2. How does it work and for what purposes?

10. Are there any ongoing or planned projects for improving co-operative and helping its member farmers?
    10.1. Please identify and describe in more details? *(project, goal, sponsor institution)*.
11. Please identify the infrastructure, equipment, materials which may impact upon the production processes?

	Unit	Location	Value
Collection centre	____________	____________	___________ THB.
Truck	____________	____________	___________ THB.
Warehouse	____________	____________	___________ THB.
Machinery	____________	____________	___________ THB.
Others______________________	____________	____________	___________ THB.

12. How many labours are hired and engaged in this co-operative (peak and off-peak seasons)? How does it cost?

Procurement and production management

13. What are the main products being produced? (ask for recorded data)

Products	Total purchase	Price/kg.	Total sales	Price/kg.
Durain	__________	__________ THB.	__________	__________ THB.
Mangosteen	__________	__________ THB.	__________	__________ THB.
Longan	__________	__________ THB.	__________	__________ THB.
Mango	__________	__________ THB.	__________	__________ THB.
Other	__________	__________ THB.	__________	__________ THB.

14. What is its primary emphasis?
15. What do you think would be the most potential product, especially fresh fruits?
    15.1. Please describe the market share for conventional, organic, pesticide-safe products.
    15.2. Please describe the market trends for agricultural products, particularly fresh fruits.
16. Please describe the main source of agri-food supply? *(member farmer, non-member farmer).*
    16.1. Could you please describe the processes of getting products from rural food producers?
    16.2. Are there different processes of different suppliers? *(between member and non-member farmers).*
17. Could you please describe how the procurement activity has been setting up?
    17.1. How often the procurement activity has been setting up?
    17.2. Could you please describe the processes of getting products from your member farmers?
    17.3. Have you had set up standardised ordering processes that both parties (co-operative and member) can easily understand and follow?
18. Have you had any contract so far with your members regarding trade activity?

18.1. What type of contract do you regularly use in your trading? *(please describe term and condition).*

18.2. Do you run any contract schemes (contract farming) directly with your members? If so, please describe.

19. How is transport arranged? *(from farm to consolidation point).*

19.1. Did you consolidate products for your member farmers? If so, please describe.

20. Did you do grading for your member farmers? If yes, please describe. *(criteria, requirements)*.

20.1. Any sizing and grading standards used fir this commodity? Please describe.

20.2. How much of a problem is grading for you?

20.3. What do you do with the products does not meet the requirement?

21. Does you perform value-addition activities after receiving products from member farmers before supply to your buyers?

21.1. Does the produce undergo any type of processing or semi-processing? *(chemical and physical treatments or transformed into new form).*

22. Does the product undergo cooling during processes?

22.1. Where cooling carried out, methods, time and cost is required?

22.2. Once cooled, does it move on its way to the final market with the cool chain management? If so, who executes the operation, procedures, time and costs?

23. Please identify the points in the production system where packaging occurs?

23.1. What is the size of package used? *(dimension, number of units of product per package, weights).*

23.2. Who undertakes this process, how long does it take, and cost required?

23.3. Does the package meet the handling and buyer's requirements?

24. Please identify the points in production system where the storage takes place?

24.1. Please describe the storage facilities and equipment?

24.2. How long is the holding period?

25. Please identify the points in production system where the inspection take place?

25.1. Could you please describe the procedure? *(when, who and why this action carried out).*

25.2. Is this operation required to meet market requirement?

25.3. Which difficulties/challenges do you perceived regarding this activity?

26. What paperwork and systems do you have to engage with the government or major buyer (supermarkets, exporters) to undertake your business?

26.1. Are there any data that you are mandated to provide/submit to the government or major buyers? Could you please specify?

27. Do you keep records of production processes?

27.1. What records do you have to keep by law? *(purchasing, processing, selling, transporting).*

28. Do you get a 3rd party to manage your record keeping and submittals to the government?

Selling and delivering management

29. What proportion of your products are being sold?

	Fresh	Processed	Total
Durain	___________%	___________%	____________
Mangosteen	___________%	___________%	____________
Longan	___________%	___________%	____________
Mango	___________%	___________%	____________
Others______________________	___________%	___________%	____________

30. How frequently do you normally sell your products? (monthly, weekly, daily).
    30.1. When each product off market? *(growing, harvesting, selling periods)*
31. Could you please describe how the procurement activity has been setting up?
    31.1. How does the purchase order place to you? Please describe.
    31.2. How long does it take during the procurement processes? *(time and cost)*.
32. Have you had any contract so for with a major buyer regarding trade activity?
    32.1. What type of contract do you regularly use in your trading? *(term and condition)*.
33. Who is your major buyer of fresh product?

