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Hybrid Simulation-based Planning Framework for Agri-Fresh Produce Supply Chain

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Hybrid Simulation-Based Planning Framework for Agri-Fresh Produce Supply Chain

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Thesis submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy

Dublin Institute of Technology

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Dedicated to my Parents, Wife and Sons

Yasseen, Yahia and Younus

With all my Love and Appreciation

ACKNOWLEDGMENTS

ABSTRACT

The ever-increasing demand for fresh and healthy products raises the economic importance of managing Agri-Fresh Produce Supply Chain (AFPSC) effectively. However, the literature review has indicated that many challenges undermine efficient planning for AFPSCs. Stringent regulations on production and logistics activities, production seasonality and high yield variations (quantity and quality), and products vulnerability to multiple natural stresses, alongside with their critical shelf life, impact the planning process. This calls for developing smart planning and decision-support tools which provides higher efficiency for such challenges. Modelling and simulation (M&S) approaches for AFPSC planning problems have a proven record in offering safe and economical solutions. Increase in problem complexity has urged the use of hybrid solutions that integrate different approaches to provide better understanding of the system dynamism in an environment characterised by multi-firm and multi-dimensional relationships. The proposed hybrid simulation-based planning framework for AFPSCs has addressed internal decision-making mechanisms, rules and control procedures to support strategic, tactical and operational planning decisions.

An exploratory study has been conducted using semi-structured interviews with twelve managers from different agri-fresh produce organisations. The aim of this study is to understand management practices regarding planning and to gain insights on current challenges. Discussions with managers on planning issues such as resources constraints, outsourcing, capacity, product sensitivity, quality, and lead times have formed the foundation of process mapping. As a result, conceptual modelling process is then used to model supply chain planning activities. These conceptual models are inclusive and reflective to system complexity and decision sensitivity. Verification of logic and accuracy of the conceptual models has been done by few directors in AFPSC before developing a hybrid simulation model. Hybridisation of Discrete Event Simulation (DES), System Dynamics (SD), and Agent-Based Modelling (ABM) has offered flexibility and precision in modelling this complex supply chain. DES provides operational models that include different entities of AFPSC, and SD minds investments decisions according to supply and demand implications, while ABM is concerned with modelling variations of human behaviour and experience.

The proposed framework has been validated using Table Grapes Supply Chain (TGSC) case study. Decision makers have appreciated the level of details included in the solution at different planning levels (i.e., operational, tactical and strategic). Results show that around 58% of wasted products can be saved if correct hiring policy is adopted in the management of seasonal labourer recruitment. This would also factor in more than 25% improved profits at packing house entity. Moreover, an anticipation of different supply and demand scenarios demonstrated that inefficiency of internal business processes might undermine the whole business from gaining benefits of market growth opportunities.

LIST OF ABBREVIATIONS

ABM	Agent-Based Modelling
AFPSC	Agri-Fresh Produce Supply Chain
AFSC	Agri-Food Supply Chain
CLD	Casual Loop Diagram
CSR	Corporate Social Responsibility
DES	Discrete Event Simulation
DP	Dynamic Programming
EU	European Union
FAO	Food and Agriculture Organisation
GATT	General Agreement on Tariffs and Trade
IP	Integer Programming
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LP	Linear Programming
M&S	Modelling and Simulation
MAD	Mean Absolute Deviation
MLIP	Mixed Linear Integer Programming
MS	Management Science
NLP	Non-Linear Programming
OR	Operations Research
PI	Performance Indicator
SC	Supply Chain
SCM	Supply Chain Management
SD	System Dynamics
SFD	Stock and Flow Diagram
SP	Stochastic Programming
TGSC	Table Grapes Supply Chain
WTO	World Trade Organisation

LIST OF NOTATIONS

t	Simulation time in days
$\widehat{Q}_h^G(t)$	Estimated Quantity for Harvesting at day t
w	Average weight for fresh produce unit
n	Number of Trees in Farms
$U_i(t)$	Number of un-harvested units on the ith tree at day t
$R(t)$	Rate of ripening for un-harvested units at day t
r_1	A positive parameter for equation (2)
r_2	A positive parameter for equation (2)
$D^H(t)$	Number of Seasonal Harvesters recruited for day t
$\overline{P}^H(t)$	Perceived Harvester Productivity
$K_i^H(t)$	Number of Working Days for Harvester i when it is hired at day t
S^H	Size of Seasonal Harvesters Pool
$E_i^H(t)$	Work experience of Harvester i when it is hired at day t
E_{max}^H	Maximum Harvester work experience
r_3	A positive parameter for equation (5)
$Q_h^G(t)$	Actual Harvested Quantity at day t
$Q_l^G(t)$	Wasted Quantity During Harvesting Operations at day t
$P^H(t)$	Average Harvester Productivity at day t
a_1	Time to perceive change in harvesters' productivity
$\widehat{Q}_r^P(t)$	Estimated Quantity in packing house receiving area at day t
$Q_u^P(t)$	Unpacked Quantity at the end of day t
$Q^O(t)$	Outsourced Quantity at day t
$Q_r^P(t)$	Actual Quantity in packing house receiving area at day t
$Q_h^P(t)$	Actual Quantity handled and processed in the packing house at day t
$D^P(t)$	Number of Seasonal Packers recruited for day t
$\overline{P}^P(t)$	Perceived Packer Productivity
$K_i^P(t)$	Number of Working Days for Packer i when it is hired at day t
S^P	Size of Seasonal Packers Pool
$E_i^P(t)$	Work experience of Packer i when it is hired at day t

E_{max}^P	Maximum Packer work experience
r_4	A positive parameter for equation (12)
$Q_P^P(t)$	Actual Packed Quantity at day t
$Q_l^P(t)$	Wasted Quantity During Packing Operations at day t
$P^P(t)$	Average Packer Productivity at day t
a_2	Time to perceive change in packers' productivity
$Q_p^E(t)$	Planned Quantity to be dispatched for shipping at day t
$OAF(t)$	Outsourcing Availability Fraction at day t
RD	Received demand at the beginning of season
MD	The Overall Market Demand
MS	The AFPSC market share
CS	Customer Satisfaction Percentage
$CS_{\min\_eff}$	Minimum Effect of Customer Satisfaction on RD
TO%	Seasonal Labour Market Turnover
OAF_{min}	Minimum value for Outsourcing Availability Fraction
OAF_{max}	Maximum value for Outsourcing Availability Fraction

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PUBLICATIONS

1	Mesabbah, Mohammed, Wael Rashwan, and Amr Arisha. *"An empirical estimation of statistical inferences for system dynamics model parameters." In 2014 Winter Simulations Conference (WSC):edited by A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, and J. A. Miller, 686-697. Piscataway, New Jersey: IEEE*
2	Crowe, John, Mohammed Mesabbah, and Amr Arisha. *"Understanding the dynamic behaviour of three echelon retail supply chain disruptions." In 2015 Winter Simulations Conference (WSC):edited by L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossett, 1948-1959. Piscataway, New Jersey: IEEE.*
3	Mesabbah, Mohammed, et al. *"Hybrid modelling for vineyard harvesting operations" In 2016 Winter Simulations Conference (WSC):edited by T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, 1642-1653. Piscataway, New Jersey: IEEE.*
4	Mesabbah, Mohammed, et al. *"Seasonal recruiting policies for table grape packing operations: a hybrid simulation modelling study." In 2017 Winter Simulations Conference (WSC):edited by W. K. V. Chan, A. D'Ambrogio, G. Zacharewicz, N. Mustafee, G. Wainer, and E. Page, 1642-1653. Piscataway, New Jersey: IEEE.*

CHAPTER 1: INTRODUCTION

Europe's food industry is counted as the most significant sector in terms of turnover, value-added processing, and employment. The industry accounts for more than 285,000 SMEs that generate more than 50% of the food industry turnover and value added, and provide 30% of the employment in the sector (FoodDrink Europe, 2016). On the national side, the agri-food sector is Ireland's largest indigenous industry with gross annual output approaching €22 billion, which accounts for 60% of exports by indigenous firms and employs more than 135,000 people (DAFM 2017).

Agriculture products are distinguished by the continuous and significant changes in product quality and safety throughout the entire supply chain (Akkerman, Farahani, and Grunow 2010). Among the vast varieties of agriculture crops, fresh produce crops (i.e., fruit and vegetables) are critical as they constitute a substantial portion of the annual agricultural crops and have been identified as the fastest growing economic segment of agriculture products (Shukla and Jharkharia 2013). Fresh product markets are also dynamic and evolving faster than traditional crops such as grains and seeds (Huang 2004). For instance, the global production has increased by 94% from 1980 to 2004, and the annual consumption has witnessed annual increase by 4.5% approximately during the same period (Olaimat and Holley 2012).

However, Agri-Fresh Produce Supply Chains (AFPSC) face various challenges that call for significant improvement in the planning and decision-making strategies. Consumers are becoming more concerned with product's origin, and the environmental impact of

growing and production (Ahumada and Villalobos 2009a). The ever-increasing demand from consumers for healthy products (PBH 2015) along with the stringent regulations on production and logistical activities the complexity of AFPSC's network structure and design is ever increasing. In addition, globalisation, modern technology, changing market conditions (e.g. consumption trends and consumer preferences) and product vulnerability to climate change and environmental disruption add to the management challenges (Zhang 2006). Agri-fresh produce is also subject to production seasonality and high yield variations in terms of quantity and quality. Product quality and safety are downgraded over time, with both negatively affected by environmental conditions during harvesting, storing, and handling activities (van der Vorst, Tromp, and van der Zee 2009). Product freshness is critical for consumers and can significantly impact their buying decisions (Aiello, La Scalia, and Micale 2012). Moreover, agri-fresh products are characterised by critical shelf-life that forces retailers sometimes to spoil products if they exceed their "best-before dates" (Aung and Chang 2014).

AFPSC business is also challenged by different risks such as stochastic global demand, price fluctuation, exchange rates, changing economic conditions and political conflicts (Tsolakis et al. 2014). Globalised market emergence and recent international trade agreements have created fierce competition between growers and suppliers serving these markets (Zhang 2006). Meanwhile, the industry faces strict trade regulations and legislations which pressurise AFPSC managers (Georgiadis and Athanasiou 2013).

Therefore, managers in the fresh-produce business are forced to develop smart planning and decision-making tools to resolve industry challenges and offer insight into

system complexity at different levels. Accordingly, they have to have to recognise the types of activities that constitute the whole Supply Chain (SC), the operations within each activity, the main problems and their causes, which decisions are efficient and which are not, and the impact of these decisions on the overall SC performance. However, complex planning decisions are raised at different levels of the supply chain such as farm location and infrastructure decisions – *strategic level* –, design of harvesting and packing operations – *tactical level* – and quantities of crops to be harvested and resources requirements – *operational level* (Osvald and Stirn 2008). It is evident that a decision at any planning level may affect another decision at different planning level and vice versa. For instance, seasonal workers hiring policy – tactical decision –impacts on worker experience which impacts their productivity, which is one of the factors the determine the number of workers to hire – operational decision – at any particular day (Mesabbah et al. 2016). The deep understanding of the relationships between business decisions is essential for efficient planning and decision-making processes (Jahangirian et al. 2010). On the other hand, planning becomes more complicated if conflicting objectives or different stakeholders are involved. For example, for some crops, growers have to have to harvest all the products when they reach to a specific degree of ripeness otherwise they will overripe and become spoiled. On the other hand, if the harvested quantity exceeds the processing plant capacity they will not be received and be in danger of deterioration.

Therefore, there is a growing interest in addressing the complexity of the entire system by understanding the relationships between different decision-making levels and how that impacts overall performance (Jahangirian et al. 2010). Considering the broad spectrum of decisions in AFPSC and their complexity, traditional decision making and planning tools

are shown to be less efficient due to their limited ability to model complex, multi-firm, multi-dimensional relationships. They impose many assumptions and simplifications on the system structure, to reduce decisions complexities. Alternatively, simulation methods are able to address decision-making problems at the different management levels (i.e. strategic, tactical and operational) in addition to capturing system's complexity, dynamics and stochastic behaviour (Terzi and Cavalieri 2004). Simulation models can also be used for conducting large-scale virtual experimentation on these systems rather than physical experiments which are often expensive and time-consuming (Hester and Cacho 2003). However, these approaches have not received enough attention in AFPSCs literature (Ahumada and Villalobos 2009a).

1.1 Research Motive

1.1.1 Growing Demand and Economic Importance

The world's population is overgrowing; it is predicted that it will increase by 35% by 2050 and, therefore, food demand is expected to double by that time. This raises concerns regarding global food security and nations' ability to increase food production to secure the needs of its people (Godfray et al. 2010). On the other hand, growing competition between food producers for natural resources such as water, land and energy negatively affects food production (Tilman et al. 2001). In addition, global warming and substantial climate changes are other threats to be considered. As a response, food supply systems are required to act quickly to match the growing demand for food. Therefore, new policies and planning methods are needed to replace those that are currently employed to produce, store, process, and distribute food in more efficiently.

Economically speaking, there is increased attention towards agri-fresh produce cultivation (Shukla and Jharkharia 2013). Demand for fresh produce has been accelerated compared with other crops such as grains (Yu and Nagurney 2013). This is motivated by the global promotion regarding consumption of fruit and vegetables for better health and well-being (Rekhy and McConchie 2014). Concurrently, the global production of fruits and vegetables has increased by nearly 47% between 2000 to 2014 (FAO 2015). A recent study in the US has suggested that more than 50% of this production is consumed in fresh forms (PBH 2015). The agri-fresh produce market represents nearly 23% of all US food expenditures (Epperson and Estes 1999). Similarly, in the European Union (EU), fresh produce accounted for approximately 20% of the total agriculture output (Eurostats 2015). In Ireland, the production of fruits and vegetables has witnessed an increase of 11% between 2000 and 2014 however, the deficit in trade balance for these products has raised from $306 million to $995 million during the same period (FAO 2015).

It is estimated that 40-50% of fresh produce production is wasted across the various stages and functions of the AFPSC (i.e., growers to consumers). Such waste contributes to hunger and poverty while undermining economic growth (Kaipia, Dukovska-Popovska, and Loikkanen 2013). Inefficient planning of SC functions and activities along with a lack of coordination between the involved stakeholders have highlighted causes of this waste (Gustavsson et al. 2013). Preventing production waste does not only have a significant impact on economy, but it also preserves natural resources such as land, water, and energy (Soysal 2015).

1.1.2 Hybrid Simulation Approaches

Managers and stakeholders of AFPSC are under pressure to adopt new policies and practises in order to improve the overall performance of their business. Given the complexity and dynamism involved in these SCs, there is a need for structured approaches to help managers and decision-makers in examining the efficacy of new policies and strategies (Ting et al. 2014). As mentioned earlier, simulation approaches are best suited to play this role. Simulation modelling is a strong approach for evaluating different decisions and strategies using based on "what-if" analysis scenarios (Min and Zhou 2002). There exist three primary simulation approaches, each of them capable of addressing different aspects of system dynamism and complexities (Jahangirian et al. 2010). Discrete Event Simulation (DES) is an approach that can be employed for complex, dynamic and stochastic systems where variables' state change at discrete time advances. Therefore, it is believed that DES models are best suited for operational and tactical decision-making levels (Brailsford and Hilton 2001). System Dynamics (SD) is a modelling approach based on causality relationships among various system entities and could be efficiently used to study the long-term effects of business policies (Sterman 2000). Hence, SD modelling is recommended as a useful approach for at the level of strategic planning (Tako and Robinson 2012). Finally, Agent-Based Modelling (ABM) is a robust approach for capturing heterogeneity and variations among simulated entities and their complicated relationships. It allows more realistic modelling of complex systems when human behaviour patterns exist (Shen and Norrie 1999).

Integrated planning is needed in the context of agri-fresh produce business particularly at the upstream echelons (Ahumada and Villalobos 2009a). Giving the

multifaceted planning decisions, in this case, adopting a single simulation approach might fail in addressing all these decisions. For example, an SD model will be able to investigate the impact of capital investment decision – strategic level– on the annual production yield, but it will fail to envisage how harvesting schedule – operational level – or seasonal labourer hiring decision – tactical level and heterogeneous human behaviour – might affect that annual production. Having said that none of the three techniques has superiority in addressing all three levels of decision making at the same time, several researchers have investigated hybrid simulation modelling (Mustafee et al. 2015). Hybrid simulation enables leveraging single approach strength and addresses more aspects of system complexity that cannot be achieved using an individual approach (Powell and Mustafee 2014).

Hybrid simulation modelling is a relatively new research area with good momentum. These hybrid simulation models have demonstrated their ability to address different aspects of decision making levels in areas such as construction (Pena-Mora et al. 2008), solar energy production (Zhao et al. 2011), healthcare (Brailsford et al. 2013), and transportation (Zhang, Chan, and Ukkusuri 2011). Therefore, given the multifaceted aspects of integrated planning for complex agri-fresh produce business, this research is motivated to investigate how hybrid simulation modelling can be employed in AFPSC context.

1.2 Research Question and Objectives

The aim of this research is to develop a framework for the integrated planning of AFPSCs, which managers and stakeholders can use in a practical and reflective way. This framework can be used as a decision support tool for developing effective policies and strategies for the overall AFPSC. Hence, the fundamental research question is:

"How can advanced modelling and simulation techniques be employed to support agri-fresh produce supply chain managers in effectively modelling and planning their activities on the strategic, tactical and operational levels?"

This question can be divided into four research questions (RQ) as follows:

RQ 1: How are modelling and simulation techniques currently employed in AFPSCs?

RQ 2: What are the main planning decisions and performance indicators that AFPSCs' managers should consider?

RQ 3: How can a modelling and simulation-based framework be developed for AFPSC planning?

RQ 4: How far would a developed framework be useful for decision-making in AFPSC and to what extent can it be applied?

To address these questions and ultimately achieve the aim of the research, the main objective is thus to:

"Develop a hybrid-simulation based integrated planning framework to support managers in agri-fresh produce supply chain."

This research objective can be divided into a set of sub-objectives which are associated with these research questions. This association is presented in Table 1-1

Table 1-1: Research questions and associated objectives

Research Questions	Research Objectives
RQ 1: How are modelling and simulation techniques currently employed in AFPSCs?	**1:** Identify the different models employed for AFPSC planning (Literature Review).
RQ 2: What are the main planning decisions and performance indicators that AFPSCs' managers should consider?	**2a:** Gain in-depth understanding of AFPSC system (Exploratory Study).
	2b: Explore decision making aspects for AFPSCs.
RQ 3: How can a modelling and simulation-based framework be developed for AFPSCs planning?	**3:** Identify required components for developing integrated planning framework (i.e., Framework Development).
RQ 4: How far would a developed framework be useful for decision-making in AFPSC and to what extent can it be applied?	**4:** Validate and Implement the Framework (Case Study).

1.3 Thesis Layout

The thesis layout is illustrated in Figure 1-1. Chapter two presents a review of AFPSCs literature to show their characteristics and main challenges. The literature review will also cover the existing modelling and simulation approaches along with their application in addressing complex AFPSC planning problems. The objective is to gain thorough insights on the current decision-making approaches thereby identifying research limitations and gaps.

Chapter three highlights the applied research methodology and shows the relationship between research questions/objectives and research philosophies and strategies. Chapter four presents the exploratory study which is included to understand the system and develop a conceptual model for AFPSC planning decisions. Chapter five offers a detailed explanation of the proposed framework. Finally, chapter six and seven utilise a case study approach to

empirically evaluate the proposed framework, discuss results, conclude the thesis and highlight future work.
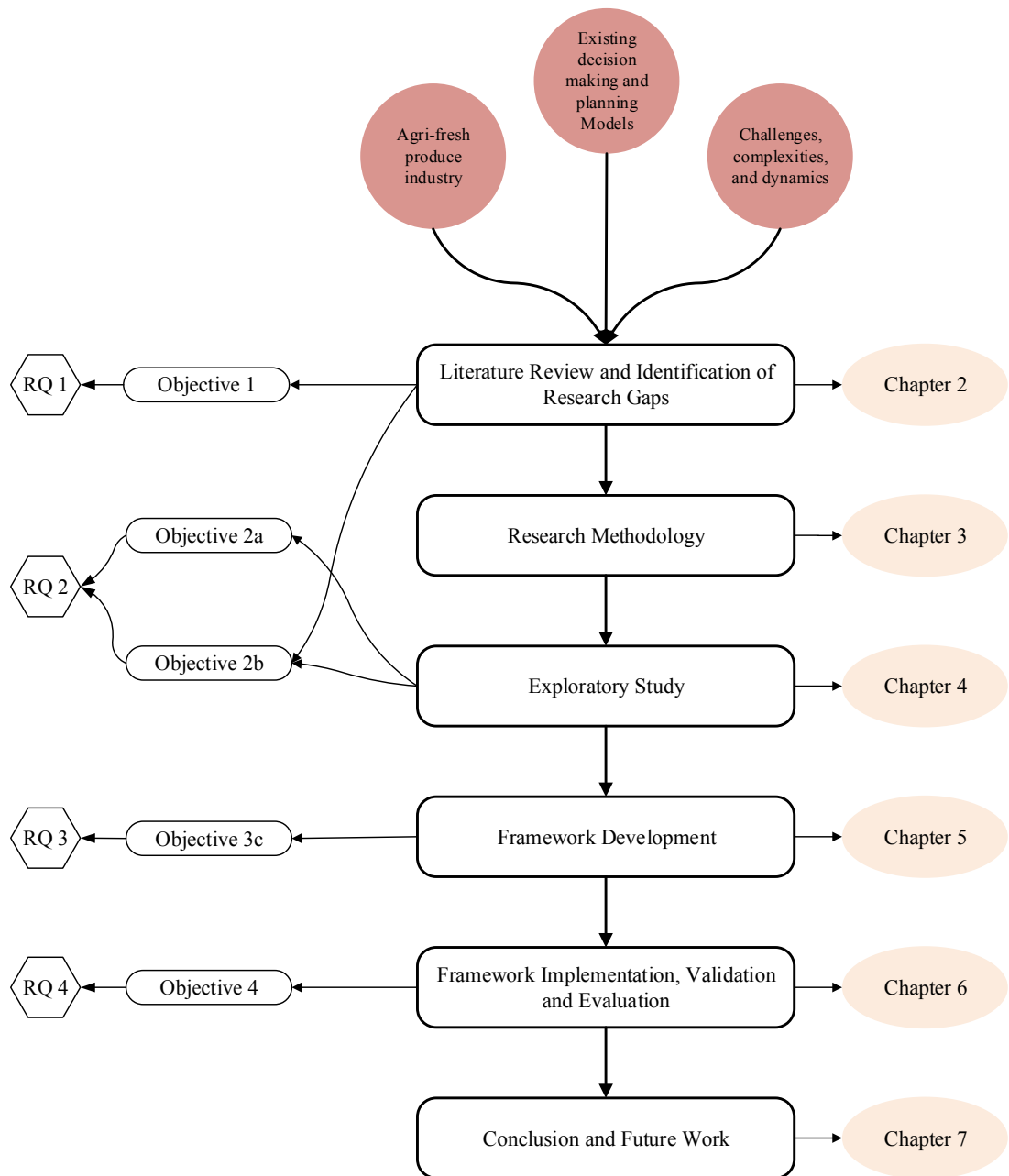
Figure 1-1 Thesis Layout.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The term Supply Chain (SC) refers to "A network of organisations that are involved through upstream and downstream linkages in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer." (Christopher 2005, 13). A demonstration for a SC network is provided in Figure 2-1. The main objective of any supply chain is to facilitate the flow of products across the entire network and satisfy customers' needs (Ellram 1991). To achieve this, SCs are required to be efficient, flexible, agile, and responsive to various exogenous influences such as process disruptions, swing prices of oil and gas, economic crises and political conflicts (Christopher, Lowson, and Peck 2004).