	Broker	Supermarket	Exporter	Self-marketing	Other
Price/kg.	______THB.	______THB.	______THB.	______THB.	______THB.
Share	________%	________%	________%	________%	________%
Contract	_________	_________	_________	_________	_________
Grading	_________	_________	_________	_________	_________
Market information	_________	_________	_________	_________	_________
Collective	_________	_________	_________	_________	_________

34. Please describe your business relationship with your major markets.
    34.1. Are there any support programs/services have been provided?
    34.2. Are there any regular face-to-face meeting with your major buyers or factory (farm) visit to see how your business work?
    34.3. Have your buyer share any market information?
35. Do you have to qualify for a "preferred contractor" relationship with major buyers?
    35.1. Do you have to go through some kind of qualification procedure to be able to supply to supermarket? If so, please describe.
    35.2. Are there any specific requirements for organic/pesticide-safe products that different from the conventional products?
36. How is your product graded? Please describe.

36.1. Any sizing and grading standards used for this commodity? If yes, please describe. *(product shape, size, weight, colour, cleanliness)*.

36.2. Any special nature of products to supermarket? *(pesticide-safe, organic products)*.

36.3. What is the average quantity of your products rejected by major buyer?

36.4. What do you do with the products does not meet the buyer requirement?

37. How you maintain the quality of your product when it moves to the buying point?

37.1. Please describe the current accreditation system used for your product.

37.2. Do they differ between different buyer?

38. How is transport arranged?

38.1. How is the agri-food product distributed geographically to various buyers?

38.2. Did you currently manage transportation activity on your own? If yes, please describe.

38.3. If no, who is responsible for this activity to move products from farm to buying point? *(using 3rd party, or buyer's transportation service).*

38.4. Please identify each point in the commodity system where the product undergone movement from co-operative to buying point?

Where transportation take place	Method	Quantity	Distance	Duration
From____________to____________	__________	________kg.	________km.	________min.
From____________to____________	__________	________kg.	________km.	________min.
From____________to____________	__________	________kg.	________km.	________min.

39. Could you please describe the constraints affecting transportation activity? *(lack of refrigerated, road condition, controlling and monitoring facilities).*

40. Please describe any type of damage/bruising which occurring to the product during transport?

40.1. Who is responsible for the damaged products during the transportation?

40.2. What do you do with the damaged products?

40.3. What is the average quantity of the damaged products per shipment?

41. If you use a 3rd party by external partners, please describe the problems incurred while using them?

42. What percentage of production costs is attributable to transportation activity?

42.1. Please identify the costs involved the transportation activity.

Cost components	Unit	Cost/unit
Labour/driver	_________________	_____________THB.
Packaging, container	_________________	_____________THB.
Vehicle	_________________	_____________THB.
Fuel	_________________	_____________THB.
Others_________________________	_________________	_____________THB.

43. What are the payment mechanisms used in your transaction? *(cash, bank transfer).*

43.1. In case of bank transfer, please describe the procedures to claim on your payment.

43.2. How long does it normally take to receive payment?

43.3. Are there any problems with payment? *(term of payment, delay).*

44. Is there any market information available for the commodity you have operated?

44.1. What is the source of the supply information, and is it reliable?

44.2. What type of market information available and frequency of information provided? *(market price, demand, market requirements).*

Current situation, challenges and problems faced

45. Could you please the current situation and the development of Thailand's agri-food industry? *(market mechanisms, distribution channels, market trends).*

45.1. What have been the main changes in market structure of agriculture sector over the past 5 year from your experienced?

45.2. What market conditions are most likely to change, and which will stay the same?

45.3. How have the distribution channels been changed?

45.4. How has the management of rural farmers change recently? *(change in farming practices).*

46. How have different market mechanisms system affect co-operative?

47. What do you perceive to be the advantages and disadvantages for co-operative of dealing with modern trade market? *(the formalised procurement system with high standards).*

48. What do you understand to be the main requirements placed on co-operative in term of working with supermarket procurement system?

49. What barriers or obstacles have you encountered, or do you envisage with regard to running co-operative? *(market restructuring, inadequate advice and support, financial, training, transport).*

50. In your opinion, what are the main challenges faced by the rural farmers? *(problem in supplying product, marketing, quality, transportation).*

C.4 Simi-structured Interviews with the Commission Agents

Organisation information

1. Could you please describe some general information about your organisation?
    1.1. Could you please describe your organisation involvement in food collective and the ways in which you work with rural farmers?
    1.2. How is your organisation position in its industry? Is it progressing, declining?
2. Please elaborate on the kind of agricultural services that you provide for your supplier.
3. Please identify and describe linkages, relationships with other organisations? *(private and public sector).*
    3.1. Do you work together with other partnerships in term of production?
    3.2. How does it work and for what purposes?
4. How many labours are hired and engaged in your organisation? (peak and off-peak season).

Procurement and production management

5. What are the main products being produced? *(ask for record data)*.

Products	Total purchase	Price/kg.	Total sales	Price/kg.
Durain	___________	___________ THB.	___________	___________ THB.
Mangosteen	___________	___________ THB.	___________	___________ THB.
Longan	___________	___________ THB.	___________	___________ THB.
Mango	___________	___________ THB.	___________	___________ THB.
Other	___________	___________ THB.	___________	___________ THB.

6. What is its primary emphasis?
7. What do you think would be the most potential product, especially fresh fruit?
    7.1. Please describe the market share for conventional, organic, pesticide-safe products?
    7.2. Please describe the market trends for agricultural products.
8. Please describe the main source of agri-food products supply? *(60% from farmers, 30% local collector, and 10% others).*
    8.1. Could you please describe the processes of getting products from your suppliers?
    8.2. Are there different processes of different suppliers?
9. Could you please describe how the procurement activity has been setting up?
    9.1. How often the procurement activity has been setting up?
    9.2. Could you please describe the processes of getting products from your suppliers?
    9.3. Have you had set up standardised ordering processes that both parties (you and your suppliers) can easily understand and follow?
    9.4. How long does it take for getting products after made purchase contract? *(3days, 5days)*.

9.5. Please describe the main difficulties faced in procuring agri-food products, particularly with rural farmers?

10. Have you had any contract so farm with your suppliers/rural farmers regarding trade activity?
    10.1. What type of contract do you regularly use in your trading? *(term, condition).*
    10.2. Do you run any contract schemes (contract farming) directly with your suppliers? If so, please describe.
11. How is transport arranged? (from farm to your buying point).
    11.1. Did you consolidate products for your suppliers? If so, how does it work?
    11.2. Do they have to pay extra, or any requirements for this service?
12. Did you do grading for your suppliers? If yes, please describe. *(criteria and requirements).*
    12.1. Any sizing and grading standards used for this commodity? If yes, please describe.
    12.2. How much of a problem is grading for you? *(<10%, 20%, or over 50%).*
    12.3. What do you do with the products does not meet the requirements?
13. Do you perform value-addition activity after receiving products from farmers before supply to your buyers?
    13.1. Does the procedure undergo any type of processing or semi-processing? *(chemical and physical treatments transformed into new form).*
14. Does the product undergo cooling during processes? Please describe.
    14.1. Where cooling carried out, methods, time and cost is required?
    14.2. Once cooled, does it move on its way to the final markets with the cool chain management? If so, who executes the operation, procedure, time and cost?
15. Please identify the points in the production system where packaging occurred?
    15.1. What is the size of package used? (dimension, weight, unit of products).
    15.2. Who undertakes this process, how long does it take, and cost required?
    15.3. Does the package meet the handling and buyer's requirements?
16. Please identify the point in production system where the storage takes place?
    16.1. Please describe the storage facilities and equipment?
    16.2. How long is the holding period? *(time and cost required).*
17. Please identify the point in production system where the inspection takes place?
    17.1. Could you please describe the procedure?
    17.2. Is this operation required to meet market requirement?
    17.3. Which difficulties and challenges do you perceived regarding this activity?
18. What paperwork and system do you have to engage with the government or major buyers to undertake your business?
    18.1. Are there any data that you are mandated to provide/submit to the government or major buyers? Could you please specify?

19. Do you keep records of production processes?
    19.1. What record do you have to keep by law? *(purchasing, selling, transporting).*
    19.2. What format was used? *(written, electronic).*
20. Do you get a 3rd party to manage your record keeping and submittals to the government?

Selling and delivering management

21. What proportion of your products are being sold?

	Fresh	Processed	Total
Durain	___________%	___________%	____________
Mangosteen	___________%	___________%	____________
Longan	___________%	___________%	____________
Mango	___________%	___________%	____________
Others_____________________	___________%	___________%	____________

22. How frequently do you normally sell your products? (monthly, weekly, daily).
    22.1. When each product off market? *(growing, harvesting, selling period).*
23. Could you please describe how the procurement activity has been setting up?
    23.1. How does the purchase orders place to you? Please describe the procedure.
    23.2. How long does it take during the procurement processes? *(time and cost required).*
24. Have you had any contract so far with a major buyer regarding trade activity?
    24.1. What type of contract do you regularly use in trading? *(term, condition).*
25. Who is your major buyer of fresh product?