SC typically involve multiple stakeholders with conflicting objectives which often results, in sub-optimal performance of the SC and undermines full integration of its activities and processes (Simchi-Levi, Kaminsky, and Simchi-Levi 2004, van der Zee and van der Vorst 2005). Hence, Supply chain management (SCM) is defined as "the *integrated planning*, coordination and controlling of all business processes and activities in the SC to deliver superior consumer value at minimum cost to the end consumer while satisfying requirements of other stakeholders" (Van der Vorst and Beulens 2002, 410). The planning complexity emerges from the embedded dynamism, large-scale nature of processes and flows, and multi-functional activities. By increasing the number of entities involved in SC

and the diversity of products and/ or services that SC handles, the level of SC complexity significantly increases (Li et al. 2010).
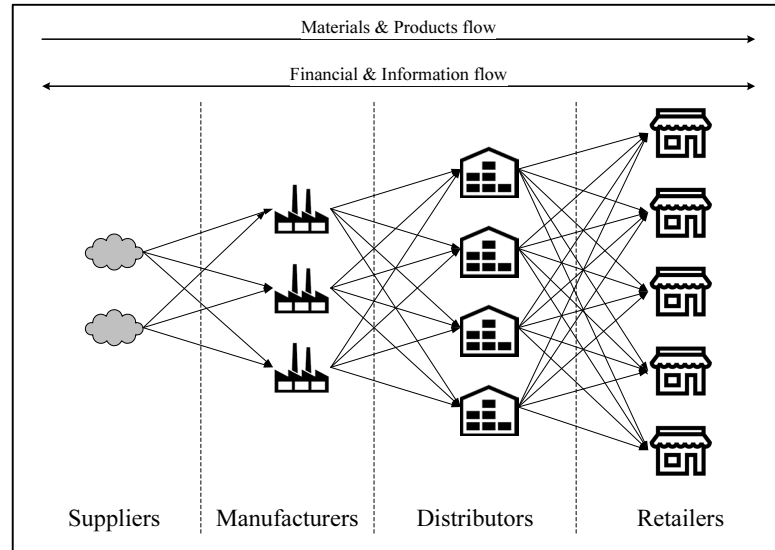
Figure 2-1 Classical Structure of Supply Chain

2.2 Agri-Fresh Produce Supply Chain

Agri-food products flow from farms to consumers in complex supply chains consisting of dynamic and interrelated echelons (i.e. Agri-food supply chain (AFSC)). Aramyan et al. (2006) suggested that AFSCs have unique characteristics compared to other SCs, which include:

1) *Production Nature*: Agri-food products are mainly dependent on *biological* processes, which are connected to environmental factors such as production region climate, weather conditions and natural resources availability. These factors result in high production lead times, impose high variability in production and create a vulnerable supply chain to disruption risks.

2) *Product Nature*: Agri-products have specific characteristics such as perishability, quality and safety constraints. These characteristics create the need for a particular SC design and require special conditions during the different SC functions.

3) Societal, consumer behaviour and concerns with food safety, traceability, workers welfare and environmental pressure.

Agriculture products significantly contribute to the global economy and constitute the majority of raw materials for other manufacturing processes. Among vast varieties of agriculture products, as shown in Figure 2-2, fresh products, also known as fresh produce (mainly fruits and vegetables), are the most critical ones (van der Vorst, Tromp, and van der Zee 2009). The intrinsic characteristic of these products is freshness. Fresh produce has to have to be presented at retailer shelves as 'ready to eat' products, at a certain freshness. They have limited shelf-life and high vulnerability to quality downgrading, safety risks and products spoilage (Ahumada and Villalobos 2009a).
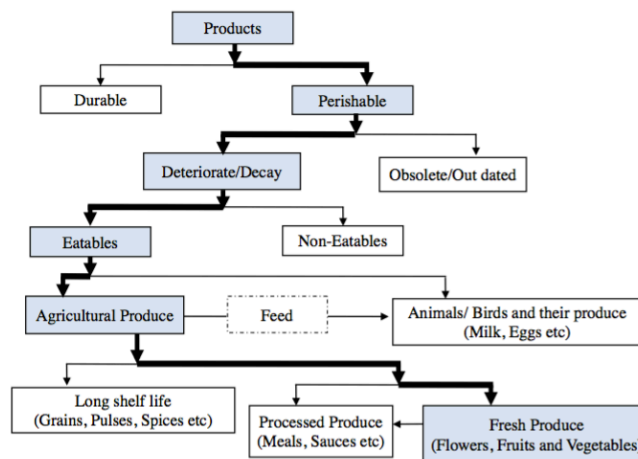
Figure 2-2 Products Differentiation (Shukla and Jharkharia 2013)

AFPSC constitutes of different processes including growers, agricultural cooperatives, food processors, distribution centres and retailers (Figure 2-3) (Soto-Silva et al. 2016). There is

no one definitive structure of AFPSC as it varies in terms of a number of SC stakeholders (i.e., growers, distributors, etc.), types of products, geographical locations and market conditions.
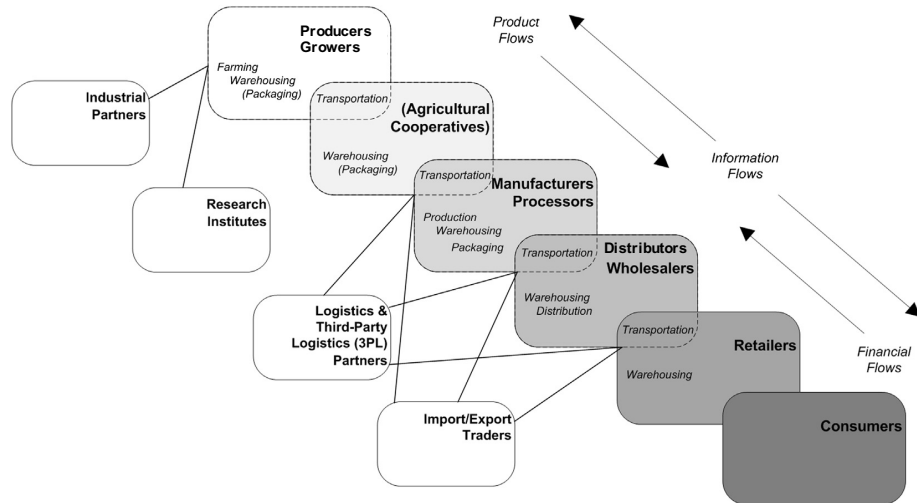
Figure 2-3 Schematic Agri-fresh Produce Supply Chain (adapted from (Tsolakis et al. 2014))

AFPSC research has received increased attention from both researchers and practitioners motivated by five primary factors (Shukla and Jharkharia (2013):

1) *Supply Chain Globalisation*: growers have to efficiently manage and plan their global supply chain activities to extend their business overseas and export food products for competitive prices.

2) *Technological Advances*: The improvement in genetic and chemical engineering contributes to the development of more productive seeds, fertilisers, and pesticides. In addition, the introduction of more efficient farming machinery helps to improve the yield and decrease dependency on external workers and weather conditions.

3) *Trade Agreements*: The international trade agreements (e.g. General Agreement on Tariffs and Trade (GATT) and World Trade Organisation (WTO)) have reduced trade

barriers between countries, though they've increased competition and created channels for cooperation between SC members across borders.

4) *Consumers Awareness*: Food consumption habits and preferences have changed in recent decades. Demand for healthy food and tracing source of products have changed the consumers' preferences and increased demand for high quality and traceable produce at affordable prices.

5) *Environmental Concerns*: The agricultural practices are currently under public scrutiny because of the increasing usage of fertilisers and pesticides, water and energy consumption, contribution to greenhouse gases and product waste. The field witnessed dramatic changes in many regulations and legislations to protect the environment and the public health.

2.3 Business Challenges in AFPSC

Agri-fresh products have several unique characteristics that cause business challenges and undermine efficient planning of supply chain functions. These characteristics include;

1) *Product Freshness*: It is a critical criterion that significantly impacts consumers' decisions for buying agri-fresh produce products (Aiello, La Scalia, and Micale 2012).

2) *Short Shelf-life*: It puts an extra burden on SC in terms of the cost of products waste and disposal (Willem, Roberto, and Jack 2014).

3) *Quality and safety*: Fresh products quality is negatively affected by climate change and environmental disruptions, specifically if precautions are not adequately considered during harvesting, storing and transportation activities (van der Vorst,

Tromp, and van der Zee 2009). This creates strains on AFPSC logistics and quality management and requires the availability of suitable facilities, tools and management practices along the whole supply chain (Zuurbier 1999).

4) Production *Seasonality*: It results in high variations in the yield quantity and quality. This is due to the biodiversity and random factors of the weather and biological hazards. A trade-off between supply variation and production lead times need to be balanced to create a competitive advantage and supply sustainability for AFPSC.

In addition to the unique product characteristics, many supply chain challenges face the industry as presented in the following sub-sections.

2.3.1   Supply and Demand Challenges

Nowadays consumers expected the availability of fresh food products all year round (Trienekens and Zuurbieri 2008). Hence, on the macro level, governments and large-scale food organisations (such as food and agriculture organisation (FAO)) are required to develop policies and regulations to stimulate the supply of fresh produce to meet the growing global demand. In this context, Atallah, Gomez, and Bjorkman (2014) introduced a macro-level planning model to evaluate food localisation decisions for fresh vegetables in the US. The policy anticipated various locations over different seasons to cope with the growing national demand, raise year-around products availability and reduce production and transportation costs.

On the micro level, meeting customers demand is a critical success factor for fresh produce supply where failure to meet demand or oversupply reduce profits which negatively impacts other supply chain partners (Andrew and David 1999, Sun 2013). The supply and

demand of agri-fresh produce are usually characterised by volatility and uncertainty due to 1) products seasonality; 2) yield variations; 3) fierce competition and 4) consumers' attitudes. Successful AFPSC has to balance their production capacity against customer demand. However, investment in fresh produce takes time to influence supply where demand and prices are uncertain. Hence, the planning of fresh produce production to meet customer demand is a challenging task. Lin and Chen (2003) addressed this issue and developed a policy for accepting customer orders simultaneously with placing orders to suppliers. The authors considered forming a strategic alliance with both upstream and downstream partners to streamline products flow. Similarly, Tan and Comden (2012) envisaged an annual planting policy in order to match growers supply with retailers demand, under maturation, harvesting and yield uncertainties. Lodree and Uzochukwu (2008) studied inventory policy of fresh vegetable growers considering product freshness and deterioration impacts on customer demand volatile.

2.3.2   Competition Challenges

Competition is another dimension in AFPSC complexity. The high demand for fresh products year-round motivates food organisations and growers to invest in fruit and vegetable products. However, the seasonality and limited shelf-life of fresh products undermine year-round supply from specific production areas. Globalisation and international trade agreements provide channels for importing and exporting fresh products from growing regions to consumption markets (Shukla and Jharkharia 2013). This creates multiple forms of competition among producers in the growing regions (i.e., growers and shippers) at domestic and regional levels. Suppliers are competing on exporting there because of the

significant difference of the selling prices in international markets. Moreover, differences in weather conditions, operations practices, production costs, institutional regulations, and transportation, make the competition even more fierce (Zuurbier 1999). On the other hand, in the consumer markets, consumers expect the highest quality and freshest products on retailers' shelves with competitive prices (Yu and Nagurney 2013). Therefore, suppliers, wholesalers and retailers are competing with consumers' satisfaction and trust on the one hand, and creating a consistent supply of high quality and traceable food products on the other hand (Yu and Nagurney 2013).

AFPSC members are in need for innovative solutions which add competitive advantages to their business. Price reductions and promotions are among the policies that add competitive advantage and increase market share in fresh produce market (McLaughlin 2004). Also, the strategic configuration of SC networks to unlock coordination and integration between SC members can help in facing this competition (van der Vorst, Tromp, and van der Zee 2009). For example, Designing agriculture cooperatives for small-scale farms allows producers to efficiently gain new value-added or niche markets for their products (Jang and Klein 2011). The coordination between SC partners can also help develop shared "price-discount" and advertising (e.g., branding) initiatives to attract more demand (Cai et al. 2010).

2.3.3 Cultivation and Harvesting Challenges

Cultivation and harvest operations are vital for the fresh produce industry since they significantly impact produce yield in terms of quality and quantity (Caixeta 2006). These operations are labour-intensive; however growers rely on seasonal labourers markets,

because of products seasonality, seasonal labourers are often characterised by low qualifications and high diversity in skills (Whatman and Van Beek 2008). Hiring workers under seasonal recruiting contracts results in inconsistent employee performance, reduction in operations efficiency, increase in products loss and, hence, increase in operational costs (Meyers et al. 2006). In addition, there are many social problems associated with seasonal labourer markets especially during the on-season periods (Cittadini et al. 2008). For example, the supply might be affected by competition between growers for labourers of a particular region during harvest season (Mesabbah et al. 2016). These social problems besides the heterogeneous characteristics of the seasonal labourer can become a significant challenge for planning harvesting operations, which are also counted as the most costly area of operations in fresh produce production (Ampatzidis et al. 2014).

Harvesting schedule is one of the critical decisions related to harvesting operations in fresh produce supply chain. Usually, harvesting is triggered by reaching specific maturation characteristics for the products which are firmly connected to weather conditions and biological growing process (Widodo et al. 2005). It is risky to supply either under-ripe or over-ripe product. Thus, the issue of how efficiently harvesting operations schedule could be planned is of utmost importance. Therefore, many researchers attempted to address harvest operations efficiency in the context of fresh produce. For instance, Wishon et al. (2015) discussed tactical planning for harvest scheduling and seasonal labourers acquisition for average size vegetable farms in Arizona. Ampatzidis et al. (2014) have studied harvesting efficiency on an operational level. This was achieved by exploring different sequences for harvesting operations and resource allocation plans for table grape and sweet cherry crops in Greece and Washington respectively. Few studies have considered product quality during

harvest operations. For example, a seasonal harvesting schedule was also optimised for an orange farm in Brazil taking into consideration some biological factors that impact products quality (Caixeta (2006). Some other researchers have focused on harvest efficiency in terms of product losses (Ferrer et al. 2008, Arnaout and Maatouk 2010, Ahumada, Rene Villalobos, and Nicholas Mason 2012).

2.3.4 *Post-Harvesting and Logistics Challenges*

Agricultural production has witnessed significant improvements in yields and availability of better varieties. However, better management of agricultural SCs can achieve substantial breakthroughs, especially considering that one-third of the production is estimated to be wasted, with fresh produce having the highest percentage of waste (Gustavsson et al. 2011). An efficient planning of post-harvest and packing activities as well as distribution, storing, transportation, and handling operations can serve in reducing the production waste (Murthy et al. 2009). The challenge is that once products are harvested, the deterioration process commences based – significantly – on the post-harvesting, storing and transportation conditions (Nagasawa, Kotani, and Morizawa 2009). Post-harvest activities include moving products from farms to processing facilities (i.e., packaging house) and packing operations. (Ahumada and Villalobos 2009b).

The packaging of products plays a significant role in preserving product quality and freshness during distribution activities (Blanco et al. 2005). Packing is, also, necessary for product labelling and differentiation of product quality grades, which affect the efficiency of distribution activities and customers' requirements (Accorsi et al. 2014). However, few researchers have addressed agri-fresh produce packing issues in literature. For instance, a

packing house plan for the fruit industry in Argentina is developed to improve packing house profits (Blanco et al. (2005). The authors considered the process of product handling including quality differentiation and preparation for packing.

Another critical challenge that strains fresh produce distribution and logistics efficiency is to find a balance between logistics costs from one hand and preserving products quality and shelf-life on the other hand (Soysal et al. 2012). Efficient design for the cold chain (e.g. air-conditioned truck and cold stores) is required in maintaining the temperature of products at certain levels and, hence, preventing both quality and shelf-life from decay (van Donselaar et al. 2006). In this regard, van der Vorst, Tromp, and van der Zee (2009) introduced research regarding the design for a temperature controlled supply chain for the pineapple, from growers in Africa to distribution centres in Europe. The outcomes of this study concluded that the availability of quality information during distribution phases and decision-making tools are essential basics for the designs of such SC. Other studies have highlighted the utmost importance of controlling product temperature during distribution and logistics activities (Aung and Chang 2014, Rong, Akkerman, and Grunow 2011). In addition, Soysal et al. (2012) have defined more issues that are connected to AFPSC logistical activities including, for example, batch homogeneity control, dynamic inventory control, and multiple temperature considerations.

2.4 AFPSC Planning and Decision Making

Given the high complexity and dynamism of AFPSC systems, integrated planning tools that support decisions making by different actors are needed. Different decisions are incorporated in AFPSC that needs integrated planning tools to support decision making such as harvest

planning, resources scheduling, logistics and transportation planning, among others (Ahumada and Villalobos 2009a). Three different levels of decision making are involved in AFPSC planning; 1) strategic; 2) tactical and 3) operational levels (Simchi-Levi, Kaminsky, and Simchi-Levi 2004). ***Strategic*** levels are linked to long-term impact decisions such as farm design (Cittadini et al. 2008) and Food hub location (Etemadnia et al. 2015). ***Tactical*** levels are concerned with mid-term impact decisions such as harvest schedule (Caixeta 2006) labour needs (Wishon et al. 2015). Finally, ***operational*** levels are linked to short-term (mostly daily activities) decisions such products flows (Velychko 2014) and vehicle route selection (Osvald and Stirn 2008). It is evident that decisions at any planning level will have impact others and the understanding of these relationships is vital for effective decision making and planning activities (Jahangirian et al. 2010).

A comprehensive review of the critical business decisions related to the different planning levels of AFSCs is presented by Tsolakis et al. (2014). Another study on planning models used for AFPSC problems is introduced by Ahumada and Villalobos (2009a) . Their review presents a classification of the different models across the three planning levels. Similarly, Soto-Silva et al. (2016) investigate different planning models employed for planning problems, but only for fruits supply chain. Both reviews suggested that mathematical and simulation-based models are commonly used for planning of AFSC. However, they concluded that there is a lack of models and tools designed for integrated decision making in this context.

2.5 Modelling Approaches

Decision support models facilitate exploring and implementing practical solutions for the systems that involve complex interactions among system entities and within a rapidly changing environment (Altay and Green 2006). They can be classified into two main types, 1) mathematical modelling, and 2) simulation modelling (Timothy and Paul 2004). The former is commonly used to optimize system performance, while the latter is often engaged in understanding system's behaviour and its response to certain exogenous or endogenous effects. The mathematical models include linear programming (LP); integer programming (IP), mixed linear integer programming (MLIP); non-linear programming (NLP); dynamic programming (DP); goal programming (GP) and stochastic programming (SP) (Jordan and Smith 1999). On the other hand, there exist three primary simulation modelling approaches: 1) Discrete Event Simulation; and 2) System Dynamics; and 3) Agent-based Modelling (Jahangirian et al. 2010). Mathematical and simulation models are different in the way they are developed, the complexity degree they can handle, assumptions they impose, and data that is required.

It is evident from the literature that mathematical modelling is widely used in various sectors to resolve SC planning problems (Mula et al. 2010). However, it is suggested that mathematical models are only suitable when a limited number of variables and constraints are considered (Méndez et al. 2006). Literature also indicates that simulation modelling has gained popularity because of its ability to address complex, dynamic and stochastic nature of problems. It can be used in conducting practical large-scale experimentation rather than physical experiments which are often expensive and time-consuming (Hester and Cacho

2003). For instance, a DES model is used to evaluate different designs for harvest operations for a potato grower to improve resources efficiency and utilisation (Zhou, Leck Jensen, et al. 2015). While using an SD model, several demand and supply disruption scenarios have also been investigated for the multi-echelon supply chain of fast moving consumer goods (Crowe, Mesabbah, and Arisha 2015). Finally, Nienhaus, Ziegenbein, and Schoensleben (2006) present an ABM model that investigates the role of human behaviour in bullwhip effect with the aid of the beer distribution game. More detailed overview of modelling approaches is given in **Appendix 1**.

2.6 Review of Modelling Approaches for AFPSC Planning

2.6.1 Review Objective

To understand the current state of the art regarding modelling applications in AFPSCs, an extensive literature review has been conducted. This review, on the one hand, endeavours to address the second research question (RQ2) and its associated objectives (*section 1.2*). On the other hand, it seeks to complement attempts from other scholars to gain a better understanding of the types and capabilities of modelling techniques and methodologies in AFPSC planning. Eight literature review articles have been studied to understand how mathematical and simulation models are employed in AFSC application as presented in Table 2-1. The table shows the research characteristics of each study that include time horizon, SC functions, modelling types, model environment (i.e., deterministic or stochastic), decision levels (i.e., operational, tactical and strategic) performance areas, and agri-products focus.

Table 2-1: Recent reviews of AFSCs literature

Lit. Review Papers	Time Horizon	Dataset size	SC Focus	Model Types	Model Environment	Decisions Level	Performance Indicators	Product Focus
Glen (1987)	Up to 1985	112	- Harvsting - Production	Analytical Mathematical Simulation	Na	Na	Na	Agri-Products
Lucas and Chhajed (2004)	1954 - 2002	35	- Location Problems	Mathematical	Na	Na	Na	Agri-Products
Timothy and Paul (2004)	1959 - 2000	Na	- Harvsting - Production	Mathematical Simulation	Na	Na	Na	Agri-Food Products
Ahumada and Villalobos (2009)	1985 - 2008	62	- Production - Harvesting - Inventory management - Distribution	Mathematical	Deteminstics Stochastic	Operational Tactical Strategic	Na	Agri-Food Products
Akkerman, Farahani, and Grunow (2010)	1970 - 2010	Na	- Distribution	Mathematical Simulation Heuristics	Na	Operational Tactical Strategic	Quality & Safety Environmental	Agri-Food Products
Soysal et al. (2012)	1987 - 2012	36	- Logistics	Analytical Mathematical Simulation	Na	Na	Costs Responsiveness Quality Environmental	Food Products
Shukla and Jharkharia (2013)	1991 - 2009	86	- Demand Forecasting - Prodcution - Inventory management - Transportation	Mathematical Simulation	Na	Na	Na	Agri-Fresh Produce
Soto-Silva et al. (2016)	1976 - 2015	28	- Planting - Production - Harvesting - Inventory management - Distribution	Mathematical Simulation Heuristics Hybrid	Na	Operational Tactical Strategic	Na	Fresh Fruits

The literature review is based on a framework which is driven by an analysis of three perspectives: 1) Supply Chain perspective; 2) Decision Making perspective; and 3) Modelling perspective.

SC perspective, Scholars have focused on various **SC operations** in their classifications. These functions include: 1) production; 2) harvesting; 3) inventory; and 4) distribution (Ahumada and Villalobos 2009a). Various SC functions are also identified when assessing AFPSCs applications such as network design; packing; and pricing.

Recent Agri-food businesses are comprised of complex supply chain networks that facilitate distributing products from farms to consumers (Tsao 2013). Efficient network design is vital for AFPSC research, especially in cases where the overseas distribution of products from growing areas to consumption marketplaces is considered (Souza Monteiro

2007). In literature, some researchers applied decision-making models for network design for AFPSCs problems (Govindan et al. 2014, van der Vorst, Tromp, and van der Zee 2009).

Packing function also plays a vital role in preserving product quality and freshness during distribution activities (Blanco et al. 2005). This results in inefficient packing as one of the main sources of products waste, which have an impact on incurred costs and the environment (Manfredi and Vignali 2014). The labelling of different assortments of products is also vital as it affects the efficiency of the SC (Accorsi et al. 2014). Packing related problems are addressed in some previous reviews under production function category; however, it is important here to discuss them in different contexts (Shukla and Jharkharia 2013). This is due to most of the related activities to production function being pre-harvesting activities while packing usually take place right after harvesting (Ahumada and Villalobos 2009a).