	Broker	Supermarket	Exporter	Self-marketing	Other
Price/kg.	______THB.	______THB.	______THB.	______THB.	______THB.
Share	________%	________%	________%	________%	________%
Contract	_________	_________	_________	_________	_________
Grading	_________	_________	_________	_________	_________
Market information	_________	_________	_________	_________	_________
Collective	_________	_________	_________	_________	_________

26. Please describe your business relationship with your major markets.
    26.1. Are there any support programs/services have been provided?
    26.2. Are there any regular face-to-face meeting with your major buyers or factory visit to see how your business work?
27. Do you have to qualify for a "preferred contractor" relationship with buyers, particularly supermarket?
    27.1. Do you have to go through some kind of qualification procedure to be able to supply to supermarket? If so, please describe the processes.

27.2. Are there any criteria or specific requirements for organic/pesticide-safe products that different from the conventional product?

28. How is your product graded? Please describe.
    28.1. Any sizing and grading standards used for this commodity? If yes, please describe.
    28.2. Any special nature of products to supermarket?
    28.3. What is the average quantity of your products rejected by major buyer?
    28.4. What do you do with the products does not meet the buyer requirements?
29. How you maintain the quality of your product when it moves to the buying point?
    29.1. Please describe the current accreditation systems used for your products.
    29.2. Do they differ between different buyers?
30. How transport is arranged?
    30.1. How is the agri-food product distributed geographically to various buyers?
    30.2. Did you currently manage transportation activity on your own? If yes, please describe.
    30.3. If no, who is responsible for this activity to move products from farm to buying point?
    30.4. Please identify each point in the commodity system where the product undergone movement from co-operative to buying point?

Where transportation take place	**Method**	**Quantity**	**Distance**	**Duration**
From____________to____________	__________	________kg.	________km.	________min.
From____________to____________	__________	________kg.	________km.	________min.
From____________to____________	__________	________kg.	________km.	________min.

31. Could you please describe the constraints affecting transportation activity? *(lack of refrigerated, road condition).*
32. Please identify any type of damage/bruising which occurring to the product during transport?
    32.1. Who is responsible for the damaged products during the transportation?
    32.2. What do you do with the damaged products?
    32.3. What is the average quantity of your damaged product per shipment?
33. If you use a 3rd party by external partner, please describe the problem incurred while using them?
34. What percentage of production cost is attributable to transportation activity?
    34.1. Please identify the costs involved during this stage of transportation.

Cost components	**Unit**	**Cost/unit**
Labour/driver	_________________	_____________THB.
Packaging, container	_________________	_____________THB.
Vehicle	_________________	_____________THB.
Fuel	_________________	_____________THB.
Others__________________________	_________________	_____________THB.

35. What are the payment mechanisms used in your transaction?
    35.1. In case of bank transfer, could you please describe the procedure to claim on your shipment?
    35.2. How long does it normally take to receive payment?
    35.3. Are there any problem with payment? *(term, delay, cost).*
36. Is there any market information available for the commodity you have operated?
    36.1. What is the source of the supply information, and is it reliable?
    36.2. What type of market information available and frequency of information?

Current situation, challenges and problems faced

37. Could you please describe the current situation, and the development of Thailand's agri-food industry? (market mechanisms, distribution channels, market trends).
    37.1. What have been the main changes in market structure of agricultural sector over the past 5 years?
    37.2. What market conditions are most likely to change, and which will stay the same?
    37.3. How have the distribution channels been changed?
    37.4. How has the management of rural farmers change recently?
38. How have different market mechanisms system affect your organisation?
39. What do you perceive to be the advantages and disadvantages for you of dealing with modern trade markets? *(the formalised procurement system with high standards).*
    39.1. What of you observed have been the key problems for your organisation in working with modern trade markets?
40. What do you understand to be the main requirements place on your business in term of working with supermarket procurement system?
41. What barrier or obstacles have you encountered, or do you envisage with regard to running business? *(market restructuring, market information, inadequate advice, financial).*
42. What concern you most about current operations?
    42.1. What major operational weaknesses need to be immediately addressed?
    42.2. In your opinion, what are the main challenges faced by the rural farmers?

C.5 Simi-structured Interviews with the Rural Farmers

Organisation information

1. How long you have been engaged in agricultural? *(years).*
2. What is your estimated yearly household income? *(THB/year).*
    2.1. Is the main household income from own farming?
    2.2. What is the proportion (percentage) of household from own farming?
3. What is the total size of your farm (owned/rented) rai?
    3.1. If rented, how many rai and how does it cost?
4. How labours are hired and involved in farming activities? *(peak and off-peak seasons).*
    4.1. What is the principle source of labour? *(family, neighbour, hired).*
    4.2. How does it cost for hired?

Production management

5. What proportion of your agricultural being produced?

Product	Producing area	Harvesting area
Durain	______________Rai	______________Rai
Mangosteen	______________Rai	______________Rai
Longan	______________Rai	______________Rai
Mango	______________Rai	______________Rai
Others______________________	______________Rai	______________Rai

6. Could you please describe the farming life cycle?
    6.1. What steps you perform? *(crop selection, land preparation).*
    6.2. What information is required at each step?
    6.3. How does it cost in each step?
7. Please identify and describe other pre-harvesting processes which might favourably affect production cost and quality?
    7.1. Are there any physical or chemical treatments to the crops? Please describe. *(time and cost required).*
8. Are all the crops harvested at one time? If more than one could you please specify?

Product	Cultivating	Harvesting	Quantity	Suitable for sell
Mango	_______to_______	_______to_______	_________kg.	_________kg.
		_______to_______	_________kg.	_________kg.
		_______to_______	_________kg.	_________kg.
		_______to_______	_________kg.	_________kg.

9. Who is responsible with harvest activity? (farmer, co-operative, local collector, other).
    9.1. If were not you, please describe more details how does it work? *(procedure, time, cost).*
10. Do you perform value-addition activity after harvesting process before supply to your buyers?
    10.1. Does the product undergo any type of semi-processing? *(cleaning, cutting, packing).*
11. Does the product undergo cooling after harvesting? If yes, please describe.
    11.1. Where the cooling carried out, methods, time and cost required?
    11.2. Once cooled, does it move on its way to the buying point with cool chain management? If so, who executes the operation, procedures, time and cost?
12. Please identify the point in the post-harvest system where packaging occurs?
    12.1. What is the size of the package used? (dimension, weight).
    12.2. Who undertakes the packaging? How long does it take, and cost required?
    12.3. Does the package meet the handling and buyer's requirements?
13. Please identify the point in the post-harvest system where the storage takes place?
    13.1. Please describe the storage facilities and equipment?
    13.2. How long is the holding period? *(time and cost required).*
14. Please identify the point in the production processes where the inspection takes place?
    14.1. Could you please describe the procedure? (where, when, who carried out).
    14.2. Is this operation required to meet market requirements?
    14.3. Which difficulties/challenges do you perceived regarding this activity which may affect production process?
15. Could you please provide more information about getting certifications?

	Farming	**GAP**	**Organic**	**Pesticide-safe**
Which certificates are you holding	__________	__________	__________	__________
How long does it last (year)	__________	__________	__________	__________
Any funding to apply for it	__________	__________	__________	__________
How does it cost (THB.)	__________	__________	__________	__________
Certificate provider (organisation)	__________	__________	__________	__________

16. What paperwork and system do you have to engage with the government or your buyers to undertake your business?
    16.1. Are there any data that you are mandate to provide/submit to the government or major buyers? Could you please describe.
    16.2. Are there any government officer visits your farm for data collection regarding farming activities?
17. Do you keep records of production processes?
    17.1. What records do you have to keep by law?
    17.2. What format was used?

Selling and delivering

18. Who are your major buyers of the product?

	Co-operative	Broker	L-Farmer	Self-marketing	Other
Price/kg.	______THB.	______THB.	______THB.	______THB.	______THB.
Share	________%	________%	________%	________%	________%
Contract	_________	_________	_________	_________	_________
Grading	_________	_________	_________	_________	_________
Market information	_________	_________	_________	_________	_________
Collective	_________	_________	_________	_________	_________

19. How frequently do you normally sell your products?
    19.1. How long is the sales period last? (a month, 3 months).
    19.2. How average quantity sales per time? (kg./time).
20. Please describe your business relationship with you major buyers.
    20.1. Do you have to qualify for a "preferred contractor" relationship with buyers?
    20.2. Do you have to go through some kind of qualification procedure to be able to supply your products? If so, please describe.
21. Could you please describe how the procurement activity has been setting up?
    21.1. How does the purchase order place to you? Please describe.
    21.2. How long does it take during the procurement process?
    21.3. What procurement process have you had to adopt, and do they differ between different buyers?
22. Have you had any contract so for with a major buyer regarding trade activity?
    22.1. What type of contract do you regularly use in your trading?
    22.2. How you communicate with your major buyer in term of setting up contract?
23. How can you access to the information regarding market price, conditions?
    23.1. How frequently do you normally access to the information?
    23.2. What are the rules on data sharing?
    23.3. What are the main challenges and problems faced regarding to data sharing?
24. How is your product graded? Please describe.
    24.1. Any sizing and grading standards used for this commodity? Please describe.
    24.2. Are there any special nature of products for different market channels? *(premium grade for supermarket).*
    24.3. What is the average quantity of your product rejected by the major buyers?
    24.4. What do you do with the product does not meet the buyer requirements?
25. How you maintain the quality of your product when it moves to the buying point?