Pricing is also a critical factor which affects product demand and is one of the challenges which face the coordination between SC actors (Sun 2013). Few studies have employed models to address products in pricing AFSCs context (Cai et al. 2010).

Traditionally, SCM is defined as the management of product, information, and financial flows through networks of connected entities on inter- and intra-organisational levels in order to create added value and achieve customer satisfaction (Stock and Boyer 2009). Intra-organisational level of SC analysis has focused on a single firm (e.g., grower, distributor, retailer, etc.) while the inter-organisational level focus on the chain, network and macroscopic (i.e., industry or Macroeconomy) perspectives (Mena, Humphries, and Wilding 2009). Therefore, it is essential to assess the levels of analysis in the previous research efforts

that focus on AFPSCs. This will help to reveal insights regarding the focus of researchers and practitioners when addressing issues related to agri-fresh produce business. Also, a vital topic is the mapping of modelling approaches and their capabilities with the SC analysis levels in the models used. Similarly, it enables researchers and practitioners to link various levels of SC analysis and the different SC members' concerns in terms of their decisions and performance areas.

Decision-Making perspective is addressed in a few number of reviews. The authors focused on the scope and levels of decisions which include 1) operational; 2) tactical; and 3) strategic levels (Soto-Silva et al. 2016). The performance indicators (PIs) which are meant to be improved are addressed only in two reviews, both of them focused on logistics and distribution applications. In the context of AFPSCs, a wide range of indicators are identified, these indicators can be classified under five principal areas: 1) Financial; 2) Operations; 3) Quality and Safety; 4) Customer; and 5) Environment. For instances, *Financial* PIs include costs (Amorim, Günther, and Almada-Lobo 2012) and profits (Ahumada, Rene Villalobos, and Nicholas Mason 2012); *Operations* PIs such as capacity utilisation (Vanberlo 1993), on-time delivery (Osvald and Stirn 2008) and loss rates (Bohle, Maturana, and Vera 2010); *Quality and Safety* PIs such shelf-life (Aung and Chang 2014) and products freshness (Tsao 2013); *Customers* PIs include service level (Shukla and Jharkharia 2011) and traceability (van der Vorst, Tromp, and van der Zee 2009); and *Environment* PIs like carbon footprint (Accorsi et al. 2014) and water consumption (Atallah, Gomez, and Bjorkman 2014).

Modelling Perspective, the majority of reviews focused on modelling types employed in the application. Out of the eight reviews, five types are identified: 1) analytical; 2)

heuristics; 3) hybrid; 4) mathematical; and 5) simulation models. Classifying kinds of environmental variables that are addressed in these models (i.e., model parameters) is only considered in one review (Ahumada and Villalobos 2009a). Such classification is vital along with analysing modelling types, as it helps to map the modelling approaches capabilities in addressing the uncertainties in AFPSC problems.

There is also an evident lack of assessment regarding the purpose of modelling approaches as some models are used for improving system performance (Normative models) while others are employed to understand and evaluate systems' behaviour (Descriptive models) (Bertrand and Fransoo 2002). This assessment is useful to link modelling approaches with the context that they are applied for (e.g., which models are mostly used for improving performance and, which are more suitable for exploring and anticipating performance scenarios).

To gain a deeper insight into the three perspectives in AFPSCs, a detailed framework has been developed in Figure 2-4 based on three dimensions: 1) *Supply Chain*; 2) *Decision Making*; and 3) *Modelling* Dimensions. Each dimension contains a set of sub-analytical dimensions, where a collection of analytical categories are defined for each one. These analytical categories are derived deductively, before analysing the underlying dataset in this review, based on previous literature reviews mentioned in table 2-1. Then inductively, based on the analysis of the material collected for the current review by means of generalisation (Seuring and Muller 2008).
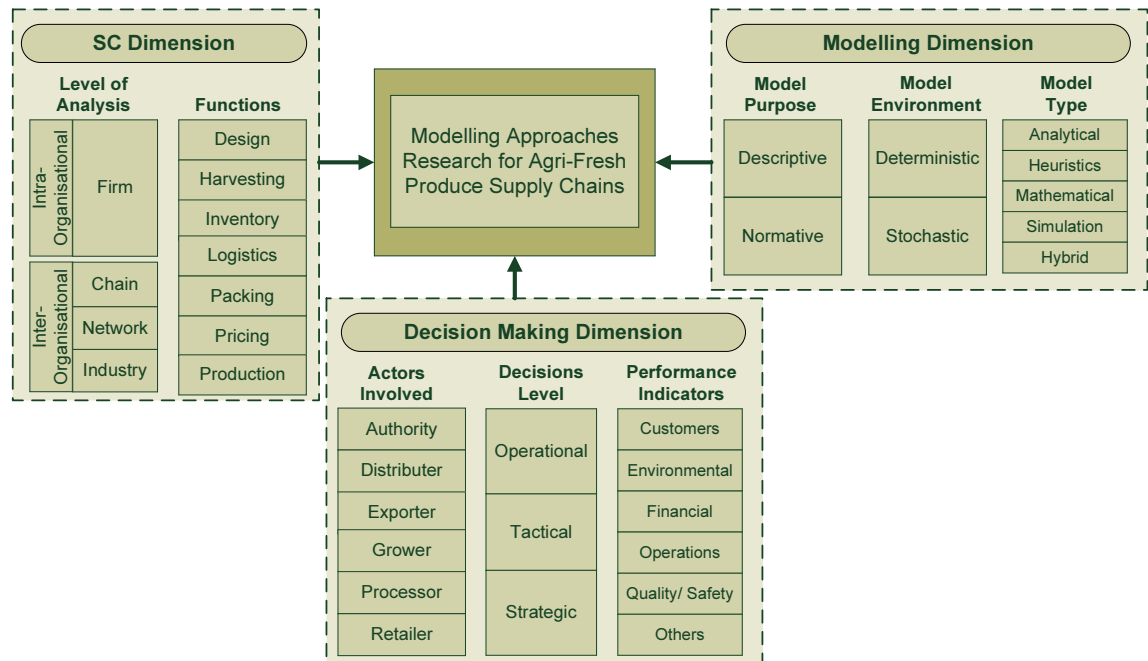
Figure 2-4: Framework for reviewing modelling research efforts in context of AFPSCs

2.6.2   *Dataset Descriptive Analysis*

The temporal distribution of the research papers of the final dataset which are analysed in the review is presented in Figure 2-5. It shows the trend in modelling research efforts regarding AFPSCs over the last 25 years. The research output was limited during the period between 1990 and 2007 (less than 5 papers published annually). Since 2008, research witnessed an increase in the number of published articles and reports. This development can be justified by the increased attention towards the global factors affecting the related business area such as food and fuel prices, of which have witnessed drastic increases of up to and over 200% for some items (Kim 2010). The rise in oil prices has a compound effect on the agri-fresh produce sector. Firstly it impacts on the costs of transportations and energy needed for the cold chain and the different operations such sowing, harvesting, etc. Secondly, it is affected by the increased demand for vegetable oils which are necessary for biodiesel production

(Shukla and Jharkharia 2013). The research development in this area is also motivated by recent changes in consumer behaviour and growing demand for fresh produce (Reynolds et al. 2014).
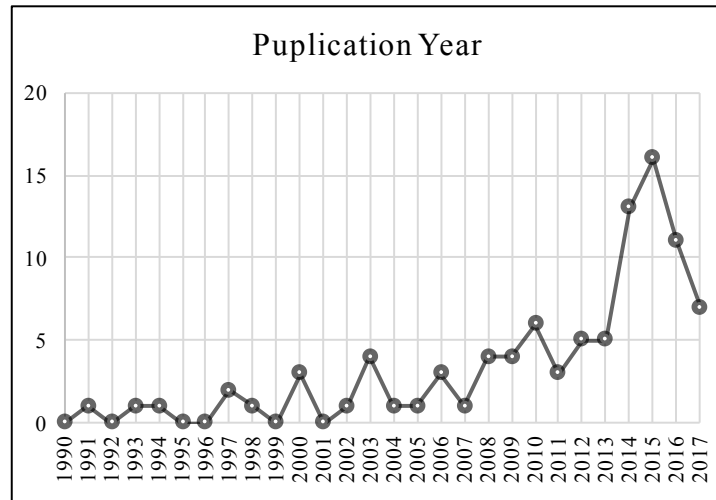
Figure 2-5: Temporal distribution of the analysed papers

From a journal perspective, the papers of the underlying dataset are published in 39 peer-reviewed Journals. It is noticeable that 50% of the papers are published in only six journals, Table 2-2 presents the distribution of the papers over them. However, it is apparent that the top two journals (**IJPE and EJOR**) are not directly connected to agricultural or food research areas. The two journals are closely related to the operational research and decision-making model research. Also, journals that have direct research interests in agriculture and food businesses have limited orientation towards the adoption of modelling approaches to address planning problems in AFPSCs context.

Table 2-2: The Top Four Journals

Journal Name	Abbreviation	No. of Papers
International Journal of Production Economics	IJPE	15
European Journal of Operational Research	EJOR	12
Computers and Electronics in Agriculture	CEA	7
Agriculture Systems	AS	5
Journal of Food Engineering	JFE	4
Journal of the Operational Research Society	JORS	4
Total		47 (50 %)

2.6.3 Review Results

In this section, the analytical results across the three dimensions for the AFPSC applications dataset are presented. Detailed information about this dataset and how its material is gathered and is provided in section 3.6.1.1. Appendix 2 gives a summary of all applications in this dataset along with detailed attributes for each application subject to the review framework.

2.6.3.1 SC Dimension

Distribution of the articles reviewed across the SC analytical dimension is summarised in Table 2-3. *Inter-organisational* level of analysis has received the highest share of researcher's attention. The clear focus of the developed models was towards analysing *Chain* level, where SC constitutes of only one actor (e.g., grower, distributor) from two or more supply echelons. Modelling SC *networks* have received less attention, which suggests there is reduced interest in addressing competition and/ or vertical integration between the SC actors. A macroscopic view (i.e., *industry* level of analysis) of the models developed models also received poor attention although the sectorial importance of AFPSC to the global

economy (Jang and Klein 2011). Focal firm analysis has received a good share of the research efforts. This reflects the tendency of researchers to reduce the degree of complexity in AFPSC when only a single echelon is addressed. This force rigid assumptions regarding the upstream and/ or downstream relationships.

Evaluating SC functions that are studied in the literature shows considerable interest in addressing *logistics* and *harvesting* activities. One reason is that due to both activities having a significant impact on product freshness (van der Vorst, Tromp, and van der Zee 2009). Also, production and *inventory* functions (which ranked 3rd and 4th respectively) contribute significantly to cost across AFPSC. *Pricing* and *packing* functions have received the least attention although the importance of the former to buyers' choices (Sun 2013) and significance of the latter to preserving product quality and safety (Blanco et al. 2005). A reasonable number of articles showed interest in modelling SC *design* problems such as facility location (Etemadnia et al. 2015) and supplier selection (Lin and Chen 2003).

Table 2-3: Evaluation Results for SC Dimension

Level of Analysis		Functions	
Intra-Organisational		Design	17
Firm	33	Harvesting	30
		Inventory	21
Inter-Organisational		Logistics	42
Chain	35	Packing	12
Network	16	Pricing	7
Industry	10	Production	24

2.6.3.2 Decision Making Dimension

Growers have dominated researchers' focus as key actors involving in the decision-making models for AFPSC. Distributors and retailers come at the second and third places respectively, as presented in Table 2-4. This is aligned with the outcomes of SC dimension analysis where harvesting and logistics SC functions are very related to growers, distributors and retailers, received the most attention among SC functions.

Regarding *Decisions level*, it is noticed that the majority of the developed models focus on the tactical and operational levels (Table 2-4). Although a recent review of hierarchical decision making in agri-food supply chains highlighted the importance of the strategic decisions over both tactical and operational ones, this is not yet reflected in the researchers' attention in the AFPSC literature (Tsolakis et al. 2014).

Table 2-4: Evaluation Results for Decision Making Dimension

Actors Involved		Decisions Levels		Performance Indicators	
Authority	12	Operational	40	Customer	11
Distributor	33	Tactical	59	Environmental	15
Exporter	8	Strategic	18	Financial	85
Grower	55			Operation	30
Processor	15			Quality/ Safety	32
Retailer	29			Social	5

The financial *performance indicators* (PIs) are found to be the most popular indicators used to evaluate the managerial practices and decisions in AFPSC models. Most of these indicators have a focus on the cost of production, harvesting, inventory and/ or logistics operations. Other indicators enacted reflect the related profits, sales and revenues. Similarly, the

operational indicators received considerable attention in the reviewed articles. These indicators employed to improve the efficiency and effectiveness of agri-fresh produce models. These indicators include resources and capacity utilisation (Zhou, Jensen, et al. 2015); operations waste (Li et al. 2015); and travel distances (i.e. food miles) (Orjuela-Castro, Herrera-Ramirez, and Adarme-Jaimes 2017).

The recent few years have witnessed a growing consciousness among consumers regarding public health issues and food *quality and safety* (Jongen and Meulenberg 2005, Bourlakis and Weightman 2004). As a reflection, a considerable number of articles have focused on the quality and safety indicators (ranked third). Since 2008, at least two papers every year are published concentrate on either quality or safety issues in AFPSC. These indicators include shelf-life time (Aung and Chang 2014); products freshness (Ghezavati, Hooshyar, and Tavakkoli-Moghaddam 2017); traceability (Gautam et al. 2017); and foodborne (McKellar et al. 2014). On the other hand, *Customer's* related PIs, such as demand satisfaction and service level, have received little consideration. Customer demand is one of the main sources of uncertainties that challenge AFPSC planning. Hence, more research effort is required to address customer's demand dimension in modelling AFPSCs.

There is also a growing attention regarding the social and environmental aspects of the food industry. This concern was motivated by the climate changes (greenhouse gases and global warming), scarcity of the natural resources, calls for fair labourer conditions, food security and public health issues (Li et al. 2014, Elkington 2004). The last four years of the review time horizon (i.e., 2014 and 2017) witnessed considerable attention for *environmental* aspects in the fresh produce industry. Environmental indicators are mainly centred around

greenhouse gases resultant from different operations of AFPSC. However, some other indicators related to water consumption (Atallah, Gomez, and Bjorkman 2014) and land use (Santos et al. 2015) are also reported as important environmental indicators. From *the social* perspective, few applications have considered social indicators such as public health (Bouwknegt et al. 2015) and employment (Cittadini et al. 2008) and building social trust (Wang, Chen, and Wang 2015).

2.6.3.3 Modelling Dimension

In evaluating the purpose of AFPSC models, it is noticed that *normative* models are dominant over *descriptive* models (Table 2-5). This suggests a tendency of decision makers towards problem-solving rather than understanding system behaviour or the root causes of the problems. This also explains why *mathematical* models are dominant over other model types. Mathematical models are usually employed to discover optimal decision alternatives which either maximise or minimise one or more performance indicator. They also tend to be static and require deterministic assumptions towards external variables (Pidd 2004). This is reflected in the dominance of the *deterministic* over *stochastic* models in the dataset, which affected the modelling efforts of systems' complexity and uncertainty. Therefore, more attention is required towards applying stochastic models that are capable of handling sources of uncertainties such as demand uncertainty (Tromp et al. 2016), supply disruptions (Sun 2013), and price variability (Teimoury et al. 2013).

By conducting an analysis regarding the modelling types in AFPSC research, it has been revealed that mathematical models received the most attention from researchers followed by analytical and simulation models, while both heuristic and hybrid models have

received the least amount of attention. Mathematical models are usually chosen for optimisation purposes, and most of them optimise single objectives (70%) while others (30%) optimise multi-objectives. Multiple solution techniques are used in the mathematical models such as linear programming (Cameron and Aruna 2016), mixed integer linear programming (Amorim, Günther, and Almada-Lobo 2012), stochastic programming (Hsu, Hung, and Li 2007) and goal programming (Allen and Schuster 2004a). The analytical models, on the other hand, are mostly based on systemic models, e.g., life cycle assessment (LCA) (Blackburn and Scudder 2009), and game theory (Wang and Chen 2017). Heuristic models mainly rely on artificial intelligence and meta-heuristic techniques such as genetic algorithms (Sarker and Ray 2009) and particle swarm (Govindan et al. 2014), along with few articles which use simple heuristics (Arnaout and Maatouk 2010). Finally, simulation-based models are mainly divided between two techniques, the first is discrete event simulation (DES)(van der Vorst, Tromp, and van der Zee 2009) and the second is system dynamics simulation (SD) (Ferreira, Batalha, and Domingos 2016).

Table 2-5: Evaluation Results for Modelling Dimension

Model Purpose		Model Environment		Model Type	
Descriptive	29	Deterministic	65	Analytical	16
Normative	65	Stochastic	29	Heuristics	11
				Mathematical	60
				Simulation	13
				Hybrid	6

A cross-dimensional analysis was conducted to gain more profound insights regarding the literature and research gaps in the agri-fresh produce applications.

2.6.4   Level of Analysis Vs. SC Actors

Intra-Organisational SC Level of Analysis

In the context of AFPSC, when combining the SC and decision making analytical dimensions, the analysis shows that models employed for planning a single firm are frequently used for growers' echelon (Figure 2-6). On the other hand, growers received less focus in the research that considers planning at both chain and network levels of analysis. Growers are vital for AFPSC and supply usually starts at this layer. Studying the relationships between growers and other actors either from same layer (i.e., cooperation) or different SC echelons (i.e., integration) is of the utmost importance for efficient planning of AFPSC. Thus, there is a need for more research on modelling AFPSC planning problems while considering grower relationships with other SC actors.

Inter-Organisational SC Level of Analysis

As mentioned earlier, distribution and logistical activities are vital to the AFPSC due to their impact on the products' quality and safety (Ahumada and Villalobos 2009b). Looking at SC actors that are usually involved in these activities (i.e., processor, exporter, distributor), it was evident that distributors are the most frequent actor when inter-organizational of analysis is considered. Industry (or macro) level is the exception in this case, as the focus at that level is directed at growers (Atallah, Gomez, and Bjorkman 2014) or legal authorities (Marquez, Higgins, and Estrada-Flores 2015). This might be a potential research perspective, where researchers may think of employing modelling approaches for planning distribution and logistics functions for AFPSCs.

Modelling the whole food chain from farm to fork is a complex task in AFPSC. Considering the inter-organisational level of analysis, particularly on the chain and network level, suggests that the maximum number of SC echelons to be observed is four, and this occurred in one article only (Orjuela-Castro, Herrera-Ramirez, and Adarme-Jaimes 2017). A system dynamics model is introduced in this article to study a fresh Mango SC that consists of grower, processor, wholesaler (i.e., distributer) and retailer. The models that address three SC echelons are presented in 11 papers (approx. 11.5% of the whole dataset). Some of these models have focused on the network level of analysis while the others have considered the chain level of analysis. It is worth noticing that all of them have included a distributor echelon that is modelled along with grower-retailer in 6 cases; exporter-retailer in 2 cases; and one case for grower-processor; processor-retailer; and processor-exporter.

Assessing the temporal development of the literature, it is noticed that the multi-echelon analysis for AFPSC modelling started at 2009 with an exception for one application reported in 2000 (van der Vorst, Beulens, and van Beek 2000, van der Vorst, Tromp, and van der Zee 2009) with approximately one application published annually. More modelling efforts are required to evolve that trend and encourage researchers for attempting to model the complexity of AFPSC.
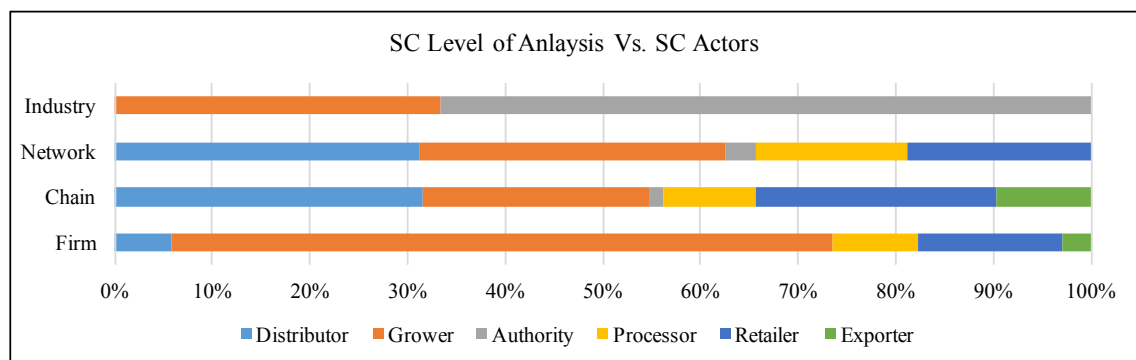
Figure 2-6: SC Level of Analysis against SC Actors Involved in the Analysis

2.6.4.1 Model Types Vs. Decision Levels

It is essential to understand how different modelling types are employed at various managerial levels in AFPSC. As mentioned earlier the tactical and operational planning models dominate the strategic models in the food industry (Table 2-4). From a distinct perspective, mathematical models have a clear dominance over the three decision levels compared to the other modelling types (Figure 2-7).
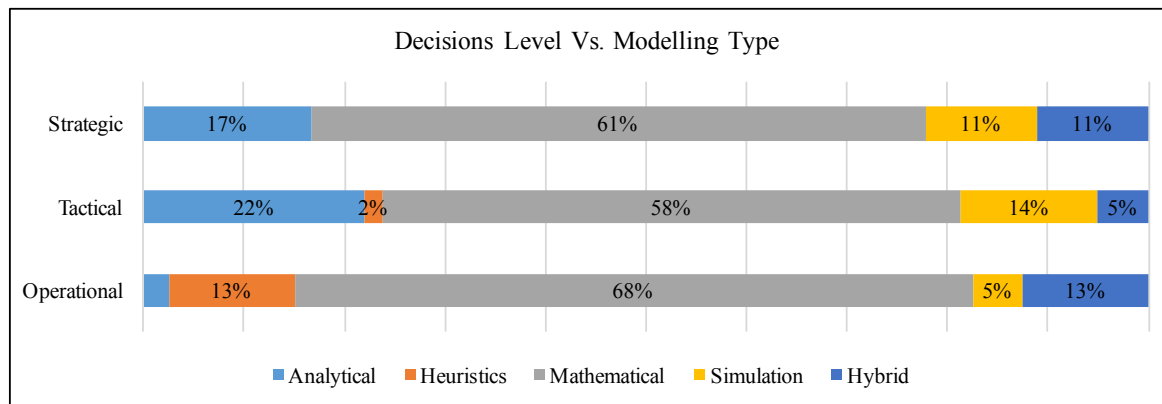
Figure 2-7: Decisions Level against Modelling Type

Single Decision Making/ Planning Level Analysis

The analysis here focuses on mapping the modelling types across a single decision-making level (e.g., operational level). Mathematical models have focused on various operational decisions related to product flow, resource hiring and allocation, planting and harvest quantities and truck/ vehicles routing. Most of these models employed either LP or MLIP techniques for formulating the mathematical relationships between system components under the deterministic assumptions of model parameters. However, few models have considered uncertainties related to demand, shelf-life decay, and resource productivity. Heuristic models are also used based on simple or meta-heuristic techniques to model

decisions related to harvesting, inventory control, and vehicle routing. These models impose deterministic assumptions for exogenous variables, except a solo model that addresses the randomness behaviour in products delivery (Hsu, Hung, and Li 2007). At the operational level, only one study developed a simulation model to plan machinery usage in the harvesting operations to improve system's efficiency and resources utilisation (Zhou, Jensen, et al. 2015). Two hybrid models (e.g. LP model and fuzzy model) are developed to relax some rigid constraints connected to uncertain factors such as costs and productivity elements in fresh produce distribution operations (Miller et al. 1997), (Broekmeulen 1998).
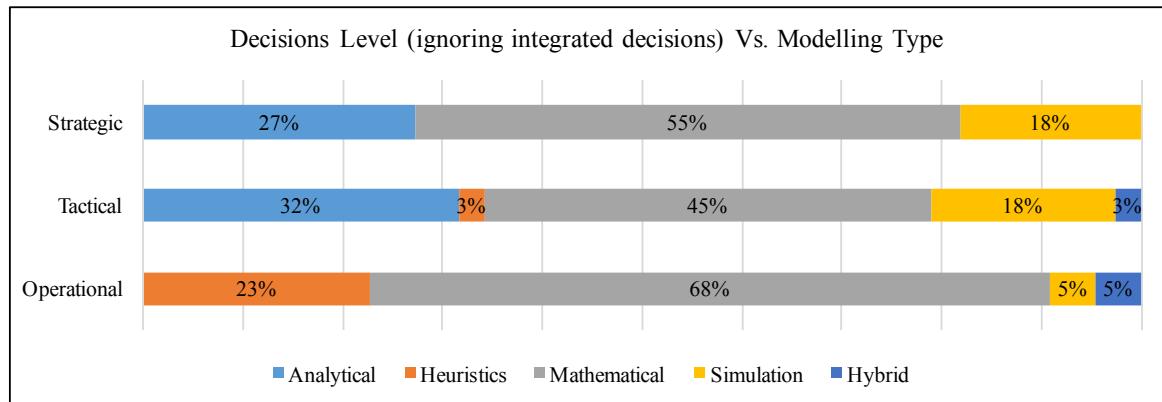
Figure 2-8: Modelling Type against Solo Decision-Making Level (i.e., ignore integrated decisions)

From the tactical perspective, mathematical models have focused on seasonal planting and harvesting schedule in terms of crop selection (Sarker and Ray 2009), labour and resources planning (González-Araya, Soto-Silva, and Espejo 2015), and customer order planning (Grillo et al. 2016). Few of these models considered uncertainties connected to crop yield (Tan and Comden 2012) and market demand (Hu, Chen, and Huang 2014). While no studies have examined the variations of seasonal labourers productivity (Whatman and Van Beek 2008). Other mathematical models have addressed supplier selection and coordination decisions to meet customer demand and mitigate disruption impact (Mateo et al. 2016, Sun

2013). Similarly, analytical models have focused on the coordination and cooperation decisions between supply chain parties based on game theory approach to preserve products quality and safety (Wang, Chen, and Wang 2015), costs sharing (Qi et al. 2017) and pricing products (Wang and Chen 2017). Other analytical models, such multi-criteria decision making and life cycle assessment, were used for decisions related to transportation planning (Marquez, Higgins, and Estrada-Flores 2015), packaging design (Manfredi and Vignali 2014), and inventory control (Kanchanasuntorn and Techanitisawad 2006). Some of these models considered uncertainty factors connected to product perishability and weather disruptions along with both demand and supply disruptions.