25.1. What quality processes have you had to adopt, and do they differ between different buyers?

26. How is transportation arranged?
    26.1. How is the product distributed geographically to various buyers?
    26.2. Did you currently manage transportation activity on you own? If so, please describe.
    26.3. If no, who is responsible for this activity to moves product form farm to the buying point?
    26.4. Please identify each point in the transportation where the product undergone movement from farm to the buying point?

Where transportation take place	Method	Quantity	Distance	Duration
From____________to____________	__________	________kg.	________km.	________min.
From____________to____________	__________	________kg.	________km.	________min.
From____________to____________	__________	________kg.	________km.	________min.

27. Could you please describe the constraints affecting transportation activity?
28. Please identify and describe any type of damage/bruising which occurring to the product during transport?
    28.1. Who is responsible for the damaged products during the transportation?
    28.2. What do you do with the damaged products?
    28.3. What is the average quantity of your damaged product per shipment?
29. What percentage of production cost is attributed to transportation activity?
    29.1. Please identify the costs involved during this stage of transportation.

Cost components	Unit	Cost/unit
Labour/driver	________________	_____________THB.
Packaging, container	________________	_____________THB.
Vehicle	________________	_____________THB.
Fuel	________________	_____________THB.
Others_________________________	________________	_____________THB.

30. What are the payment mechanisms used in your transaction?
    30.1. In case of bank transfer, could you please describe the procedure to claim on your shipment?
    30.2. How long does it take to receive the payment?
    30.3. Are there any problem with payment?
31. Are there any market information available for the commodity you have produced?
    31.1. What is the source of the supply information, and is it reliable?
    31.2. What type of market information available and frequency of information?
32. Please describe other operations point in food system where operation occurs.

Social scheme and government support

33. Do you participate in any networking activities among farmers, being as part of an association? (co-operative, social enterprise) could you please specify?
    33.1. How long have you been in this social scheme?
    33.2. Are there any costs or specific requirements for joining the social scheme?
    33.3. What are the rules once you are in?
34. Why did you decide to join this social scheme?
35. What do you perceive to be the advantages and disadvantages of producing under contract with social scheme instead of producing to sell in other market channels?
    35.1. Do you thank that farmers can get advantages of selling through social schemes?
36. What are the opportunities and benefits do they offer to you?
    36.1. How social scheme's services benefits the member farmers? (agricultural inputs, storage, transportation, machinery, information, marketing).
    36.2. Are there any services which provided by social scheme? Please specify.
37. Please rate the important of each potential benefit of participating with the social scheme.

	Unimportant	**Average**	**Important**	**Rank**
Extra income	__________	__________	__________	__________
Guaranteed purchase	__________	__________	__________	__________
Guaranteed minimum price	__________	__________	__________	__________
Acquiring new knowledge, training	__________	__________	__________	__________
Group relationship with other farmers	__________	__________	__________	__________
Access to agricultural inputs	__________	__________	__________	__________
Collective procurement	__________	__________	__________	__________
Market opportunities (high- value)	__________	__________	__________	__________
Others___________________________	__________	__________	__________	__________

38. What data that farmers are mandated to provide to the social scheme? Could you please specify?
    38.1. What information legally you have to provide?
39. How do you think farmers that participating with social schemes generally compared to non-participating farmers? *(must better, the same, worse)* Please describe.
40. Could you please specify agricultural support related to farming activities? Where and how did you get it, how does it cost?

Inputs	**Provided by**	**Cost**	**Cost paid by**
Seed, tree sapling	____________________	_________THB.	_____________
Fertiliser, pesticide	____________________	_________THB.	_____________
Labour	____________________	_________THB.	_____________

Land	___________________	________THB.	_____________
Farming equipment	___________________	________THB.	_____________
Transportation	___________________	________THB.	_____________
Training for farming practise	___________________	________THB.	_____________
Market information	___________________	________THB.	_____________
Others________________________	___________________	________THB.	_____________

41. How difficult is to access the support assistance from the government?
42. For non-participating farmers, have you considered joining social schemes? Please describe the reasons why you are joining or not interesting.

Current situation, challenges and problems faced

43. Could you please describe the current situation, and the development of Thailand's agri-food industry? *(market mechanisms, distribution channels, market trends).*
    43.1.What have been the main changes in market structure of agricultural sector over the past 5 years from your experienced?
    43.2.What market conditions are most likely to change, and which will stay the same?
    43.3.How have the distribution channels been changed?
    43.4.How has the management of farming practices change recently?
44. How have different market mechanisms system affect to you?
45. What do you understand to be the main requirement place on your farming in term of working with the current market mechanisms?
46. What barriers or obstacles have you encountered, or do you envisage with regard to running your business? (agricultural inputs, market channels, market information, financial, transportation).
47. What concern you most about current operation?
    47.1.What major operational weakness need to be immediately addressed?
    47.2.In your opinion, what are the main challenges faced your farming and current operation?