Contrary to the operational level, more simulation models are employed at the tactical level in AFPSC planning problems. In these models, decisions related to the transportation and storage conditions are modelled to assess their impact on product safety using either SD approach (McKellar et al. 2014) and DES (Rijgersberg et al. 2010). Other SD models are used to evaluate different packaging designs for fresh produce products (Orjuela-Castro, Herrera-Ramirez, and Adarme-Jaimes 2017) and explore product sourcing and imports policies (Teimoury et al. 2013). DES is also used for investigating ordering and replenishment policies for fresh lettuce retailers to reduce product loss and enhance customer satisfaction (Tromp et al. 2016). Single heuristic model is used at this decision-making level; the model is based on fuzzy sets for grading fresh fruit and segregating quantities valid for exports from entire yield (Lambert et al. 2014). One *hybrid* model, an evolutionary algorithm combined with an LP model, is employed to facilitate finding optimal crop planning on a macro level in order to maximise the return on investments (ROI) and secure country demand (Sarker and Ray 2009).

On the ***strategic*** level, mathematical models usually focus on decisions that are related to long-term capital investments such as food hub location and capacity design to optimise logistics costs (Etemadnia et al. 2015), planning growing areas on macro level to meet population demand and reduce water consumption (Atallah, Gomez, and Bjorkman 2014) and planning farms size and variety selection for perennial crops to optimise ROI (Catala et al. 2013). However, these models impose linear relationship assumptions between system components and ignore complexity and dynamism of planning problems. Analytical models employed at the strategic planning level are mainly used to assess the environmental (e.g., CO_2 emissions) impact of AFPSCS when restructuring decisions, such as transformation from conventional to organic production (Falcone et al. 2016) and adopting recyclable packaging materials (Accorsi et al. 2014) are considered.

Although their ability to model complex and dynamic systems is apparent, only two articles have employed simulation models for strategic planning of AFPSC problems. A DES model was used to explore different configurations for fresh-cut pineapple SC between Ghana and Europe (van der Vorst, Tromp, and van der Zee 2009). One scenario is to locate the processing unit in Ghana and use air transportation for the processed products, while the other is to establish it in Europe and use sea transportation for unprocessed pineapples. Both scenarios are examined using DES against a set of environmental, economic, quality and safety measures. In the second article, an SD model was developed for a macro level planning of citrus production in Brazil (Ferreira, Batalha, and Domingos 2016). The objective of the model was to investigate the gradual introduction of new orange varieties and cultivation technologies to improve net income per hectare.

Integrated Decision Making/ Planning Analysis

Integrated decision making is presented in around 23% of the entire dataset (Figure 2-9). Models, that incorporate decisions at operational and tactical levels simultaneously received the highest attention (68% of integrated planning models). Most of these models have focused on harvesting, logistics functions. Models that integrate decisions at tactical and strategic levels simultaneously have received relatively less attention (22.7% of integrated planning models) and mainly focus on design and production functions. A solo application has integrated operational and strategic decisions, and another has combined the three levels simultaneously. Both applications have focused on design and logistics functions. Although the complexity increases when more than one planning level is modelled, mathematical modelling approaches are dominant models for integrated planning for AFPSC. Simulation modelling, which is a robust modelling approach suitable for complex system modelling, is employed only in 2% (just 2 papers) of the integrated planning models.
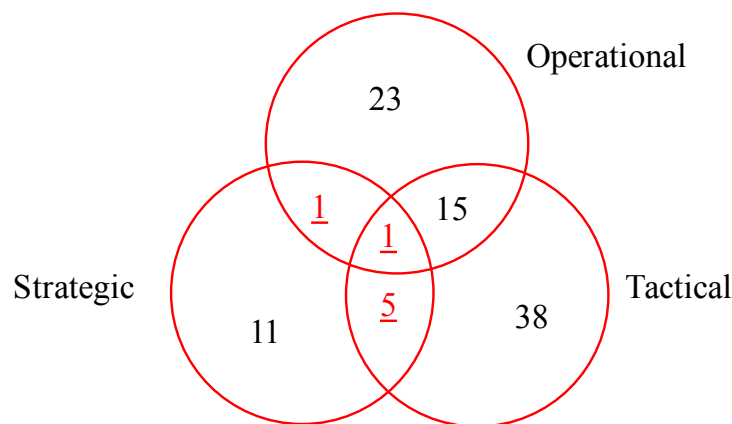
Figure 2-9: Integrated decision making in AFPSC models

At **_operational-tactical_** planning level, many **_mathematical_** models are employed. These are used to plan decisions relating to harvest, planting operations, resource recruiting and distribution at the **_operational_** level. This is concurrent with seasonal crop planning and land

use (Darby-Dowman et al. 2000) with growers' outsourcing and cooperation decisions (Nagasawa, Kotani, and Morizawa 2009) at a ***tactical*** planning level. Other mathematical models are used to plan order quantities and product flows simultaneously with coordination between SC members (Su, Wu, and Liu 2014), supplier selection (Lin and Chen 2003) and cold storage design (Rong, Akkerman, and Grunow 2011). An ***Analytical*** model based on game theory is used to identify optimal ordering quantities between a grower and distributor and explore coordination scenarios for product pricing and sharing costs to keep the freshness of products (Cai et al. 2010). One ***simulation*** model is used at this integrated planning level. the model is used to study the dynamic behaviour of fresh produce supply chain in Netherlands using DES approach (van der Vorst, Beulens, and van Beek 2000). At an operational level, the model investigates decisions related to orders and deliveries between producer, distributor and retailer. Tactically speaking the model explores the efficacy in using an IT system to support ordering policies and allow real-time inventory management. The model is used to evaluate different scenarios regarding these decisions against a set of financial, operational, and quality indicators. A ***hybrid*** model is used at this integrated planning level for supplier selection and to optimise ordering quantities via a stochastic model complemented by an evolutionary algorithm to solve the mathematical model (Lin and Chen 2003). The objective of the model is to maximise the net profit while keeping supply and demand violations at the minimal level.

For the ***tactical-strategic*** planning level, mathematical models are used to plan farms and facilities locations (e.g., processing units or distribution hub) along with decisions related to network design and supplier selection (de Keizer et al. 2017), distribution route planning (Accorsi et al. 2016), and cooperation with other SC members to preserve products quality

(Tsao 2013). Another LP model is used to macro level planning for cherry production in Argentina (Cittadini et al. 2008). Decisions related to Orchard design and variety selection are considered along with tactical decisions connected to labourers training programs and irrigations technologies. The objective of the model is to improve growers' income and sustain labour workforce for this industry.

Only one application has integrated *operational* and *strategic* decisions (de Keizer et al. 2015). Design and logistics functions are modelled in this application to plan daily products flows and food hub location decision. Integration between the three levels is presented, also in one application only (Govindan et al. 2014). Similar to previous applications, designs and logistics, functions are modelled for planning facility location, the formation of transportation fleet and products flows.

2.6.4.2 SC Level of Analysis Vs Modelling Purpose and Decisions Level

When three analytical dimensions are combined, multiple cross-dimensional analysis can be conducted. For example, the model purpose can be analysed against SC levels and decision planning levels (Figure 2-10), this will help to understand decision-making behaviour when applying modelling approaches for AFPSC problems. Decision making in AFPSC planning is often supported by optimisation approaches (i.e., normative models) on both inter and intra-organisational levels (Figure 2-11). This contradicts with Brandenburg et al. (2014) findings that descriptive models are mostly employed for inter-organizational levels (i.e., chain or network) compared to normative models.
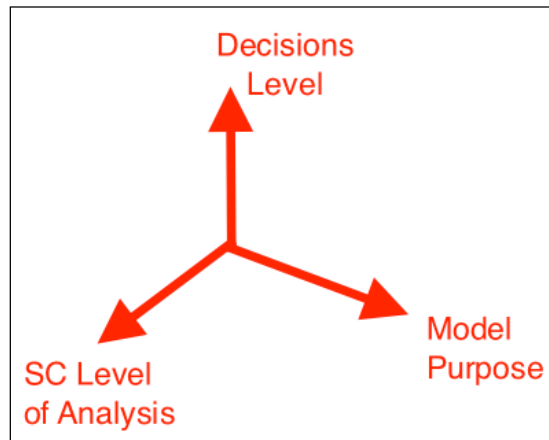
Figure 2-10: Three-Dimensional Analysis example
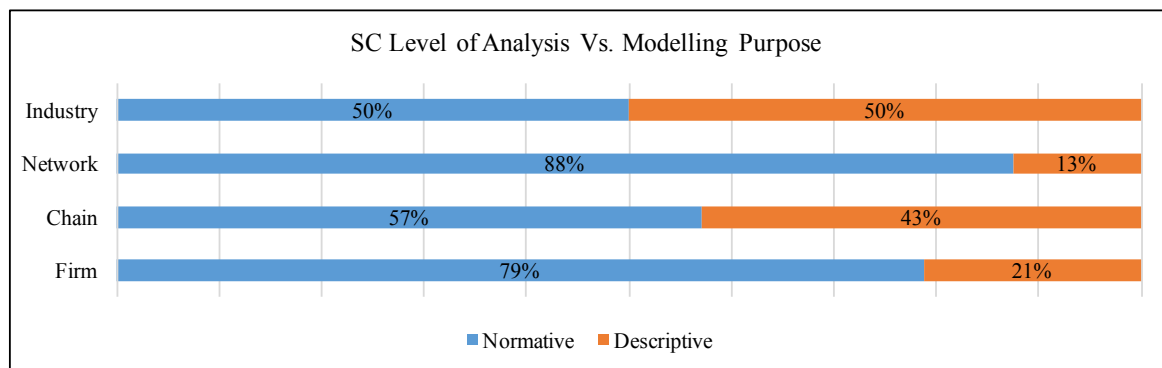
Figure 2-11 SC Level of Analysis against Modelling Purpose

Normative Models for Intra-Organisational Level

Normative models are used for intra-organisational level of analysis (i.e., single firm) to evaluate operational and tactical planning decisions, while strategic decisions received less attention (Figure 2-12). 23% of the articles which used normative models were applied to a single firm. For example, Darby-Dowman et al. (2000) presented a stochastic model for planning planting and harvesting operations over one season. The model showed two stages of planning; one was related to the optimal use of land and time of vegetable crop planting while the other focused on the daily harvest operations. Similarly, a multi-criteria decision-making model was introduced for crop selection and land division for some vegetable crops.

Operationally, the model plans resource allocation during the planting process. A single normative model for a single firm application has integrated decision planning for tactical and strategic levels (Hester and Cacho 2003). In this model, the authors presented a strategic planning for apple orchard planting. The model considered the product selection decision in terms of apple variety to be planted in the orchard. It also investigates the biological impact of the annual thinning decision on the orchard performance.

Normative Models for Inter-Organisational Level

On inter-organisational levels, normative models for the supply chain and network levels have similar characteristics as the models of single-firm applications. On the contrary, the normative models that focus on industry applications are concerned only with the tactical and strategic levels. However, this is not surprising as the actors involved in these applications are usually representing an authority or organisation such as local governments (Atallah, Gomez, and Bjorkman 2014, Teimoury et al. 2013).

Integrated planning is presented in 33% of normative models developed for inter-organisational AFPSC applications. Similar to the single firm applications, most of these integrated planning models are employed at operational and tactical decision-making levels. For example, Rong, Akkerman, and Grunow (2011) introduced an optimisation model for fresh vegetable SC to control quality degradation of the products. The model considered products distribution and inventory levels subject to both products temperature and quality. Operational decision planning is integrated with a strategic decision only in one model (de Keizer et al. 2015). In this model, the authors addressed the hub allocation of food product and products flows over the SC network from growers to retailers through that hub. The

ultimate goal of the model is to enhance the service level and reduce distribution costs while maintaining quality requirements. Another model integrated strategic decisions with tactical decisions for a fresh food SC network (Tsao 2013). A full integration between the three levels of decision making was presented in a study where a multi-objective simulation was developed to find the optimal number and locations of facilities, transportation fleet formation, delivery routes selection and products flow (Govindan et al. 2014). The objective of the model was to support sustainability trends by considering environmental performance indicators (PIs), such as Co_2 emissions along with other financial or cost related PIs. It is also noticed that none of these integrated models is employed for macro-level of analysis (i.e., industry).

<figure>
SC Level of Analysis Vs. Decision Levels for Normative Models

Industry: Tactical 60% | Strategic 40%
Network: Operational 57% | Tactical 79% | Strategic 36%
Chain: Operational 65% | Tactical 50% | Strategic 5%
Firm: Operational 54% | Tactical 58% | Strategic 12%

■ Operational ■ Tactical ■ Strategic
</figure>
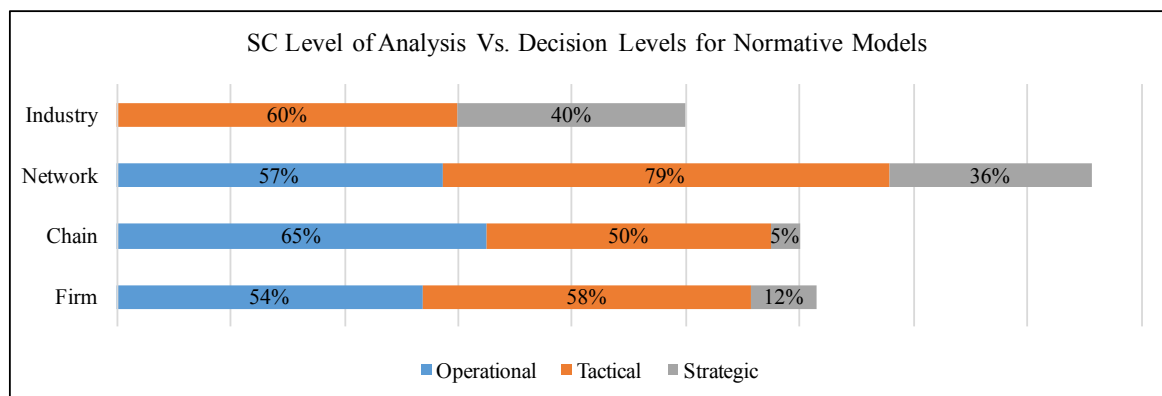
Figure 2-12: SC Level of Analysis against Modelling Purpose for Normative Models

Descriptive Models for Intra-Organisational Level

Descriptive models are used to explore and understand systems behaviour and the relationships between its parameters (Wu et al. 2010). In the AFPSC context, descriptive models applied for the intra-organisational level of analysis (i.e., single firm) are focused on operational decision making compared with tactical and strategic levels (Figure 2-13).

Usually, descriptive models are efficient in examining operational decisions such as resources planning of agri-fresh produce processes on resource utilisation and operations cost (Ampatzidis et al. 2014, Zhou, Jensen, et al. 2015). This may explain the focus of these models on harvesting and packing functions where extensive resources (i.e., workers or machines) are needed. Two descriptive models are used for tactical planning, the first model is to explore the impact of different packing programs on exports of Persian lime in Mexico (Lambert et al. 2014), while the second examines different ordering and replenishment policies to reduce products losses at lettuce retailer (Tromp et al. 2016). Similarly, two descriptive models are used for strategic planning on a single firm level. Both of them are employed to examine the efficacy of replacing conventional products with organic ones for apple orchards in Canada (Keyes, Tyedmers, and Beazley 2015) and wine vineyard in Italy (Falcone et al. 2016). The objective was to assess how organic production will affect the greenhouse gas emissions against the investment costs.
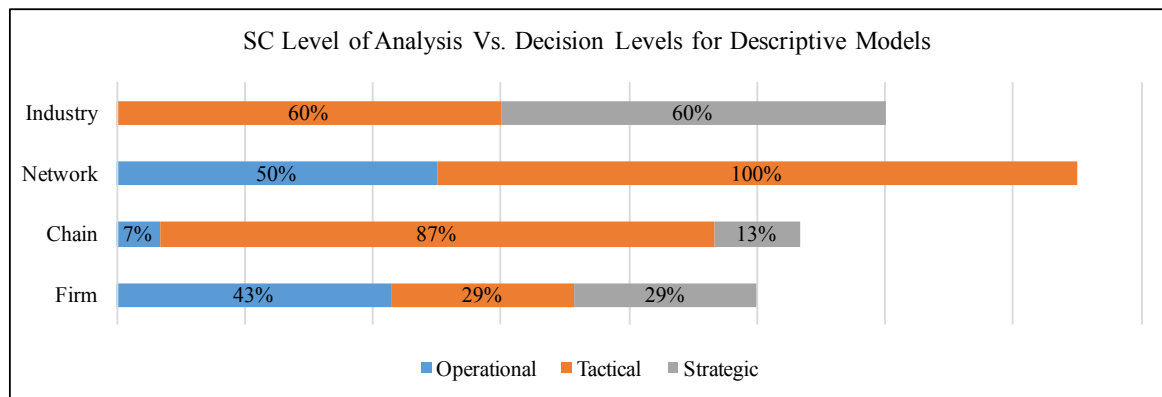
Figure 2-13: SC Level of Analysis against Modelling Purpose for Descriptive Models

Descriptive Models for Inter-Organisational Level

In contrast to single firms, descriptive models are mostly utilised to examine tactical decision in the industry, supply chain, and supply network applications (Figure 2-13). Integrated

planning applications represent 13% (3 papers) of the descriptive models used for inter-organisational level of analysis for AFPSC applications. Two of them integrate operational and tactical decisions while the third model incorporates tactical and strategic decisions. The latter model studies different options for cultivation practices and design for fruit orchard to investigate their long-term financial impact and manpower employment in this sector (Cittadini et al. 2008). The planning was on the macro scale for the cherry fruit industry in the South Patagonia region in Argentina. An operational-tactical planning model was employed to explore the impact of cooperation between growers for harvesting fresh produce over different periods of flowering to face multiple markets demand (Nagasawa, Kotani, and Morizawa 2009). The authors suggested two scenarios of cooperative and non-cooperative farms and studied how each of them will impact the overall market consumption of their produce.

2.6.5   *Research Gaps and Future Considerations*

A systematic literature review is applied to assess the research efforts in AFPSC application. Although growing research efforts are witnessed in the AFPSC planning field, there is still potential for further development and elaboration for better employment of modelling capabilities and techniques.

<u>Coordination between SC Actors</u>

Researchers have indicated the importance of the coordination between SC parities which include; improved transparency and traceability (Fritz and Schiefer 2008), increased competitiveness (Farahani et al. 2014), and risk mitigation (Leat and Revoredo-Giha 2013). In the underlying dataset, few models addressed cooperation and coordination between

growers-distributers to preserve product quality (Cai et al. 2010) and growers-retailers to mitigate supply disruption (Sun 2013) and between distributors-retailers to maintain quality and safety (Qi et al. 2017), setting price (Wang and Chen 2017) and mitigate demand risk (Su, Wu, and Liu 2014). Accordingly, a research gap can be identified where insufficient models address coordination between AFP supply chain parties.

Despite that, model-based planning research focused mainly on the distribution and logistics functions in agri-fresh produce sector; limited attention has been paid to other supply chain functions such as packing, production and pricing. These functions are of utmost importance for AFPSC planning. For example, Packing function plays a vital role in preserving products quality and freshness during distribution activities (Blanco et al. 2005), and pricing is also one of the challenges that face coordination between SC actors (Sun 2013). Therefore, it is recommended for researchers and practitioners to consider these functions when modelling AFPSCs, particularly for the inter-organisational level.

Non-Financial PIs

The research in the food industry has a significant focus on the financial indicators in various forms such as cost, revenue, or profit. However, more attention is required to use other indicators, in particular, those that are related to agri-food characteristics: 1) safety, 2) quality, and 3) sustainability (Akkerman, Farahani, and Grunow 2010). These indicators are motivated not only by the recent regulations and legislations related to these PIs but also by their impact on competitiveness which might have adverse financial effect if the SC failed to address these indicators adequately (Adler-Nissen et al. 2013). In terms of sustainability, environmental indicators received less attention with the little mention of social indicators

(Kleindorfer, Singhal, and Wassenhove 2005). Environmental indicators focus mostly on greenhouse gas emissions that result from transportation, production, cold facilities and harvesting operations. There is a gap in assessing the impact of irrigation, fertilisers, and pesticides on the environment. These indicators are intimately connected to agri-fresh produce activities. On the other hand, related social topics have received less attention, but this can be justified as they are not well defined in the SC literature due to the challenges in quantifying their indicators (Lehtonen 2004).

Performance indicators that are related to product safety and quality received adequate consideration in AFPSC planning models. This is due to food safety and quality having a sensitivity to many factors, most important environmental stresses and time (Aung and Chang 2014). However, most of the mathematical and analytical models require assumptions to simplify system complexity and quantify its performance. For example, some models use a rough approximation of quality degradation based on the time effect independent from other factors such as environmental conditions and distribution operations effect (Ahumada and Villalobos 2009b). In addition, most of the applications did not consider storage temperature during distribution, though it is one of the most crucial factors that degrade food quality and safety. Hence, there is a need for more research addressing biological dynamics that are connected to fresh produce quality and safety (Hester and Cacho 2003).

Strategic Planning and SD modelling

The analysis of the dataset also shows a paucity of models that address strategic decision making in AFPSC planning applications. One of the reasons for this issue is the short life

cycle of the products which incentivised more focus on short-term operational decisions (e.g., sowing, harvesting, transportation) compared to strategic decision making (e.g., network design, investment decisions). Another interpretation is the level of complexity that exists at the strategic decision-making level of the agri-fresh produce industry due to many factors. These factors include but are not limited to dynamic environments, rapid changes in consumptions trends, global warming effects. The majority of researchers have used mathematical models, which lack the ability to address such complexities.

Simulation modelling approaches might be a suitable aid to address strategic decision making for agri-fresh produce context. In particular system dynamics, which is an efficient approach for modelling complex and dynamic systems, could be efficiently used to study the long-term effects of various scenarios on system behaviour. (Sterman 2000). A limited number of applications in the underlying dataset have employed SD models (McKellar et al. 2014, Teimoury et al. 2013). However, these models are used mostly for tactical decisions, and only one application used an SD model for strategic planning (Ferreira, Batalha, and Domingos 2016). Hence, both researchers and practitioners are encouraged to employ more SD models to address research questions related to strategic decision making in the agri-fresh produce planning context. SD models will also allow the studying of the efficacy of different policy for improving the performance, and/or scenario for envisaging the impact of possible disruption or risk scenarios on supply chain behaviour (Crowe, Mesabbah, and Arisha 2015).

Social and Human Behaviour and ABM

As mentioned earlier, globalised markets of fresh produce products are dynamic and even evolving faster than other traditional crops. This creates fierce competition between different

actors on markets share. Few applications have used game theory models to improve economic performance indicators for groups of competing players (e.g., growers) in such markets (Sun 2013, Cai et al. 2010). However, these models force simplifications on the players, (i.e., SC members) options, and payoffs. They also assume homogenous characteristics of the players in these models. While in reality, these actors have heterogeneous attributes in terms of their business sizes, products variations, utility functions, risk aversions, and network connections. Moreover, in some cases, the competition may be between SCs rather than individual members (e.g., groups of growers and group of retailers). In these cases, models employed should be able to address actors' heterogeneity and reflect different social and human behaviours.

Growing, harvesting and post-harvest operations are critical for product quality. During these processes, the most considerable operational costs and wasted produce occurs. Production seasonality forces growers to rely on seasonal labour markets which are often characterised by low qualifications and high diversity in skills (Whatman and Van Beek 2008). Also, there are many social problems associated with seasonal labour markets especially during the on-season periods (Cittadini et al. 2008). However, most of the models that address these operations assume homogeneous characteristics of the workers (Saedt, Hendriks, and Smits 1991, Ampatzidis et al. 2014). Seldom models considered variations in workers' productivity (Bohle, Maturana, and Vera 2010, Arnaout and Maatouk 2010). However, many assumptions were applied to simplify these variations and make them static and deterministic to suit the mathematical models used. Hence, there is a need for modelling approaches that are able to address labourers' heterogeneous characteristics, especially at grower's echelon.

The analysis in this review suggests that there is a lack of appropriate modelling approaches that have the capability to address different social and human behaviour patterns of various entities of agri-fresh produce systems. As discussed in appendix 1, ABM is one of the most suited approaches to address heterogeneous system entities. However, there is no record of any published work in this review, which employs ABM models for planning problems related to AFPSCs.

Integrated Decision Making

There is a growing interest in addressing the complexity of the entire system and understanding the relationships between various levels of decision making and how that would impact the overall performance (Jahangirian et al. 2010). Integration between different decision-making levels is essential for the overall efficiency of AFPSC (Shukla and Jharkharia 2013). The complexity of integrated planning arising from the dynamism of temporal impact differences of the decisions studied (Tsolakis et al. 2014). This complexity is compounded when SC inter-organisational level is considered, where multiple SC members are involved. Such cases are insufficient in this review, and most of them tackle only two planning levels (just one paper (Govindan et al. 2014)). However, the majority of them employ mathematical models that lack sufficient capability to address high complexity degrees. Hence, many assumptions and simplification are applied to reduce the modelled AFPSC complexity in these cases.

Simulation models can benefit integrated planning of AFPSC systems. There are several types of simulation models which address different planning levels. As mentioned earlier SD is suitable for strategic decision planning, and both ABM and DES are ideal for

tactical and operational levels. Combining two or more of these simulation techniques will reduce the limitations of individual methods and increase their capabilities (Fakhimi and Mustafee 2012). Hybrid simulation modelling allows researchers to combine different simulation models in one to unlock their ability to handle the three levels of planning along with the various complex elements of AFPSC systems. There is no record for any hybrid model in this review which employs different simulation models for AFPSC planning.

There are a few papers in this review that present hybrid models for AFPSC problems. However, all of them are mathematical model-based combined with either: 1) simulation model to facilitate optimisation of simulated PIs (Danloup et al. 2015); 2) analytical models, particularly game theory models, to enable optimisation (Hu, Chen, and Huang 2014); or 3) heuristic models which find optimal solutions (Lin and Chen 2003). Hence, researchers and practitioners are encouraged to investigate the employment of hybrid simulation models for integrated planning of AFPSC and mainly when the planning is for more than one SC member.

CHAPTER 3: RESEARCH METHODOLOGY

Research is a journey of discovery, to create new knowledge by applying different philosophies and employing systematic methods and approaches. Research methodology can be thought of like the roadmap for this journey. However, no single methodology is valid for all research projects. Three elements determine the design and strategy of research methodology, namely: 1) the scope of the research; 2) the area of study; 3) and the type of data (Bell 2014). Selection of the research methodology should be justified considering the research objectives.

Integrated frameworks for decision making and planning of complex AFPSC is a relatively new research area with a limited number of academic and industrial publications. Therefore, in this study, an inductive approach is adopted to drive the theoretical definition of the central decisions and the levels of decision-making in AFPSCs. This is followed by a deductive approach to develop, test and validate a framework for modelling dynamics of agri-fresh produce supply chain decisions and performance. The case study technique is used as an effective strategy to gather the research objectives coherently. Several data collection techniques are used to collect primary data (site visits, interviews, observations and historical data) and secondary data (literature reviews). Figure 3-1 provides an overview of the applied research methodologies and how they are aligned with the overall research objectives.

Figure 3-1: Research Methodology

3.1 Research Philosophies

Research philosophies are the sets of assumptions and beliefs researchers hold through which they view the world. These assumptions and beliefs will guide the researcher to select the relevant strategy and research methods (Saunders, Lewis, and Thornhill 2011). There are two main avenues within research philosophy: 1) Ontology and 2) Epistemology. ***Ontology***

concerns itself with the nature of reality from the researcher's point of view. There are two main opposing ontological aspects: Objectivism and Subjectivism. ***Objectivism*** portrays the reality of existence to humans and other social actors' beliefs, while ***subjectivism*** explains social phenomena as a reflection of perceptions and following actions of humans and social actors concerned with their existence. Advocates of objectivism believe that there exists only one single reality, on the other hand, subjectivists believe in co-existence of multiple realities depending on social actors' views, perceptions and actions (Holden and Lynch 2004).

Epistemology is concerned with the nature of knowledge, how it is acquired and what constitutes acceptable knowledge in a field of study (Becker and Niehaves 2007). Similar to ontology, there is a bi-fold argument between two schools of researchers around epistemology. ***Positivism*** is concerned with facts rather than impressions or views. It seeks knowledge created through experimentations and structured observations of reality. Proponents of positivism prefer "working with an observable social reality and that the end product of such research can be law-like generalisations similar to those produced by the physical and natural scientists" (Remenyi and Williams 1998, 32). The second school, ***interpretivism***, argue that social world of business and management is different from physical sciences and is too complicated to be understood by strict laws. Interpretivists believe that rich insights that can be extracted out of this complex world will be lost if such complexity is reduced for the sake of law-like generalisations (Saunders, Lewis, and Thornhill 2011).

The outcome of interpretivist research cannot be seen as *the absolute truth* nor generalised to other contexts rather than the one under study. The main reason for that is because such an outcome is a function of a specific set of circumstances and social actors

coming together at the time of the study. This makes that kind of research highly appropriate in the context of business and management studies because of the uniqueness that exists in every single case (Saunders, Lewis, and Thornhill 2011). On the other hand, it is frequently implied that outcomes of positivist research are replicable and that researchers tend to use a structured methodology in order to facilitate this replication (Gill and Johnson 2010).

When discussing research philosophy, the influence of ontology and epistemology cannot be ignored, as the researcher's view of reality cannot be separated from the way of knowing about it (Crotty 1998). The positivist researcher is most likely to have an objective ontological view of the reality which they seek to gain knowledge and understanding of. While interpretivist researchers usually believe in a subjective ontology, it is thought to by purists from both schools that a researcher has to clearly state their stance regarding epistemology and ontology by adopting one single research philosophy (Guba and Lincoln 1994). ***Pragmatism*** is a research philosophy which has emerged in an attempt to settle the conflict between the positivist and interpretivist paradigms. This philosophy rejects the forced selection between research paradigms and instead, focuses on the practical outcome of the research (Tashakkori and Teddlie 1998). Under a pragmatic research paradigm, it is possible to follow two or more philosophies in a research project to achieve the objectives. Hence, it allows the researcher to use whatsoever methodological approach found suitable if it is considered useful in addressing the research questions (Saunders, Lewis, and Thornhill 2011). Pragmatism has to become a famous research philosophy as it allows the adoption of mixed-method approaches, for better resolution of research objectives.

3.2 Research Approaches

There are two main approaches for the development of a new theory of knowledge: 1) the *inductive*; and 2) *deductive* approaches (Table 3-1) (Marczyk, DeMatteo, and Festinger 2005). The inductive approach usually begins with a set of information and observations in which patterns and relationships are detected leading to a theory or framework. Induction is concerned with gaining an in-depth understanding of the research phenomenon within its context (Easterby-Smith, Thorpe, and Jackson 2012). On the contrary, a deductive approach starts with a suggested theory or framework, then designs a research method to test it. It usually relies on a highly-structured methodology to investigate causal relationships between variables, in order to explain the phenomenon under study, therefore, achieving generalised outcomes (Saunders, Lewis, and Thornhill 2011). A comparison between the two approaches and their characteristics is presented in Table 3-1.

Table 3-1: Research Approaches Comparison (adapted from (Saunders, Lewis, and Thornhill 2011))

	Inductive Approach	*Deductive Approach*
Research Philosophy	Interpretivism	Positivism
Investigation sequence	1- Observation 2- Patterns 3- Hypothesis 4- Theory	1- Theory 2- Hypothesis 3- Observation 4- Confirmation
Research Purpose	Exploratory: understanding of certain phenomenon	Explanatory: explaining causal relationships between variables
Data Needed	Qualitative	Quantitative
Generalisation	Not necessary	Necessary

3.3 Research Methods

Researchers have to select their research methods in light of research philosophy, approach and purpose. There exists a twofold classification of research methods: 1) ***Qualitative***; and 2) ***Quantitative*** methods (Neuman 2002). Quantitative methods examine phenomena using a quantifiable set of data in digital forms. Data analysis is often conducted based on mathematical models and statistical techniques (Creswell 2013). Quantitative research is usually enacted to question relationships between system variables. It aims to obtain generalised findings, and so it is traditionally associated with deductive studies (Bryman 2015). The quantitative research methods include experiments, surveys and structured observations (Williams 2011). Qualitative methods, on the other hand, depend on textural and descriptive data rather than numerical. Qualitative research is described as in terms of discovery and focuses on explaining phenomena from the researchers' perspectives in which they become an effective part of the study (Creswell 2013). Qualitative data is usually analysed via thematic and/ or content analysis methods to discover themes and patterns which appear in the data (Renner and Taylor-Powell 2003). Qualitative research is usually adopted to address research questions posed by the researcher; it belongs to the inductive approach, where theory building is based on observational elements (Williams 2011). Quantitative research methods include case study, ethnography, phenomenological, grounded theory and content analysis (Creswell 2013).

Many researchers locate quantitative and qualitative methods on opposite sides of the research methodology scale. Some proponents of qualitative research criticise the quantitative approach due to its rigidity which does not always permit a more detailed

explanation of many real-life phenomena. While conversely, Quantitative researchers believe that findings of qualitative research would be only relevant to a relatively small population because of the inability to generalise conclusions (Amaratunga et al. 2002). Some researchers, inspired by the pragmatic paradigm, suggest integration between quantitative and qualitative methods. This allows much-needed access to the benefits of both methodologies, to convince researchers who believe that neither of them is sufficient on its own. This integration is known as mixed-methods research (Tashakkori and Teddlie 2010). This combination is also useful for the researcher to include a broader range of research aspects and parameters (Crotty 1998). Mixed-methods research can incorporate qualitative and quantitative data collection and analysis methods. In this case, qualitative and quantitative data can be collected sequentially or concurrently during the research phases according to the research design. For example, a research question can be addressed using quantitative data through structured observations and narrative data from interviews. Under mixed method research, both inductive and deductive approaches can be used to develop and validate a theory or a framework in one study. Proponents of the mixed methods approach apply aspects of both which are necessary and beneficial to investigate the phenomenon and address the research questions which is consistent with the pragmatic philosophy (Sale, Lohfeld, and Brazil 2002). There are three main strategies for the mixed approaches according to Creswell (2013) including:

Sequential Explanatory: a strategy applied when qualitative interpretation for findings of a quantitative study is required. It begins with quantitative data collection and analysis, then a group of qualitative data to interpret and support quantitative results.

Sequential Exploratory: an appropriate strategy for developing a new theory or hypothesis through the qualitative approach which may need to be quantitatively tested or validated. It starts with qualitative data collection and analysis, followed by quantitative analysis to expose the central parameters and variables of the developed theory or hypothesis. The findings of both approaches can be integrated throughout the interpretation phase.

Concurrent Triangulation: a strategy that fits when the research needs two different methods for confirmation, cross-validation or corroboration, in a research project. Both quantitative and qualitative data are collected concurrently in one phase then their results are integrated into the interpretation phase.

3.4 Justification of selected paradigm

The overall objective of this research is to develop a simulation-based integrated planning framework for AFPSCs managers. Viewing AFPSC as a complex system involving human interactions and containing stochastic dynamic relationships between its actors undermines the argument of using positivism philosophy in this research. Therefore, the pragmatic paradigm was selected as the philosophical background of this study. It was chosen as the most appropriate philosophy to address the research questions in a complete and comprehensive way. This philosophy helps to achieve the research objectives in the adoption of different research methods and their associated approaches during various phases of this project. It also allows the employment of mixed methods including both qualitative and quantitative data collection and analysis techniques. This will result in an effective research process, leading to relevant and valid research outcomes.

There is a limited number of academic and industrial publications related to integrated planning and decision-making frameworks for AFPSC. The various aspects and components required for developing such frameworks need to be investigated throughout the current research. Therefore, the inductive approach is employed to acquire the data needed for formulating the proposed integrated planning framework followed by the deductive approach to evaluate and validate this framework.

3.5 Research Design

Research design represents a detailed work plan to describe the required steps to complete a research project and to ensure a rigorous research process to address the research questions clearly (Saunders, Lewis, and Thornhill 2011). When designing research, the strategy, data collection methods, and data analysis have to be identified. With the underpinnings of the pragmatic paradigm, this study adopts a multiphase research design as presented in Figure 3-2. The first two phases are concerned with the development of integrated planning framework for AFPSC, while the third phase is concerned with validating the proposed framework via a case study.

3.5.1 Research Purpose

Research purpose is the form adopted to address the research question, and it can be either: *exploratory*; *descriptive*, or *explanatory* (Saunders, Lewis, and Thornhill 2011). Exploratory studies are concerned with discovering the status quo and then generating insights that guide the subsequent step of the investigation. This kind of study is helpful for researchers when the research problem is not well defined, and more investigation is needed. An exploratory study often begins with a broad scope and narrows gradually as the research progresses

(Robson 2002). Such study may involve literature review, interviews with experts, focus groups and/or shadowing (Saunders, Lewis, and Thornhill 2011). Descriptive Studies are concerned with drawing a clear image about a phenomenon, that could be an event, situation or system. This kind of research could be complementing an exploratory study to facilitate the description of the phenomenon before data collection (Robson 2002). Finally, explanatory studies are used to establish causal relationships between the different factors and the phenomenon under study (Saunders, Lewis, and Thornhill 2011).
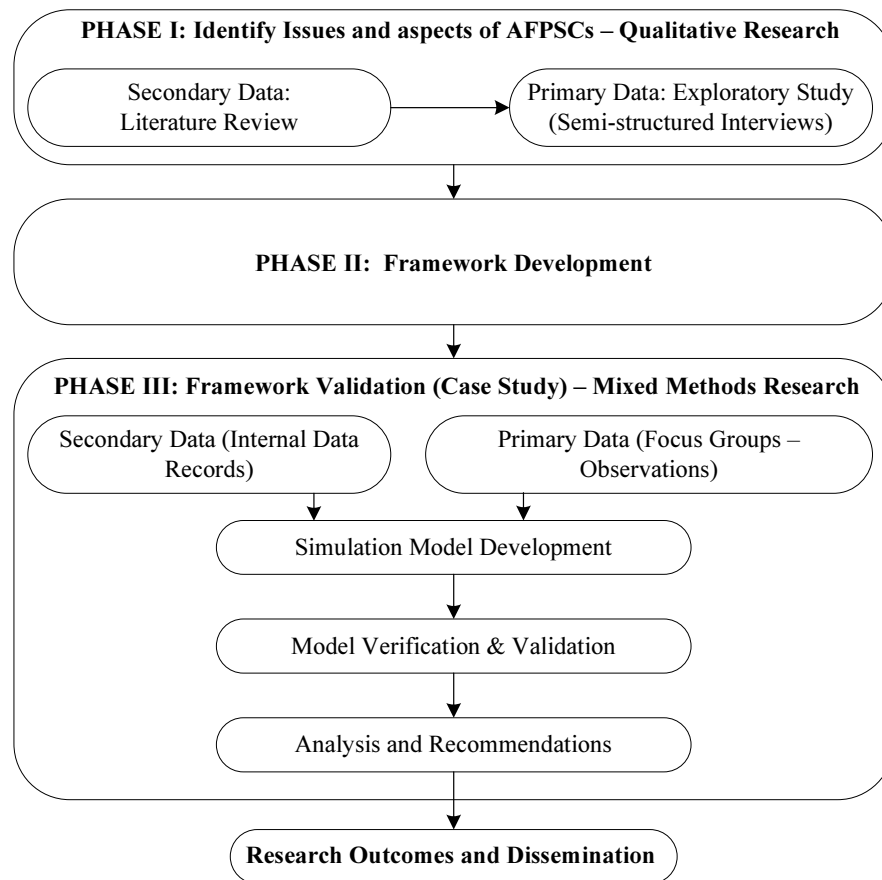
Figure 3-2: Research Design

According to the nature of the research presented in this thesis, an objective exploratory research scheme was used in the first phase to identify the main issues and challenges in

AFPSC planning problems, to investigate current trends in applying M&S techniques for addressing these problems and to spot application gaps and highlight areas for potential research. This phase involved a literature review, as a secondary source of data, to analyse applications of M&S techniques for AFPSC planning problems. The outcomes of this literature review were complemented by interviews with experts, managers, and staff from different agri-fresh produce organisations, on-site observation and shadowing for the various operations in these organisations. This exploratory research was helpful in developing conceptual models for AFPSC relationships, operations, planning decisions and PIs, which were then used during the second phase to identify the various aspects and required components for developing the simulation-based framework for AFPSC integrated planning. The requirements for modelling the complex AFPSC were described during this phase. Implementing the framework and applying it to a case study led to a confirmatory study phase (*Phase III*) which was devised to test and validate the proposed framework deductively.

Since the primary motivation behind this research is to explore innovative tools for planning complex AFPSC, this study is classified as applied research, where its central target is to add to the existing body of knowledge. This is consistent with the pragmatic research paradigm which covers used research activity (Saunders, Lewis, and Thornhill 2011).

3.6 Research Strategy and Data Collection

As mentioned in the previous section, this research was divided into three phases (Figure 3-2). The data collection methods and the research strategy over these phases are discussed in the following subsections.

3.6.1   Phase I: Identify Issues and Aspects of AFPSCs

This phase is intended to address the first two research question: 1) *How are modelling and simulation techniques currently employed in AFPSCs?* and 2) *What are the central planning decisions and performance indicators that AFPSCs' managers consider?* Qualitative research is adopted during this exploratory phase based on secondary data (literature review) and primary data (an exploratory study).

3.6.1.1 Secondary Data – Literature Review

Secondary data is a useful source of knowledge for the pursued research since it provides a wide range of related information that has been collected and analysed by other studies (Saunders, Lewis, and Thornhill 2011). When a study begins with secondary data, time, effort and costs can be saved as research objectives can be met by analysing or manipulating the collected data. In this study, literature reviews and other materials (such as reports, surveys and websites) are used to obtain the preliminary information regarding the planning and decision-making aspects of AFPSCs (chapter 2). The literature review is mostly a comprehensive exploration of the current of knowledge elements and their potential integration. Hence, the first purpose of secondary data is to support the generation and refinement of the research idea and in setting the study's objectives. The second goal is then to provide the required secondary data which contributes to achieving these objectives.

As illustrated in chapter 2, the literature review has offered an overall view of the problems and challenges facing decision makers of AFPSC. This was followed by a presentation of the various modelling and simulation techniques, and their role in the

planning and decision-making process. Then a systematic literature review is conducted on modelling and simulation application on AFPSC problems. Finally, research gaps are discerned and utilised to develop the proposed framework by providing a clear vision about the aspects and requirements of designing the structure of the framework and its components. The detailed methodology employed to collect required secondary data for the systematic literature reviews is explained in the following sections.

3.6.1.1.1 Literature Review Methodology

A systematic literature review of peer-reviewed journal articles on modelling approaches applied for AFPSCs research area was conducted to address the *first* research question. The review employs a systematic content-analysis process (Lage Junior and Godinho Filho 2010), which consists of four iterative steps:

1) Material Collection;

2) Descriptive Analysis;

3) Category Selection;

4) Material Evaluation.

The material collection is discussed in the following section, while descriptive analysis, category selection (review framework) and material evaluation (i.e., the results) are presented in chapter 2.

3.6.1.1.2 Material Collection

A comprehensive search for related journal articles was applied to produce synthesis for peer-reviewed literature. This search includes only scientific research papers which:

1) Are written in English language and published in peer-reviewed Journals between 1990 to 2017;

2) Address an AFPSC related problem;

3) Have a model developed for this problem.

Besides, papers that consider empirical research such as statistical approaches (e.g., regression models) are not considered.

The datasets for this literature review are acquired by means of keyword-based searches using electronic bibliographical sources (Seuring and Gold 2012). Databases and libraries such as Emerald, Science Direct, Scopus, Springer and Wiley are considered as sources for material acquisition. These databases are selected based on the eight literature reviews summarised in table 2-1 in section 2.6.1. Initially, a set of keywords are used to collect publications related to AFPSCs research area. Keywords are used with all possible combinations of two words each of them is withdrawn from two different sets of words. The first set includes "supply", "chain*", "manage*" and "distribute*", while the second set includes "Agri*", "fresh", "food", "vegetable*", "fruit*" and names of multiple fresh produce products (e.g., grapes, tomato, lettuce etc.).