Participant Farmer opinion on alternative operating scenarios

48. According to the alternative operating scenarios presented, do you think these concepts would be help rural farmers to improve transportation efficiency? Please describe. *(sharing vehicle through farmer co-operative and using a 3rd party vehicle to make milk-round collection have been presented).*
49. What are the advantages and disadvantages of working under the co-operative transportation schemes?

50. In your opinion, do you think the large-scale farmers will joining in the co-operative transportation? *(discussed about the farm size which is one of the key factors in the proposed co-operative transportation schemes).*
51. What are the most concerned do you have when implementing the proposed co-operative transportation schemes?
52. What kind of cost allocation methods would you prefer for sharing the cost of transportation? *(proportional and the Shapley value methods have been presented to the participants).*
53. What recommendations do you have for constructing 'best practice' model to enhance the co-operative scenarios?
54. View about the further prospect with co-operative transportation schemes?

C.6 Questionnaire Survey with the Rural Farmers

UNIVERSITY OF Southampton

RESTRUCTURING THE SUPPLY CHAIN TO BETTER SERVE RURAL FARMERS: A CASE STUDY OF THAILAND's MANGO SUPPLY CHAIN **No.**

This questionnaire survey is part of a Ph.D. research project funded by the National Science and Technology Development Agency, the Royal Thai Government. This project conducted by the University of Southampton, Faculty of Engineering and Physical Science, Transportation Research Group, with no commercial interests involved. This research aims to investigate the opportunities for improving the logistics of food supply chain management associated with rural farmers in Thailand.

We would appreciate you taking some time to answer our questions. I would like to assure you that an information you provide is just for the purpose of this project and will be treated as confidential and not divulged to any third party.

SECTION A HOUSEHOLD INFORMATION

Name of respondent:

Home address: City: Post code:

Contact number:

FARM INFORMATION

1. How long have you been engaged in agricultural? Year(s)
2. What is the proportion of household income from farming? %
3. Are you a member of co-operative? ☐ Yes ☐ No
4. How many rai of farm were owned? Rai
5. How many rai of farm were rented or leased from other? Rai
   5.1. How does it cost? THB/Rai
6. How far is your farm from the main road? Km.
   6.1. How farm is your farm from the buying (consolidation) point? Km.
7. How many labours are hired and involved in farming activities?
   7.1. Family members Person(s)
   7.2. Fired labours Person(s)
   7.3. How does it cost for hired? THB./day

HOUSEHOLD INCOME

8. What is your estimated yearly household income? THB./year

Sources of income **% of the total income**

   8.1. Farming %
   8.2. Proving labour to other farms %
   8.3. Other non-agricultural business work %
   8.4. Other__________________________ %

SECTION B GOVERNMENT SUPPORT

SOCIAL SCHEMES

9. Have you participated in any social schemes? (co-operatives) ☐ Yes ☐ No
   9.1. How long have you been in this social scheme? ____ Year(s)
   9.2. Are there any cist for joining as its member? ☐ Yes ☐ No
   9.3. How much does it cost for being its member? ____ THB./year
10. What are the opportunities and benefits do social schemes offer to you?

Factor influence	Unimportant	Average	Important	Rank
Extra income	☐	☐	☐	
Guaranteed purchase	☐	☐	☐	
Acquiring new knowledge, training	☐	☐	☐	
Group relationship with other farmers	☐	☐	☐	
Access to agricultural inputs	☐	☐	☐	
Collective procurement	☐	☐	☐	
Market opportunity (high-value market)	☐	☐	☐	

11. Did you receive any agricultural credits from social scheme, government? ☐ Yes ☐ No

Credits/Inputs/Services	Provider	Cost (THB.)	Cost paid by	Credit*
Seed, tree sapling				☐
Fertiliser				☐
Pesticide, chemical				☐
Land				☐
Farming equipment				☐
Transportation				☐
Training				☐
Market information				☐
Other________________				☐

*If co-operative/government provides inputs, they allow the input to be brought on credit

12. How often have officials from social scheme visits your farm? ____ Time/year
13. How do you think farmers that grow for social scheme are generally compared to farmers that do not grow for social schemes?

Much better	A bit better	About the same	A bit worse	Much worse
☐	☐	☐	☐	☐

14. Do you consider that your market opportunity today is greater than if you did not produce for the social scheme?

Decrease	The same	Increase
☐	☐	☐

15. How much your household's income increased/decreased as a result of growing for social scheme?
16. Overall, how would you describe your relationship with social scheme?