This initial search has resulted in a dataset of **5280** papers after removing duplicates, review papers and books using Endnote reference manager package. The dataset is refined by excluding articles that do not include modelling research. Hence another search is conducted on this dataset using another set of keywords such as "quantitative*", "model*, "simulat*", "Optimi*" and "decision*". This resulted in a dataset of **2173** papers. The next step was to filter this dataset to consider only papers that have research related to fresh

produce products (i.e., exclude products such as seeds, beef, poultry, etc.). This filtering resulted in a dataset of **360** papers. The materials of this dataset are assessed individually according to the criteria mentioned in the previous section. Out of these **360** papers, only **61** papers were found to satisfy these criteria. Those **61** papers were inserted in the final dataset considered for the analysis.

The keyword-based search conducted here is complemented by cross-referencing to include more relevant publications in the final dataset (Pinelopi 2009). Therefore, the dataset is supplemented by cross-referencing using the most recent and relevant literature review papers: (1) Ahumada and Villalobos (2009a, 62 papers); (2) Shukla and Jharkharia (2013, 86 papers); and (3) Soto-Silva et al. (2016, 28 papers). Out of these three reviews, **23** papers were found to meet the stated criteria for paper selection for the present review. These papers are inserted into the final dataset. In addition, relevant publications cited in the papers of the last dataset during the analysis were also considered and entered into it. Table 3-2 presents a summary of the final dataset and how it is constructed. This dataset is then moved from Endnote to another reference manager package called JabRef for analysing them according to the attributes of the review framework (Figure 2-4).

Table 3-2: Papers Collection Sources for the Analysed Dataset

Collection Source	# of papers	# of Relevant papers
Keyword-based search in electronic databases	360	61
Ahumada and Villalobos (2009a)	62	8
Shukla and Jharkharia (2013)	86	3
Soto-Silva et al. (2016)	28	12
Other Papers		10
Total		94

3.6.1.2 Primary Data – Exploratory Study

Development of a simulation-based framework for AFPSC planning requires a thorough understanding of how modelling and simulation approaches are employed for planning AFPSC in literature, in particular, the decision-making aspects they address. It is therefore of utmost importance to attain the perception of management on these aspects and to examine their interpretation for the different planning decisions and performance indicators discussed in the literature. A qualitative research method in the form of interviews is selected to convey the experiences and views of AFPSCs' managers and experts on planning and decision making. Ultimately, this study is undertaken to acquire the required information to identify the vital relationships, operations, planning decisions and performance metrics within AFPSC organisations. This was indispensable in the development of conceptual models for AFPSC structure, processes, and decision making.

3.6.1.2.1 Semi-Structured Interviews

Conducting the literature review as a secondary data source proved helpful in gaining an overview of the research topic in highlighting the current gaps in research. As indicated in chapter two, AFPSC planning models suffer from inefficient integration between the three decision-making levels (i.e., operational, tactical and strategic) in these models. The available models that attempted to address integrated planning were found to lack the ability to address the complexity and dynamism involved therein. This is because they force the simplification of issues to reduce the problem complexity. The research presented in this thesis attempts to address this gap by offering an integrated planning framework for AFPSC managers that can

address integrated planning complexity not only for agri-fresh produce organisations but also for the SC.

More extensive investigation of the decision-making process in the context of AFPSC was required to provide an in-depth understanding of the different decisions across the three planning levels and how these decisions impact each other. Moreover, there is also a need for a deep understanding of the primary operations that exist at each AFPSC entity and the most critical performance indicators that management need to track. Hence, *interviewing* as a qualitative data collection method was chosen to satisfy these requirements.

The advantage of interviews is that it provides researchers with data that focus on individuals' experience through interactive dialogues (Mason 2002). Such experience cannot be obtained using other methods such as surveys. There are three categories of interviews, namely: structured, semi-structured and unstructured interviews (Berg, Lune, and Lune 2004). Structured interviews are based on a set of identical questions asked in a predetermined order to all interviewees and usually offer the respondents a fixed range of answers. They are similar to surveys and are often used to collect quantitative data from interviewees (Bryman 2015). Semi-structured interviews provide more flexibility to the researcher to adjust the order of the predetermined set of questions with the ability to ask new questions according to the respondents' answers. They allow the emergence of new ideas and insights during the discussion with the interviewees (Tong, Sainsbury, and Craig 2007). Unstructured interviews are more like informal conversations between the researcher and the interviewee without any predetermined questions. In these interviews, the researcher drives

the questions and asks them according to the development of the discussion and the interviewee's answers (Miller et al. 2001).

In this phase, semi-structured interviews are selected as the primary data collection method for the exploratory study. The rationale behind this selection was to ensure controllability of the interview to uncover the most crucial decision-making aspects and central operations within agri-fresh produce organisations. This allowed a level of freedom for interviewees to respond organically and added more insights regarding issues that might not be captured by predetermined questions. This allowed a balance between planned and unplanned questions and reduced the time needed for data analysis.

Twelve managers and experts from various agri-fresh produce organisations were interviewed during this phase to study their experience in planning and decision making for their business and to discover more insights about how this business is running and how it is connected with other partners and customers. The interviews also aimed to highlight the critical factors that impact operations within the agri-fresh produce organisations. These factors were the base for providing scope and direction for the development of the integrated planning framework. In an attempt to build conceptual models for AFPSC structure, operations and the decision-making process, interview questions focused on identifying:

1) operational, tactical, and strategic decisions in agri-fresh produce organisations;

2) performance indicators that these decisions affect;

3) main operations in each organisation; and

4) factors and parameters that impact both operations and decisions.

The crucial benefit of these interviews was the realisation regarding the most critical aspects, components, building blocks and types of data required to be considered in the framework development phase (*Phase II*).

All the interviews were conducted face-to-face with the interviewees and each interview lasted for approximately 1 to 1.5 hours. After each interview, the data was transcribed and summarised for the analysis which allowed the extraction of essential and relevant information. Since the data was not too onerous, it was processed and coded manually by the researcher. This allowed for more focus on the in-depth meaning of the data through iterative reading and analysis. Once all the interviews were completed, an overall comprehension of the whole narrative was constructed, moving from particular to general (Miller and Crabtree 1992). This was followed by the development of three conceptual models (Chapter 4).

3.6.2 Phase II: Framework Development

Building on the insights obtained from the literature review and the exploratory interviews, the second phase of the research was the development of the simulation-based framework for AFPSC integrated planning. This phase is proposed to answer the third research question: *How can a modelling and simulation-based framework be developed for AFPSC planning?* This is discussed in detail in chapter 5.

3.6.3 Phase III: Framework Validation (Case Study)

Upon the completion of the framework, it was necessary to examine its validity in a manner which allows the researcher to establish preliminary conclusions regarding the relevance of

the framework to AFPSC planning. Unlike the first phase, this one was not explanatory but somewhat confirmatory and aimed to test and validate deductively what has been proposed. Hence, this phase was proposed to answer the fourth research question: *How far would a developed framework be useful for decision-making in AFPSC and to what extent can it be applied?* The answer to this question was addressed through implementation of the framework in an existing agri-fresh produce organisation. This allowed the evaluation of the framework's applicability and effectiveness. Due to its applied nature, the case study method was found to be the most suitable method to achieve the objective of this phase.

3.6.3.1 Case Study

In business and management science research, case studies are widely engaged due to their reliable results. This stems from the ability to combine quantitative and qualitative data collection from multiple sources (Saunders, Lewis, and Thornhill 2011). Moreover, they allow a number of research purposes such as theory development and theory testing (Yin 2009). When a case study is used for testing purposes, the hypothesises which are tested have to be arranged to allow the evaluation of actual outcomes of the case study against the normal findings of the proposed framework (Creswell 2013). In this case, the research approach is deductive and would result in either validating the framework or in its modification or refinement based on the case study results. In light of this, a case study in real life AFPSC organisations was applied to test and evaluate the proposed framework in a business context, to confirm its validity as an efficient AFPSC planning tool.

The selection of the case is challenging yet critical for case study research. Considering the confirmatory purpose of applying the case study model in this research

phase, two case-selection methods are identified in the literature: *typical* case and *critical* case. The former is often used as representative of a given population while the latter is used in situations where a case makes a point dramatically so that theory would be true for all other cases if it is true for the selected one (Klonoski 2013). A 'typical case' was chosen as selection method to provide an illustrative example for applying the proposed framework to a real-life AFPSC. Additional criteria for AFPSC case selection were defined as well. Firstly, access to all organisations involved was found to be necessary to facilitate initial contact. Secondly, the interest of these organisations in integrated planning tools was deemed an important factor in the success of the case study. Finally, organisations' approval of the case study is essential to permit data access and to authorise employees and workers to participate in data collection activities. In this regard, the researcher approved complete confidentiality of data and anonymity of results and hence was willing to sign any non-disclosure agreements if needed.

The case study was eventually conducted in a large table grape supply chain (TGSC) that met the case selection criteria. The table grape was selected as it is a critical fresh product. For instance, it is a non-climacteric crop, which does not become ripe after harvest, so it has to be harvested under specific conditions. This makes the products vulnerable to deterioration during the handling process and also result in critical shelf-life for these products (Grierson 2002). Table grapes also have complicated harvesting and post-harvesting operations which are mostly reliant on seasonal workers (Meyers et al. 2006, Bohle, Maturana, and Vera 2010). The selected TGSC consists of three companies that represent: *grower*, *packing-house*, and *exporter* (Figure 3-3). The administration and findings of the case study are presented in Chapter 6.
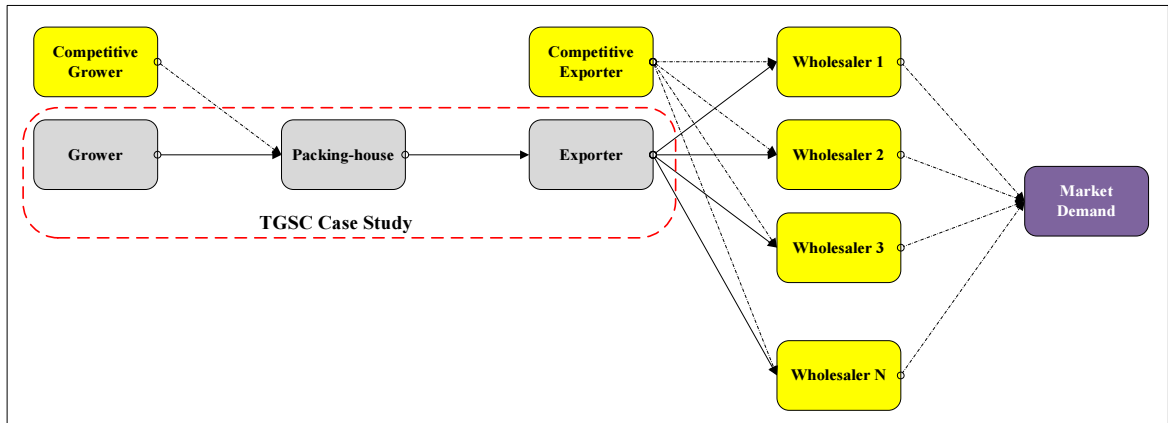
Figure 3-3: Structure of the Table Grape Supply Chain

3.6.3.2 Data Collection

During a harvesting season, multiple site visits were conducted at the premises of the three companies for the collection of the data required to implement the framework for the selected TGSC. During these visits, various data collection methods were employed to gather the data.

3.6.3.2.1 Focus Groups:

A focus group is a data collection method through which a group of participants, who share common characteristics related to the topic under investigation, are facilitated to interact and allows discussions amongst participants take place (Carson et al. 2001). These discussions are conducted many times with the participants to facilitate trends detection and to detect patterns when the data collected is analysed (Saunders, Lewis, and Thornhill 2011). During this research phase, three focused groups were constructed (one in each company) as follows:

Grower group: a grape-growing consultant, a vineyard manager, a staff member and a harvesting supervisor.

Packing-house group: an operations manager, a cold storage manager, a packing supervisor, a quality inspector, and a customer service member.

Exporter group: a customer-orders manager and a logistics manager.

The main purpose of these focus groups was to understand the different levels of operations and activities of each company and to identify the challenges and the planning decisions that face each of them. These groups were also used to determine the resource requirements and how they are acquired. Also, the identification of the important decisions, performance measures and the external factors and their impact were assessed.

3.6.3.2.2 Observations

Observation is a data collection method used to understand a setting (e.g., system or organisation) of interest in a research study. Observation is categorised under two main types: *participant* and *non-participant* observations. The former is used when the researcher becomes part of the setting observed and plays a role as a participant in the ongoing interactions. Non-participant observation, on the other hand, has limited interaction between the researcher and the setting observed, i.e., unobtrusive (Savenye and Robinson 1996). Observations can be used for gathering both qualitative and quantitative data. They can also result in extensive detailed data to find patterns and/ or to test hypotheses derived from other research studies. When observation is used as a data collection method, the researcher has to spend considerable time in the field (Lofland and Lofland 2006). Researchers' can collect observational data using field notes, audio and video recording depending on the research question and analytical method used. Video recording is recommended when the researcher is trying to understand human behaviour and how people are interacting within the setting

observed. Field notes are useful to draw anticipation of activities that can be only obtained from live observations. Field notes could be in structured formats (e.g., templates for measuring cycles) or unstructured formats subject to nature of data being observed (Cohen and Crabtree 2006).

In the context of the TGSC case study, the research was conducted locally at the premises of the three companies on multiple occasions. This allowed the observation of the various processes and the understanding of the workflow and the impact of human resources on the performance of the work activities. Both field notes and video recording were employed for observing a vast group of activities at the three companies as described in Table 3-3. Some activities were observed using video recording to track workflow, human resources behaviour and get timing data for these activities. Both structured and unstructured field notes were used for the other activities to drive workflow understanding for these activities and also to collect data for their processing times. All the collected data was analysed and used to drive process maps for these activities including product flow paths, along with state diagrams for the critical human resources (i.e., seasonal workers). This data was also used to analyse human resources behaviour in terms of processing times, productivities and the resultant loss of resources.

Table 3-3: Observations for the different activities of TGSC

Company	Observed Activity	Observation Method	Sample Size
Grower	Checking bunches ripeness	Video recording for the three activities for one picker until she fills two boxes	5 pickers every harvesting day (total 75 videos)
	Cutting ripe bunches		
	Placing bunches in boxes		
	Loading boxes on carts	Field Notes	87 carts
	Offloading carts on trucks		
	Moving trucks to weighing scalar	Field Notes	36 trucks
	Moving trucks to packing house		
Packing - House	Unloading trucks	Field Notes	36 trucks
	Moving pallets to receive area	Field Notes	139 pallets
	Moving pallets to pack area	Field Notes	42 pallets
	Placing raw grapes on packing tables	Field Notes	95 boxes
	Handling bunches	Video recording for these activities for one packing table until three boxes are filled	Two tables every day (total of 35 videos)
	Placing bunches in punnets		
	Weighing and adjusting punnets		
	Placing punnets in boxes		
	Wrapping packed boxes		
	Moving packed boxes to palletising	Field Notes	67 boxes
	Building and wrapping pallets	Field Notes	190 pallets
	Moving to fast cooling	Field Notes	54 pallets
	Moving to cold storage	Field Notes	81 pallets
Exporter	Moving pallets from storage to loading bay	Field Notes	143 pallets
	Loading Containers	Field Notes	12 containers

3.6.3.2.3 Internal Data Sources

Each company has its own IT department that is responsible for managing databases for recording production data, resources data, customer orders, etc. For the benefit of this research, access was granted to these internal data sources. This provided rich data which was used to analyse the patterns of customer orders received and market demand. Historical data derived from these internal databases proved useful at the phases of simulation model verification and validation.

3.6.3.3 Simulation Modelling

According to the designed framework in phase two, a hybrid simulation-based planning tool was developed to be employed for the TGSC case study. The simulation model incorporated three different modelling paradigms (i.e., ABM, DES and SD) to address the complex and dynamic aspects that exist in AFPSC systems in general and the TGSC case study in particular. However, translating a simulation model that integrates the three modelling techniques into computer software is quite challenging and time-consuming. Therefore, it was decided to implement the hybrid simulation model using a modelling language that is capable of integrating the three techniques in one modelling environment.

Developing a credible and valid simulation model can be done through seven basic steps as presented in Figure 3-4 (Law 2008). During the first step, system boundaries are identified, and the researcher decides the model's objectives, variables, performance measures, parameters and assumptions. In the second step, required data is collected and analysed to develop conceptual models which map the relationships between the system components to be modelled. The conceptual models have to be revised, in step three, with

key stakeholders to ensure their validity before translating them into simulation software in step four. Once the computer model is built, it should be verified and validated in step five. Model verification is required to ensure the correct transformation of the conceptual models while validation ensures that the model successfully reflects the real system behaviour (Balci 1997). Verification and validation are important parts of simulation modelling process as they guarantee the credibility of the model. In step six, the researcher has to design a set of simulation experiments that serve the main purpose of conducting the simulation study, and the design has to include the simulation configuration such as controlling parameters and simulation time horizon. Finally, in the seventh step, the researcher has to document the model, mainly for future use, and then do the analysis of simulation experiments results ending with a discussion around the main findings and presentation of key outcomes. Although these steps inherit logical order, many iterations at various stages may be required before objectives of the simulation study achieved (Maria 1997).
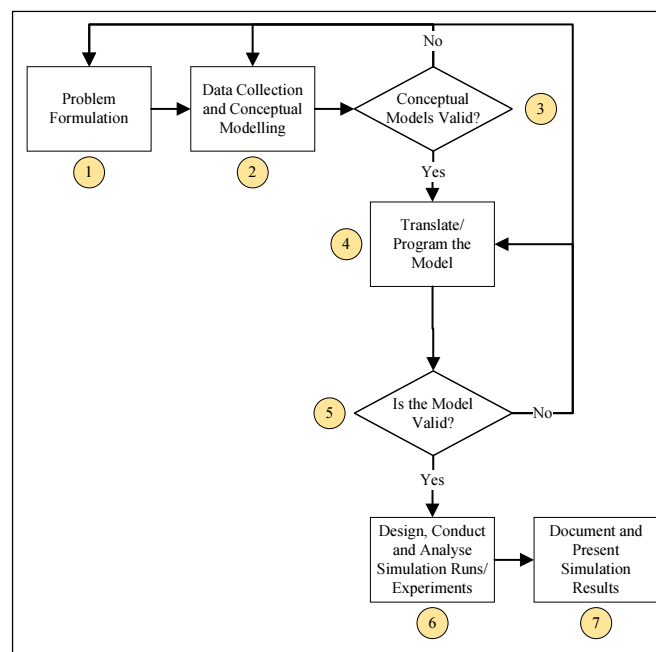
Figure 3-4: Main Simulation Model Building Steps

In this research phase, the researcher conducted the first three steps in Figure 3-4 concurrently with the data collection stage. Both focus groups and observations were used extensively for developing conceptual models for TGSC system components (i.e., process maps, products flow, human agents, feedback causal loops). These conceptual models were validated and refined over multiple iterations, apart from focus groups activities. This was an essential step in the credibility of the simulation model and hence its output. In addition, the extended discussions with the managers of the three companies had resulted in identifying the key decision variables and their alternatives to be considered in step six when simulation experiments were designed.

Once all conceptual models were validated, the model translation step began. As mentioned earlier, it was decided that a multiple-paradigm modelling language would be enacted. For that reason, *AnyLogic* was used for implementing the hybrid simulation model because it provides modelling tools for the development of ABM, DES and SD within the same working environment that facilitate smooth communication between them (Borshchev 2013). Additional benefits from using AnyLogic include its ability to merge all required data for the simulation model in an embedded database with the translated model in one computer software. It also facilitates the building of a graphical user interface (GUI) and the production of graphical dashboards for both decisions and performance indicators considered in the hybrid model. Quantitative data derived from the observations in Table 3-3 along with those extracted from the internal data sources were used to develop a database for the model inputs.

The following step after the successful transformation of the conceptual model into an executable computer model was the verification and validation of that model. The model

output is examined for reasonableness under a variety of settings and of input parameters. Verification was applied to test the model logic by reviewing its output for reasonableness under different configurations of input parameters. Validation was applied by simulation model outcomes with the data obtained during the data collection phase. Apart from the validation that was done during extended discussions with managers of the companies. The model was used, during these discussions, to investigate the outcomes under certain conditions suggested by the managers to test its validity.

Once the simulation model is verified and validated, several predetermined planning decisions and alternatives were used to design simulation experiments to foresee the consequences of these decisions. Hence, many planning scenarios (i.e., planning strategies) for TGSC case were identified to be examined to address the decision makers concerns that were related to these decisions. Depending on the model set up and the number of decisions and their alternatives, the number of potential scenarios and experiments increases significantly due to multiple possible combinations. Following the experimental design, simulation execution runs were necessary to obtain the data, which is used to analyse the simulation outcomes, where performance indicators can be retrieved and compared across these scenarios.

The final step was the documentation and presentation of the final outcomes for the simulation study. Documenting the simulation model is necessary to follow and to understand the simulation results as well as for the planning and decision-making process. The results of the model are vital for the decision maker, so the presentation of these results is important. There are many ways in which simulation results can be presented: written

reports, graphs and diagrams, and animation. A combination of graphs and animation methods was used to *visualise* the simulated processes for the user and to *provide* a graphical representation for the key performance indicators. Moreover, the model replicates all the simulation results in local MS Excel files that can be retrieved anytime for further analysis when needed.

CHAPTER 4: EXPLORATORY STUDY

4.1 Introduction

An exploratory study is designed to identify the underlying elements of AFPSC planning decisions (Figure 3-2). It was undertaken to determine the relationships between industrial processes and evaluate key performance metrics within the agri-fresh produce business. Preliminary information regarding agri-fresh produce planning problems and decision-making process were collected by reviewing the related literature and business reports. This review is followed by the exploration of the practitioner's perspectives through semi-structured interviews to feed into the next phase of framework design. Twelve interviews were held with senior managers and experts of different agri-fresh produce organisations. The study aimed to achieve four primary objectives including;

a. Illustrate the importance of developing a smart planning tool for agri-fresh produce supply chain,

b. Achieve system understanding and explore the main components of agri-fresh produce business and discuss how they are connected to each other,

c. Identify the various business decisions and planning issues that draw the attention of the decision-makers in agri-fresh produce supply chains on the strategic, tactical and operational levels, and

d. Identify the performance indicators that control agri-fresh produce supply chain on the 'whole-chain' basis. The aim is to establish a clear and limited set of performance

metrics that show performance improvement, permit root cause identification and help managers to monitor chain performance continuously.

There are three selection criteria for the interviewees of this study: 1) they have to be managers of agri-fresh produce business that belongs to one of the three entities of the AFPSC within the focus of this research (Figure 4-1); 2) They are willing to provide access to their business premises to facilitate direct observations; and 3) The selected pool of interviewees should cover diverse profiles as shown in Table 4-1. The diversity of participants' backgrounds helped to cover multidimensional nature of agri-fresh produce SC and enrich data collection process to achieve a better quality of study's outcomes.

Table 4-1: Interviewees Profiles

Organisation / SC Entity	Job Title
Grower/ Producer	Growing Consultant
Grower/ Producer	Farms Manager
Grower/ Producer	Field Operations Manager
Grower/ Producer	HR Manager
Processor/ Pack-house	Packing Station Manager
Processor/ Pack-house	Packing Operations Manager
Processor/ Pack-house	Ground Services Manager
Processor/ Pack-house	HR Manager
Processor/ Pack-house	Cold Storage Manager
Processor/ Pack-house	Procurement Manager
Exporter/ Shipper	Logistics Manager
Exporter/ Shipper	Customer Orders Manager

As mentioned before in chapter 3, semi-structured interviews were chosen to allow respondents to express their thoughts in an unhampered manner while keeping a unified outline for the discussion through a group of predetermined questions (Table 4-2) to provide

the basis for analysing the outcomes. The administration methodology of these interviews was explained previously in chapter 3, and the findings are discussed in the following sections of this chapter.

Table 4-2: Interview Pre-Determined Questions

1- Are you familiar with the applications of (M&S) for planning and decision support?
2- Do you use any of these tools while planning for your decisions? If so which tools?
3- What are the central decisions you need to plan for your business?
4- How do you classify them as operational, tactical and strategic?
5- What are the main exogenous factors that have an impact on your business? And how do they impact your decisions?
6- What are the most critical performance indicators you monitor for your business?
7- Does your business rely on seasonal labourer? If so how do they impact on the performance?
8- Do you plan your decisions cooperatively with other partners across the SC?
9- Do you think an integrated planning tool that can reflect the impact of your decisions and other SC members' decisions would be useful?
10- Would you explain the main components and processes of your organisation and how they are linked to the other organisations within the SC? (Open discussion starts from this question)

4.2 AFPSC Structure and System understanding

Multiple structures of AFPSC were identified in the literature of modelling and simulation applications in the agri-fresh produce industry. Many applications focused on the planning for a single SC function (e.g., grower or processor), others have considered supply chain planning across a chain or a network of multiple members and on a macro level. A conceptualised structure of a generic AFPSC is presented in Figure 4.1. This conceptualisation is developed based on information derived from the reviewed literature dataset (Appendix 2), site visits and preliminary interviews with industry practitioners.

AFPSC begins with potted plant nurseries (i.e. where farmers are provided with first planted trees) or input material (i.e. annual inputs are supplied for each production cycle). Growers are usually responsible for planting and harvesting activities. Their products are then transported to the processors (e.g. packing stations or food manufacturing) to conduct activities such as packing and packaging activities. Final products after processing are either sold domestically through local traders or internationally through exporters. Usually, products are distributed to retailers, groceries and/or catering shops via big distribution centres or hubs which received fresh produce products from local traders or exporters. In some situations, governments and NGOs intervene in planning AFPSC for macro-level objectives such secure food demand for a specific crop (Atallah, Gomez, and Bjorkman 2014).
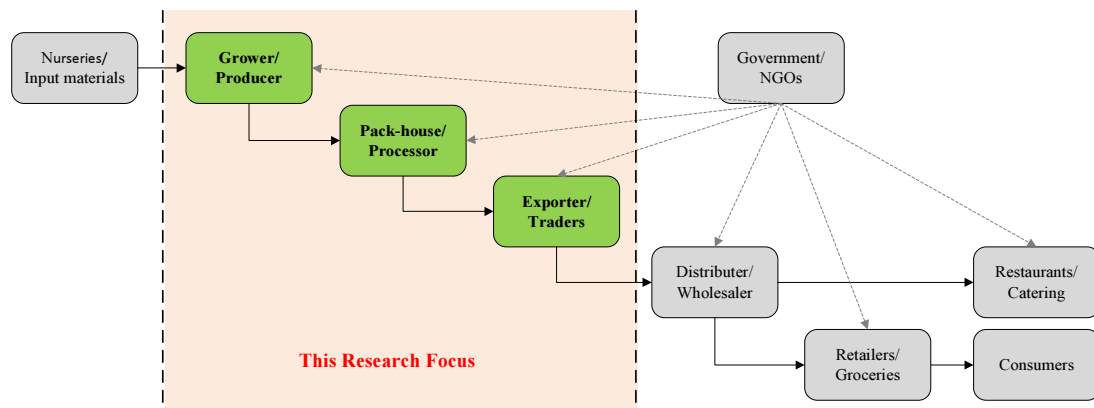
Figure 4-1: Generic Structure of AFPSC

In this research, the focus is on the upstream layers of the AFPSC namely: *Growers*, *Processors*, and *Exporters*. Many reasons motivated the researcher to limit the research boundaries to the three echelons, including:

1- The growers are responsible for harvesting operations (i.e. one of most essential activities in agri-fresh produce industry) that impact the yield and quality of the crops.

2- Post-harvesting activities (receiving, packing and storing) are critical for products freshness and shelf-life preservation. Most of the products losses and quality deterioration result during these activities.

3- Harvest and packing operations are labour intensive. Most growers rely on seasonal labour markets which characterised by high variations in workers skills and experience that alter operations efficiency.

4- Globalisation and fierce competition motivate many growers to sell their products in the international markets seeking for competitive prices.

5- Exporters play an essential role for trading fresh products from growing areas to consumption markets.

6- AFPSC inherits logistics complexities due to the multiple storing, distribution and transportation activities and the tight production lead time.

Also, the research has focused on AFPSC for perineal crops (e.g., grapes and strawberries) because of the longer product life cycle compared to annual and biennial crops. The long life cycle of perineal crops tree increases the AFPSC complexity, particularly on the strategic capacity planning. Considering either replacing or removing old-aged trees or planting new ones are long-term investment decision that has to be planned with demand uncertainties during the long life cycle.

During discussions with the interviewees about the different components that construct AFPSC and how their business is connected with other SC partners, multiple activities were identified at each SC entity along with the main factors that control them. The analysis of these discussions has resulted in various conceptualisation for different perspectives of AFPSC business model. These perspectives vary from the general view of the three echelons AFPSC (the upper level) to the individual activities perspectives (the lower level). The primary conceptual model for AFPSC business model that provides a general view of the three SC actors and their links is presented in Figure 4-2.
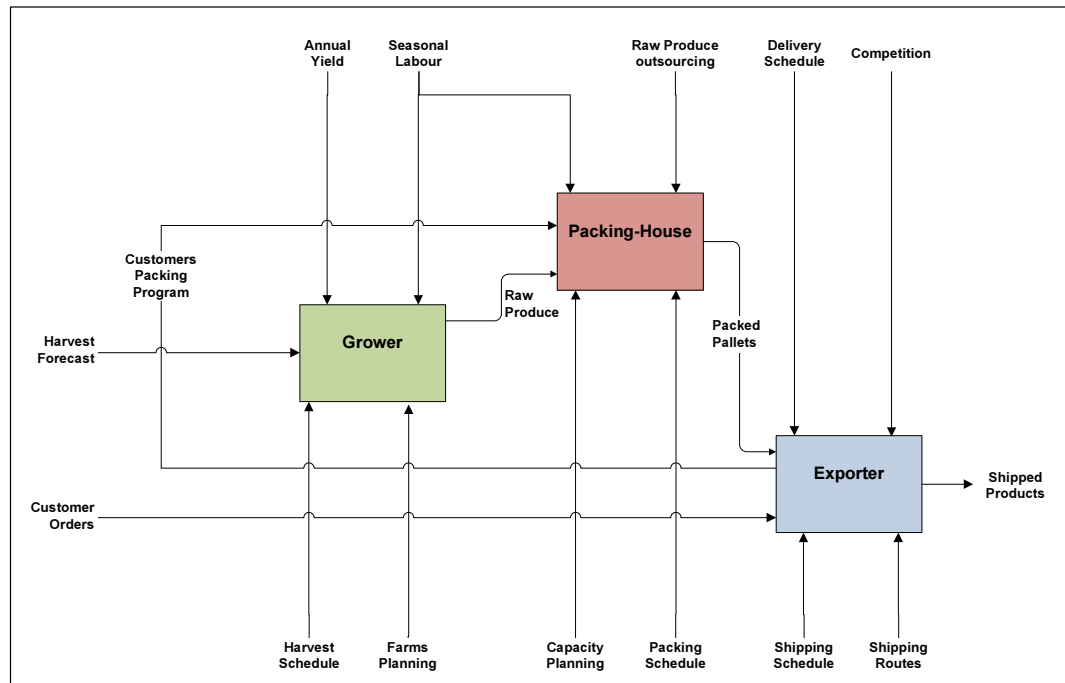
Figure 4-2: AFPSC Conceptual Model (Upper View)

4.2.1 AFPSC System Understanding

A fresh produce grower usually cultivates a specific area of grown trees for a particular crop (e.g., bananas, grapes, etc.). Some growers operate multiple cultivated areas (i.e., farms) for different sorts of products and/or other types of crops. The production cycle starts when

products reach certain ripeness degree subject to product type and its market requirement. The harvest schedule is planned based on the quantities forecast developed by the growing experts in light of weather conditions and field samples. Forecast-based harvesting plans are updated during the harvest operations subject to weather changes and required volume of products. The annual yield varies from year to year according to uncontrollable factors such as weather conditions, trees maintenance and investments in planting new areas. Seasonal labourers are also a crucial factor that impacts the annual yield and harvest efficiency particularly for the products require manual harvesting (e.g., grapes and strawberries).

After harvesting, products are transported to the packing-house where post-harvesting activities (i.e. handling, cleaning, sorting, packing, labelling and storing) take place. In most situations, packing stations should maintain a cold temperature inside the plants. Once products are received from the grower (the upstream partner), packing operations start according to a schedule based on the orders specifications received from the downstream exporter. These specifications include batch size, packaging and labelling requirements and dates of dispatching. Packing house capacity planning relies mainly on resources availability and the capacity of processing areas for different activities. Similar to the grower echelon, packing house operations are labourer intensive in particular when manual processing dominates the packing operations. Outsourcing decision is another critical issue that faces packing house managers. Managers have to plan raw produce outsourcing if products supply from upstream suppliers is lower than the required demand by downstream customers.

Exporters usually receive *customer orders* few months prior the commencement of harvesting season. Acceptance and rejection decisions for these orders are taken depending

on the deviation of the total supply quantities from 1) expected yield of the running season (anticipated by the grower(s)) and 2) expectations for outsourcing quantities in case decision makers want to avoid stock-out situations and customer dissatisfaction. Once orders are agreed with customers, the manager has to prepare customers packing program (i.e., schedule) and send it to the packing house. Then *shipping schedule* and *delivery routes* are determined according to customers *delivery requirements*. Maintaining high customers satisfaction is very crucial for fresh produce exporters to gain a competitive advantage, retain a high market share and, consequently, achieve high profits.

A more in-depth view of the main processes and their inputs (controllable and uncontrollable) for the three SC actors are presented in Figure 4-3.

4.2.2   Grower Processes

Harvesting: Usually harvested products are placed in crates which are first moved to specific collection points then moved to loading points via carts for transporting them to the packing house. The harvest process is mainly triggered by the predicted harvested quantities of that day. This forecast usually indicates expected quantities ready for harvesting and the cultivated area where harvest operations should be carried out. However, the natural ripening of the product is the main determinant for the real quantity that is ready to be harvested. The resources for the harvest process are planned according to forecasted quantities, and their productivity is a function of labourers experience. Products waste may also result due to low skilful workers recruited for the harvest process. This waste can occur if products are harvested before ripeness or because of inadequate treatment by inexperienced workers.
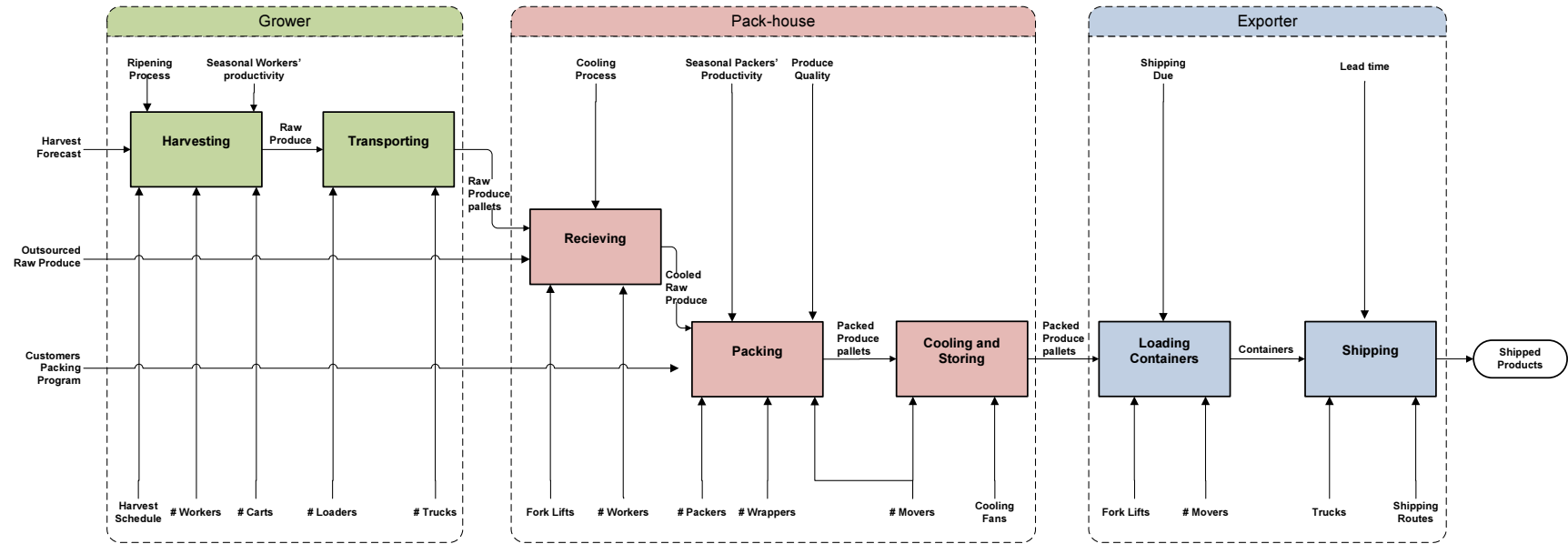
Figure 4-3: AFPSC Process Conceptual Model (Lower View)

Transportation: This process is quite simple and straightforward yet is critical as specific products are vulnerable to damage if exposed for too long outdoors or to environmental stresses such humidity and high temperature. Limited numbers of trucks are available for this process, so if high volumes of produce are harvested, they may have long waiting times before being moved to the packing house. Collected crates are loaded onto trucks by either manual/ or machinery loaders. Often these trucks need to be equipped with cold facilities to reduce products exposure to unwanted environmental conditions. Trucks should be weighed before and after loading to track total harvested products weight.

4.2.3 Packing House Processes

Receiving: When a raw products truck arrives at the packing house, the products are offloaded in an air-conditioned receiving area. Products can be unloaded manually by workers or by forklifts. In many situations, the received products have to wait for a short period to allow cooling of their temperature before the beginning of packing operations. The cooling area in the receiving room is a capacity constraint, and it may cause a severe problem to products quality if the trucks have to wait until space becomes available. As mentioned before this may expose the product to unwanted environmental conditions.

Packing: Packing is the most critical process within the packing house, as it transforms the received produce from the raw state into final products state. Products crates are moved from the receiving area to the packing conveyors or packing tables according to the design of process. Packing process relies entirely on the skills of the packing labourer who work in groups of two to three on packing tables. Packers' skills and experience have impact on their productivity as well as the products waste during packing activities. The quality of the

products that are received from the farm also has an impact on the packing waste. If high quality (i.e., most quantities comply with customer requirements) produce is received, less waste will result and vice versa. During packing process, products are cleaned, weighed, packed into boxes or punnets, and labelled subject to customers' requirements. The final packed boxes are placed on pallets, and then these pallets are moved to a ground processing area for final wrapping operation. Two significant factors impact process capacity. Firstly, the area allocated for the packing activities (e.g., convenors capacity, number of packing tables and wrapping area space), and secondly is worker productivity.

Cooling and Storing Process: Wrapped pallets are moved either directly to final storage awaiting for dispatching orders from exporter side or, in many situations, through some cooling activities to sit pallets temperature at certain limit to preserve products shelf life. The processing time and the capacity of the cooling facilities control the flow rate of the pallets from packing to final storage. Reducing the waiting time to cool the pallets before storing is essential for preserving products quality and shelf-life.

4.2.4   Export Processes

Loading Containers: The shipping schedule and orders dispatching days are planned according to customer order requirements. The lead-times of the shipping also has a significant impact on dispatching orders plans. Usually, fresh products are shipped in big containers via aeroplanes or sea vessels. On any given dispatching day, pallets are moved from the final storage area at packing house to a designated loading dock; then they are placed into the shipping containers.

Shipping: The loaded containers are moved via trucks to the selected shipping route. When matching customer orders, expected delivery date is vital for the shipping process. In some situations, due to the shortage in the number of pallets that match customer orders, delays in actual arrival date can be caused. Some customers may allow limits for early and tardy delivery dates. Failing to match these dates make the whole lot vulnerable to the rejection and returning if failure to redirect it to another customer is achieved. The losses, in this case, are decoupled – products waste in addition to unsatisfied customer. Exporters in such cases have to plan alternative shipping routes that can be fast enough to deliver delayed dispatching orders within accepted limits defined by customers.

4.3 Planning and Decision-Making Practices

During the initial discussion, it was apparent that most interviewees were not familiar with concept of modelling and simulation and how they can support planning and decision-making process for business managers. Only one respondent was aware of some concepts related to optimisation and mathematical modelling and their applications in few agriculture systems as indicated in the following statement.

> *"I have read about few case studies where mathematical models were used to plan operations scheduling for some crops in South Africa."*

Most of the managers indicated that they usually rely on few primitive models by using Microsoft Excel spreadsheets and/or Microsoft Access. By describing these models, it is evident that they are mostly used to track business performance and are used as historical reference to evaluate many decisions, which are usually made based on a trial and error concept and gaining experience from repetitive actions.

> *"As we [Grower] rely on local, seasonal pickers whom skills and experience levels are not consistent, and also the quantities we harvest differ from day to day, and we face some difficulties to determine the number of pickers to hire each day. At the beginning of season, we use historical records for similar days and situations in previous seasons as reference for this decision. Then after few weeks of tracking both numbers of pickers and quantities harvested, we can define an indicator for average picker productivity, based on that the number of pickers to recruit next working day is decided."*

While the strategy explained in the previous statement can work for some short and mid-term decisions (i.e., operational and tactical), it may fail in long-term decisions such as building new packing plants and/or expanding the cultivated area.

> *"The fact that most of the fresh produce products are based on perennial trees which are long-term investments and usually have long gestation periods from time of planting till time of the first harvest. Analysis of demand patterns and market needs is the only aid we can use when we study such decisions. There would be high risk in these decisions, particularly if demand declined for any reason, in this case, we would face a serious problem as the product cannot be stored for a long time."*

The statement above supports the view within the literature of AFPSC planning models arguing that strategic decisions with the agri-fresh produce business require comprehensive understanding from the managers to the various production cycles of the perennial crops and analysis for supply and demand responses to determine the profitability (Devadoss and Luckstead 2010).

Similarly, the managers of the processing units (e.g., packing stations), indicated that the simple spreadsheet models are not helpful for planning strategic decisions. For example, they always think about expanding the capacity of their business, especially during high season periods when products wait for long time to be processed. Long waiting time for

processing in many cases may result in quality loss and products spoilage. However, the decision to expand the processing unit capacity is risky due to many reasons that include: 1) high cost and long-term investment, 2) vulnerability to low capacity utilisation if the products flow drops either from the upstream or downstream sides.

> *"Of course, an exploratory tool that can analyse the operational performance of the processing unit under different capacity expansion alternatives simultaneously with different supply and demand scenarios would be helpful for planning such strategic decision."*

The statement above was a sample response from a fresh produce packing house manager. When he was asked how useful he believes a simulation model would be helpful for such strategic decision.

4.3.1 Planning Decisions

Although not all interviewees were aware of the terms operational, tactical and strategic for planning decisions classification, they became able to position their decisions under these categories when the researcher defined them and explained their differences. Many of the decisions identified by the interviews – were addressed before in the literature. Overview of these decisions and the planning challenges are discussed in the following sections. All the decisions over the different planning levels will be summarised over three SC echelons (growers, packers and exporters) in a conceptualised diagram at Figure 4-4.

4.3.1.1 Gower Decisions

In AFPSC, growers are responsible for producing and supplying fresh produce products to the downstream partners. Vast range of issues have to be planned for this echelon at different decision-making levels;

4.3.1.1.1 Operational Level Decisions:

At this level the grower usually plans for the following decisions:

1- A number of workers for daily operations (Bohle, Maturana, and Vera 2010).

2- A number of carts to move harvested products to trucks (Lamsal, Jones, and Thomas 2016).

3- Number of trucks to transport harvested products (Soto-Silva et al. 2017).

4- Resources distribution over operations (Ferrer et al. 2008).

5- Daily harvest volumes (Nagasawa, Kotani, and Morizawa 2009).

Planning Challenges:

At this level, operational managers face challenges that might undermine the efficient planning of these decisions. The most common problem is the seasonality of the production that leads to relying on seasonal labour markets. Heterogeneity of seasonal labourer skills, high turnover rate, and uncertainty of availability at time of recruitment are the main drawbacks of seasonal labourers recruiting. Besides, the fierce competition between the growers to hire skilled workers affects the consistency of labour supply. These challenges frequently alter the consistency of workers' productivity, which impact managers' ability to plan for the number of recruited labourers and their best work capacity. Inconsistent labourer

productivity may lead to hiring either too many or too few workers for the expected work volume.

In addition to the labourers' recruitment challenge, many fresh produce products are vulnerable to damage or quality loss if they get exposed for a long time to specific environmental conditions (e.g., high temperature or humidity). Therefore, managers have to keep a short cycle time for moving the harvested products from the farm to packing house. This requires excellent planning in logistics performance, their resources (i.e., carts and trucks) and harvest volumes decisions. However, for some product types, the dynamics of the biological ripening process undermine the ability to set effective planning for daily harvest volumes. This is indicated in the following statement by a fresh produce growing expert:

> *"Some products can be harvested before they reach the desired consumption ripeness level, they are called climacteric products. The biological ripening process for these products continues after they are harvested, this provides the SC actors with time buffer to perform multiple postharvest and logistical activities during this biological activity. Other products have more complicated ripening process, and these products are called non-climacteric products. The ripening process for these products stops once they are harvested, therefore they have to be harvested at the desired consumption ripeness level. This adds extra pressure on the SC actors, as all the postharvest and logistical activities should be applied very quick and under certain environmental conditions to preserve the products quality and consequently their shelf-life."*

For non-climacteric products, the quantity of the produce that reach the desired ripening level is uncertain and inefficient planning for logistical resources can result in either low utilisation if volumes are below expected or over utilised and severe unwanted waiting times for the

harvested produce. Uncertain amounts of ready to harvest produce also impact the efficiency of planning harvesting resources, and would lead to low harvesting throughput. In this case, actual harvest quantity will be lower than the ripe quantity consequently it may become over-ripe and ultimately spoiled.

4.3.1.1.2 Tactical Level:

At this decision level the grower usually has to plan the following set of decisions:

1- Harvest Schedule Program (Caixeta 2006).

2- Seasonal Hiring Policy (Wishon et al. 2015).

Planning Challenges:

Few challenges face growers when planning for these two decisions. To some extent, these challenges are connected to those mentioned at the operational planning level. Harvest scheduling programs define the roadmap for the daily harvest operations for all cultivated blocks over the whole season. They include the date and time of harvesting for each block, number of harvest cycles, and quantities to be harvested. All these elements are determined based on the forecast of harvested quantities that is prepared by a growing expert analysis relying on the weather conditions and field samples for ripeness testing. Forecast accuracy is dependent on weather stability which in turn impacts the biological ripening process. Therefore, the harvest program is revised and updated periodically and accordingly the harvesting schedule plan.