Very good	Good	Satisfactory	Bad	Very bad
☐	☐	☐	☐	☐

SECTION C PRODUCTIONS

PRODUCTIONS

17. What proportion of products being produced?

Crops		The total production area	Average amount harvested	Marketing contract	Quantity delivery	Average price	Total amount
1)		rai	kg./rai	☐ Yes ☐ No			
2)		rai	kg./rai	☐ Yes ☐ No			
3)		rai	kg./rai	☐ Yes ☐ No			
4)		rai	kg./rai	☐ Yes ☐ No			

The total received (total crops 1+2+3+4)

18. Does you perform value-addition activities after harvesting process? ☐ Yes ☐ No

Crops		Cleaning		Grading		Packaging		Cooling	
		Times	Cost	Time	Cost	Time	Cost	Time	Cost
1)									
2)									
3)									
4)									

19. Please identify about getting certifications related farm activity.

	Farming	GAP	Organic	Pesticide-safe
Which certificate are holding	☐	☐	☐	☐
Any funding to apply it	☐	☐	☐	☐
How long does certificates last				
How does it cost				
Who is certificate provider				

20. Are there any paperwork and system do you have to engage with the government or your buyer to undertake your business? ☐ Yes ☐ No
21. What data that you are mandated to provide to the government or buyers by laws and regulations?

Purchasing	Production	Selling	Transportation	Other
☐	☐	☐	☐	☐

MARKET DETAILS

22. How frequently do you normally sell your products in one year? ______ A year
    22.1. How average quantity sales per time? ______ Kg./time
23. Do you have to qualify for a “preferred contractor” with buyers? ☐ Yes ☐ No
24. How long does it take during the procurement processes? ______ Day(s)
25. Is there any market information available for you? ☐ Yes ☐ No
    25.1. How frequently do you normally access to the information? ______

26. Who is your major buyer of products?

	Co-operative		Social enterprise		Broker		Leading Farmer		Self-marketing	
Price										
Market share										
Guaranteed price	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Contract	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
If yes, what type	☐ Vb	☐ Wt	☐ Vb	☐ Wt	☐ Vb	☐ Wt	☐ Vb	☐ Wt	☐ Vb	☐ Wt
Harvesting	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Grading	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Market information	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Transportation	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No
Farming inputs	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No	☐ Yes	☐ No

27. Are there any grading standards used for these commodities? ☐ Yes ☐ No

28. It there any specific nature of product for supermarket buyer? ☐ Yes ☐ No

29. What is the average quantity of your product rejected by buyers? ____ %

PAYMENT

30. What is the payment mechanism used in your transaction? ____

31. How long does it normally take to receive your payment? ____ Day(s)

TRANSPORTATION

32. Did you currently manage transportation on your own? ☐ Yes ☐ No

    32.1. If no, who is responsible for this activity? ____

33. Please identify each point in the transportation where the product undergone movement from farm to buying (consolidation) point?

Delivery	Who responsible		Quantity	Distance	Duration	Cost
From________to________	☐ own	☐ Other				
From________to________	☐ own	☐ Other				
From________to________	☐ own	☐ Other				
From________to________	☐ own	☐ Other				

34. What percentage of production cost is attributable to transportation? %

Cost components	Unit	Cost/unit	
1)			THB.
2)			THB.
3)			THB.
4)			THB.
5)			THB.

35. What is the average quantity of your damaged product per shipment? ____ Kg.

    35.1. Who responsible for the damaged product? ____

SECTION D FARM EXPENDITURES

DIRECT (PRODUCTION) EXPENSES	Unit per rai	Cost (THB.)	Pay by (subsidies)
1. Seeds, tree sapling			
2. Fertiliser and soil supplements			
3. Pesticides and chemical treatments			
4. Planting			
5. Bagging on fruit tree			
6. Pruning			
7. Harvesting			
8. Cleaning, sorting, grading			
9. Packaging, wrapping			
10. Other________________________			
Total direct expenses			
INDIRECT VARIABLE EXPENSES	**Unit per rai**	**Cost (THB.)**	**Pay by (subsidies)**
11. Land preparation			
12. Labour			
13. Agricultural contract work			
14. Freight and transport			
15. Farm equipment/machinery			
16. Machinery (maintenance)			
17. Utilities (electricity, water)			
18. Cooling and storage			
19. Facilities maintenance			
20. Other________________________			
Total indirect variable expenses			
FIXED EXPENSES	**Unit per rai**	**Cost (THB.)**	**Pay by (subsidies)**
21. Property taxes			
22. Rent (land, building)			
23. Interest (real estate, mortgage)			
24. Membership fee (co-operative)			
25. Vehicle			
26. Depreciation			
27. Licenses, certification			
28. Insurance			
29. Other________________________			
Total fixed expenses			

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