During harvesting, seasonal labourers are usually recruited from local villages surrounding the production regions. In some situations, these labourers may be acquired from

different local regions or even from outside the country (Wishon et al. 2015). Growers can hire labourers either by open hiring call during season and accept them according to farms demand, or through hiring agencies or contractors. Setting the hiring policy at the beginning of season is important because 1) the manager wants to secure the farm's needs in regards to manual labourers; 2) the labourers' impact on operations efficiency; 3) hiring and operational costs and 4) preserving labourers experience and reducing training efforts. Fierce competition with other growers for skilful workers, high turnover of workers and supply inconsistency are vital factors that challenge managers when planning for seasonal labourer hiring policy.

4.3.1.1.3 Strategic Level

At the strategic level, grower has to plan the following issues:

1- Trucks and Carts fleet formation (Govindan et al. 2014).

2- Old aged cultivated area maintenance (Devadoss and Luckstead 2010).

3- Capital Investment (Govindan et al. 2014).

Planning Challenges:

Planning the capacity of carts and truck on a daily basis are two operational decisions which impact the transportation cycle time from and to packing house. At the strategic level, the grower has to decide how these resources will be recruited. Multiple alternatives were identified by the interviewed practitioners including 1) renting cost on a daily basis; 2) renting cost on seasonal basis; 3) purchasing grower's owned trucks and carts and 4) mix between the different alternatives. The decision is considered strategic because of the long-term investment embedded in the third alternative. The poor planning of purchasing tracks and carts would result in high investment cost and low resources utilisation.

Perennial crops have extended production life cycle, at the end of this cycle (old aged trees) the production (i.e., yield) begins its decline until it stops completely. By that time, the grower has to plan what to do next. Two alternatives are available: first, remove the whole aged area and use land for any other purpose or, second, maintain the old aged area by planting new trees. These newly planted trees have a gestation period that may be extended for one to three years until they start production. Similarly, a grower may need to plan for expansion of the production capacity by capital investing in buying and reclaiming more land for planting new areas. Both maintenance and capital investment decisions have a long-term impact on the whole SC. Crucial analysis for demand and price trends and market dynamics is essential for an effective strategic planning. Expanding or reducing production capacity is a critical decision for growers' profitability, particularly if demand has become above or below grower's expectations.

4.3.1.2 Packing House Decisions

Packing process is located at the core of the AFPSC operations and determines, to a great extent, the efficiency of SC and the quality of the final product. Packing houses are responsible for postharvest activities and transform harvested produce from raw status into packed products. A vast range of decisions has to take place for this echelon of AFPSC at different planning levels.

4.3.1.2.1 Operational Level

At this decision-making level the grower usually has to plan the following set of decisions:

1- Number of workers in the packing stations

2- Number of ground services workers

Planning Challenges:

The primary role of the packing house is to change the status of the received raw produce into packed products which meet consumer requirements. Ground service workers are responsible for various activities including receiving and handling the fresh products at the packing station, lining up packed boxes onto pallets, wrapping pallets and finally moving them to cooling facilities and ultimately cold storage. Packing workers are assigned to packing conveyors or tables to perform multiple tasks that may include: 1) visually inspecting the produce, 2) removing any defective items, 3) sorting and grading products, 4) adjusting the weight to match packaging specifications, 5) stacking products into boxes, and 6) sticking labels to these boxes. Accordingly, their role has a significant impact on the station's productivity, product losses, and products quality. Due to the high workload during harvesting season, packing houses rely on seasonal labourers. The same challenges that are mentioned in the grower's echelons regarding recruiting seasonal labourers are applicable here. The inefficient planning for the workers' capacity would result in either low utilisation and high operational costs or overutilization and long waiting time for the products in the receiving area, which alter the shelf life and results in product losses.

4.3.1.2.2 Tactical Level

At this decision-making level the grower usually has to plan the following set of decisions:

1- Seasonal Hiring Policy

2- Packing Schedule (Orjuela-Castro, Herrera-Ramirez, and Adarme-Jaimes 2017).

3- Outsourcing Policy (Willem, Roberto, and Jack 2014)

Planning Challenges:

The planning of packing operations and its time scheduling is entirely different from harvesting schedule. However, the latter has a more significant impact on the former, as the planning of packing station should consider the efficiency of product flow from the grower side. On the other hand, customer requirement is a factor which impacts the planning of the packing station. This schedule should indicate the work volumes over the season to meet customer orders in the due dates. The low inflow of raw produce quantities to the packing house put it at risk of inability to secure packed quantity demanded at any dispatching day. That may impact the planning for products outsourcing policy.

In some situations, the annual product yield expected from growers is lower than the total promised quantities for customers. Hence, outsourcing the gap between supply and demand becomes a critical decision to achieve customer's satisfaction. During the discussions with the interviewees, the managers explained why in some cases they are forced to accept customer orders that exceed the expected supply of the products and take the risk of outsourcing unavailability during harvesting season.

"Keeping strong relationship with our customers (great fresh produce procures in European market) and make them satisfied, sometimes force us to accept orders with

a volume higher than expected supply by our upstream partner(s). However, the embedded risk of outsourcing unavailability or high prices of the outsourced products might have significant impact on our profits."

The managers at the packing house are then required to plan for their outsourcing policy to bridge the supply gaps. This policy is critical to securing required packed orders at their dispatching days; hence arrival delays will be minimised, and customer will be satisfied. Therefore, uncertainties for outsourcing availability and products losses rate during packing operations have to be considered when planning this policy.

4.3.1.2.3 Strategic Level

Only one decision was identified for this planning level for the packing house:

1- Packing House Capacity Design (Maia, Lago, and Qassim 1997).

Planning Challenges:

The capacity design of the packing station has two elements, the first is the resource productivity level, while the second is the capacity of the physical space (i.e. facilities) where these operations take place (e.g. capacity of receiving area, packing tables, cooling facility and cold storage). Expanding the physical space of the packing house is a high cost and long-term investment decision. Hence, an efficient analysis of the supply behaviour and the anticipation of the future demand trends are critical to ensuring cost efficiency and avoiding low utilisation. Exceeding any of these constraints would result in a long cycle time for the different processes and may alter orders delivery due dates.

4.3.1.3 Exporter Decisions

The exporter is vital for the AFPSC as they play an intermediate role between upstream (i.e., grower and packing house) and downstream (Distribution centres/ Wholesalers) SC members. The exporter is responsible for marketing the local growers' annual yield to international markets. Planning requires logistics regarding the movement of products from growing areas to consumption markets. This is one the core responsibilities of the exporters.

4.3.1.3.1 Operational level

At this planning level, the manager has to plan two critical decisions for every dispatching day:

1- Number of loading workers

2- Number of orders to ship (Su, Wu, and Liu 2014)

Planning Challenges:

Loading workers are required to take packed pallets from the cold storage and pack them into shipping containers. Sometimes the manager might delegate these tasks to the packing house ground services workers if the working load inside the packing house allows. Otherwise, they have to be hired prior to any determined dispatching day.

The number of orders to dispatch is usually in compliance with the agreed customer orders delivery schedule. However, there may be a shortage in items available in the storage to cover these orders. Then it has to be decided which orders are to be released and which are to be postponed. This is a difficult decision and should be planned to minimise violating delivery dates as much as possible. However, the opposite situation may also arise when the

storage is full (or almost complete), and some space needs to be freed for new packed pallets. In this case, the manager has to release some orders earlier than the planned dispatching date. Again, deciding which orders to release is critical, as early delivery of orders is not always accepted by customers as it may clash with their plans for distribution within the SC.

4.3.1.3.2 Tactical Level

At this decision making level exporters usually have to plan around the following three factors:

1- Orders Acceptance Policy (Grillo et al. 2016).

2- Orders Shipping Schedule

3- Shipping Routes (Gigler et al. 2002)

Planning Challenges:

The annual yield of fresh produce crops varies from season to season. This is according to many biological factors and weather variations. Conversely, the demand is subject to uncertainty due to changing consumption patterns, prices, and fierce competition with either local or international exporters. All these factors undermine order volumes (demand) that match the expected production volumes (supply). If the supply exceeds the demand, the exporter will accept all incoming orders, and the difference between supply and demand will be marketed and sold locally at lower prices. The other case, when demand exceeds the expected supply, the outcomes are more complicated, as the short supply have to be outsourced from local growers adding extra-costs to the SC beside the risks of availability if the exporter decides to accept orders that exceed the supply. Failure to satisfy agreed customer orders (in terms of quantities, qualities and due dates) is significant to the whole

SC and make it vulnerable to lose potential customers for next season, besides the financial losses of the current one. However, rejecting incoming orders also affects customers' satisfaction and halt the SC ability to either attract new customer or retain the existing one. Therefore, the balance between acceptance and rejection of customer order has to be planned carefully.

Most customer orders include the quantity required and the date of delivery. All orders are received a few weeks before the harvesting season when expectations for the product flow to the packing house are available based on growers' forecasting. These expectations, in addition to actual flows of previous seasons, are the reference for exporter to negotiate the delivery dates with customers to avoid any possible violations during the season. Deviation of expected inflows to the packing houses from grower's forecast or long cycle times for packing processes inside the packing house due to capacity constraints are among the challenges that face exporters to plan orders dispatching dates and shipping schedule.

One the core tasks for exporters is the shipment of the final products to customer locations. This can involve maritime vessels, air shipping, or land travel by trucks or trains. Most of the shipping means used for AFPSCs, especially between different continents, are maritime and air shipping. Although the latter is faster than the former, the cost difference encourages exporters to rely on maritime shipping. However, in some situations, delayed orders cannot afford long lead-times of maritime shipping, so air shipping is used instead, the following statement by logistics manager supports that:

"Of course maritime shipping is far cheaper than air shipping, but long lead-times require good planning for orders dispatching from the packing house, otherwise delays will be expected and we will be forced, in many situations, to use air shipping and afford losing the profit margin in some cases to meet the delivery due dates to keep customers satisfied"

Therefore planning surrounding shipping routes is critical for customer satisfaction and for logistical costs. Uncertainties such vessels delays or unavailability of airlines when needed may impact this decision. This decision should be planned simultaneously with the customer orders shipping schedule, as the two decisions are connected, and the selected shipping routes will influence planning orders dispatching dates.

4.3.2   Key Performance Indicators

Performance indicators in any organisation are the mirror which reflects the efficiency of the planning and decision-making process within this organisation. The choice of AFPSC indicators will typically reflect the balancing of financial and operational with customer service, in terms of orders on-time delivery and products quality. Recent initiatives such as sustainability and corporate social responsibility (CSR) along with consumers' awareness encouraged some decision makers to consider performance indicators connected to business impact on the environment or the society (Chapter 2).

During interviews discussions, surrounding managers of agri-fresh produce business organisation and how they evaluate their decisions, it was clear that profit and financial considerations come at the top of their interests. The following statement is an interviewee's response which supports that.

"The main objective of our business [Fresh Produce Exporter] is to achieve the height profit and return on investment, even if other non-financial factors, such customer satisfaction, produce quality, and workers' performance are considered during planning, that will be because of their ultimate impact on one financial factor. For example, our keen is to keep customers happy is to keep sustainable relationships with them to ensure demand continuity and ultimately keep the business profitable."

The mapping between each decision and the performance indicator(s) it impacts was not easy for all the interviewees. This was mainly due to the complex systems and segregation between decisions which are taken simultaneously, and their reflection on the performance is quite tricky. For example, a grapes grower on any harvesting day has to decide the number of trucks and carts. However, evaluation of the two decisions at the end of the day will be based on operational costs; quantity moved to packing house and quantity wasted due to exposure to high temperature. In-depth process cycle time monitoring and analysis of the two resources are required to assess each decision individually and identify which of them is responsible for the long waiting times for products. A more in-depth analysis of the predecessor activities (i.e., harvesting) may indicate that the problem source is another decision (e.g., number of pickers) as high rate of picking grapes will accelerate accumulation of harvested products resulting in long waiting time for transportation.

Despite direct linkage between the different decisions and performance indicators being quite tricky, the temporal classification of these indicators over the three planning levels was apparently easier. Each manager was able to identify the frequency of tracking the performance indicators, and some indicators are monitored: 1) on a daily basis (i.e., operational indicators); 2) at the end of season (i.e., tactical indicators); and 3) over multiple of seasons (i.e., strategic indicators). The key performance indicators (KPIs) for the three

AFPSC entities are summarised in table 4-3. The indicators are classified, in this table, across the three planning levels besides a sub-classification over the identified performance indicators in literature (Figure 2-4). Due to less interest in indicators related to environment, this category was excluded.

Finally, a conceptual decision-making model that demonstrates the planning and decision making aspects for AFPSC is presented in Figure 4-4. This decision-making model along with the AFPSC structure conceptual models (Figure 4-2 and 4-3) are the pillars that were used to develop the proposed framework for AFPSC integrated planning, which is explained in detail in Chapter 5.

Table 4-3: Key Performance Indicators for AFPSC

		Operational	Tactical	Strategic
Grower	Financial		**Costs (Hiring, Logistics, Waste) – Revenues**	**Maintenance and Investment Costs**
	Operations	**Utilisation –Transportation Cycle Time – Worker Productivity**	**Total Waste – Annual Yield**	**Production Capacity**
	Customer			**Over/ Below Supply**
	Quality	**Harvested Produce Waiting Time – Produce Ripeness**		
Packing House	Financial		**Costs (Hiring, Price, Outsourcing, Waste) – Revenues**	**Investment Cost**
	Operations	**Utilisation –Processes Cycle Time – Worker Productivity – Packing Service Level**	**Packing Waste – Annual Yield**	**Packing Capacity**
	Customer		**Orders Service Level**	
	Quality	**Packing Quality – Products Waiting times**		
Exporter	Financial		**Costs (Hiring, Logistics, Price) – Revenues**	
	Operations	**Order Cycle Time**		
	Customer		**Orders Earliness and Tardiness – Customer Satisfaction**	**Demand Stability**
	Quality		**Shelf-life**	
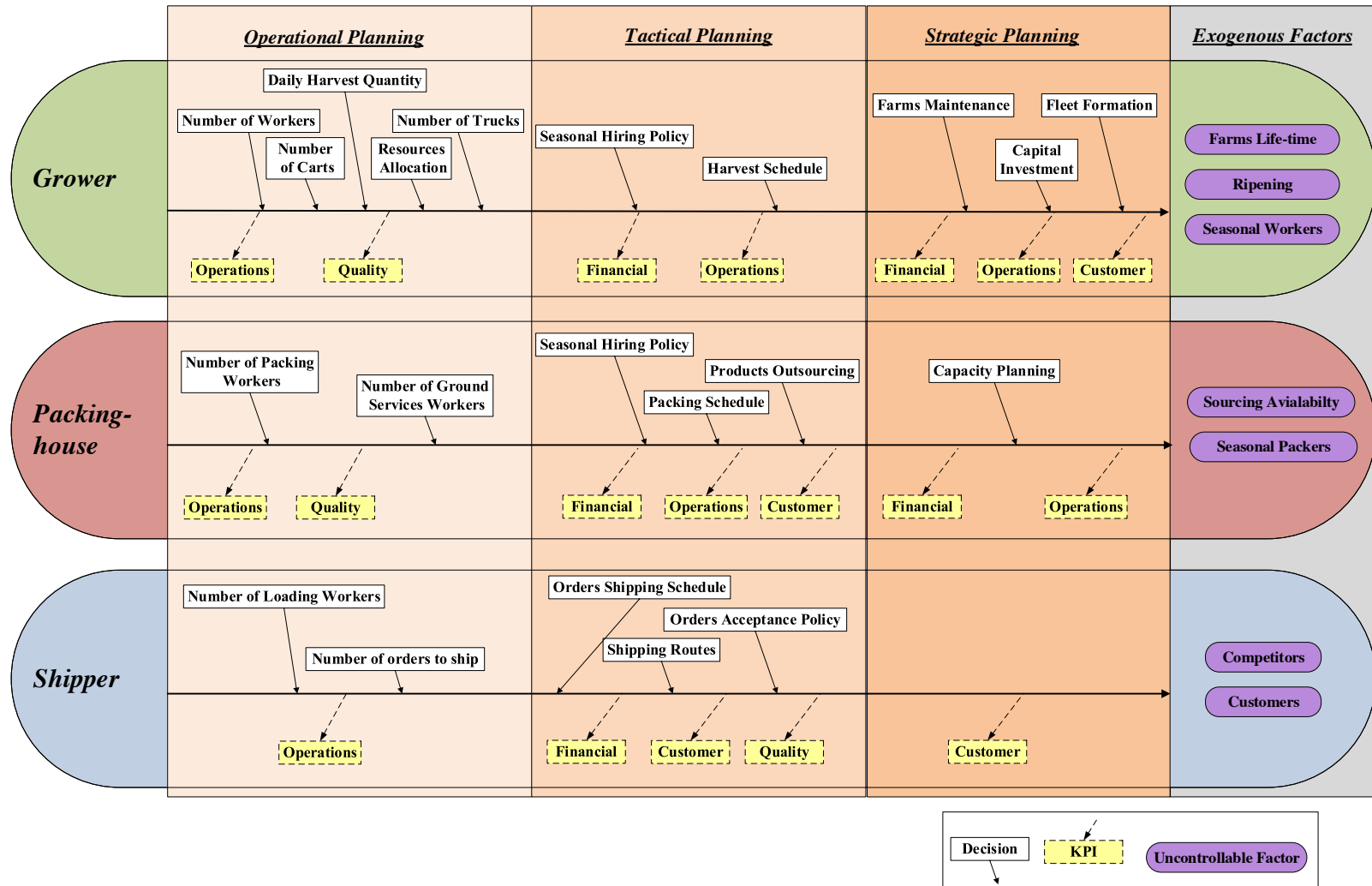
Figure 4-4: AFPSC Decision Making Conceptual Model

CHAPTER 5: THE PROPOSED FRAMEWORK

The main objective of this research is to develop a decision-making framework for AFPSCs based on a hybrid simulation technology. This chapter discusses the framework's structure and parameters based on Figure 5-1. The different components of the framework and their coordination, linkages and points of integration will also be introduced and explained in detail.

Compared to other types of crops (i.e., annual and biennial crops), the perennial crops have trees with the longer life cycle. They have long gestation intervals between planting and crop yield. This does planning for planting or replacement of trees more complicated than the other two crop types, due to the inherited dynamics. Therefore, the framework developed in this thesis targets the AFPSCs for perennial crops. However, this does not affect its generalisability over the other types of crops. The parameters associated with the farm dynamics component of the framework (Figure 5-1) would adjust the framework to any agri-fresh produce crop according to their values that are related to the crop characteristics.

The framework is developed for three echelons of the AFPSC, namely ***grower***, ***processor/packing house*** and ***exporter***. Growers are usually involving in the planning of planting and harvesting activities, which play a critical role in determining the annual yield of crops and farms production capacity. Exporters, on the other hand, are responsible for receiving customer orders, the dispatching schedule, selecting transportation means and routes that optimise product flow within the supply chain network. An intermediate role between growers and exporters is played by packing houses, where harvested products are

moved from the grower's side to be processed and packaged based on exporters requirement. In the packing-house, managers usually focus on optimising resources capacity, labourers schedule, layout design and raw material supply targeting to create a trade-off between process efficiency and customer satisfaction level.

Furthermore, the framework can be applied to various kinds of agri-fresh produce supply chains. It provides an effective planning tool for non-climacteric products (where harvesting operations are conducted based on products ripening), climacteric products and perennial and non-perennial crops.

Figure 5-1: The Structure of the Proposed Framework

The changes in product types result in different system configurations and diversity in business process structure and decisions. While harvesting operations, in the case of non-climacteric products, rely on the level of ripeness of products, climacteric products can be harvested unripe and stored unprocessed in the packing station. This provides an extended time span for the packing and shipping activities of climacteric products compared to the short shelf-life time in the case of non-climacteric products. Also, non-perennial crops are characterised by short production life cycle (one or two seasons in most cases), when it is not necessary to examine long-term investment decisions (e.g. planting new areas), in contrast to perennial crops (e.g. grapes).
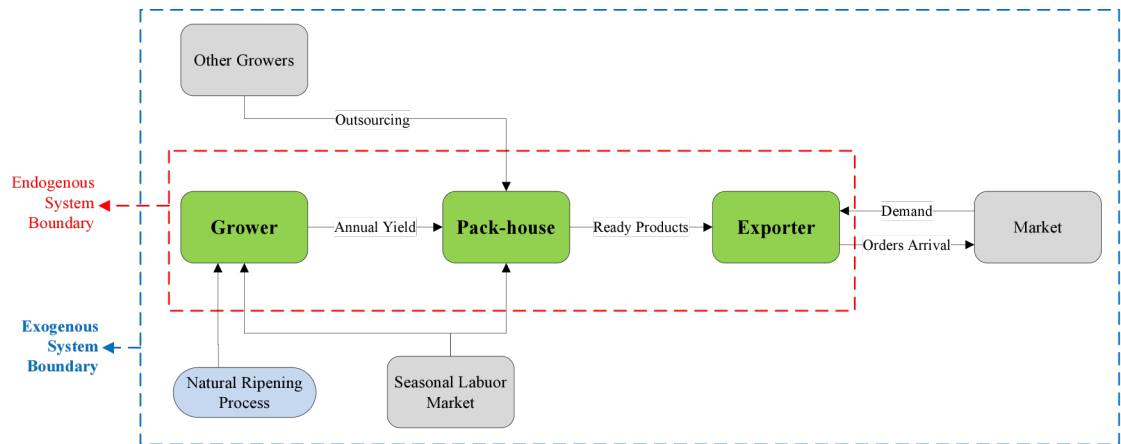
Figure 5-2: Modelled AFPSC Structure

The fundamental idea behind the framework is that it can be used for modelling centralised or decentralised AFPSC networks. In the latter model, the user can be a manager for one of the three SC entities (i.e. grower, processor, or exporter) and uses the model to plan business decisions while monitoring only the set of KPIs that belong to his own business. Meanwhile, the user can, simultaneously, explore different scenarios for the business of other entities. In the centralised planning model, the model can be used for planning the overall supply chain

rather than individual entities. In this case, the decisions can be coordinated for the benefit of ultimate SC performance.

Under both planning models, the framework allows the examination of the impact regarding possible scenarios for both endogenous and exogenous boundaries (Figure 5-2). Endogenous boundaries contain supply chain controllable variables (e.g. working hours, number of shifts, labourer's capacity, operations rules, and transportation capacity), while exogenous boundaries include uncontrollable ones such as outsourcing availability during harvesting season, products price and customer demand. AFPSC contains an elevated level of complex interactions between both endogenous and exogenous variables. The level of complexity is compounded when delayed impact of these interactions exist. For example, in perineal crops, planting new areas will have a delayed effect on the supply due to the gestation period (2-3 years in some cases) between the time of planting and time of harvesting. These interactions create complex and dynamic behaviours within the supply chain which cannot be mapped using traditional mathematical models or a single simulation paradigm. Therefore, integration between Agent-Based Model (ABM), Discrete Event Simulation (DES) and System Dynamics (SD) is found to be necessary to this research in order to model supply chain dynamics and complexity. This integration enables the proposed framework to address different planning aspects and decision-making scenarios in the studied AFPSC entities.

In the following sections, a detailed explanation of the framework components for each supply chain entity is discussed.

5.1 Decision-Making Model of Grower Entity

Making the right decisions regarding planting and harvesting operations for growers lead to ultimate success for a SC. The proposed framework includes a variety of decisions and operations scenarios to be evaluated for the grower across different planning levels (i.e. strategic, tactical and operational). These decisions, scenarios, and key performance indicators (KPIs) are presented together in a decision-making map for the fresh produce grower (Figure 5-3). The map illustrates the interrelationships between growers' decisions, KPIs and exogenous variables. The different components of the grower's decision-making map and an explanation of the selected modelling paradigm for each component are presented in the following sections.
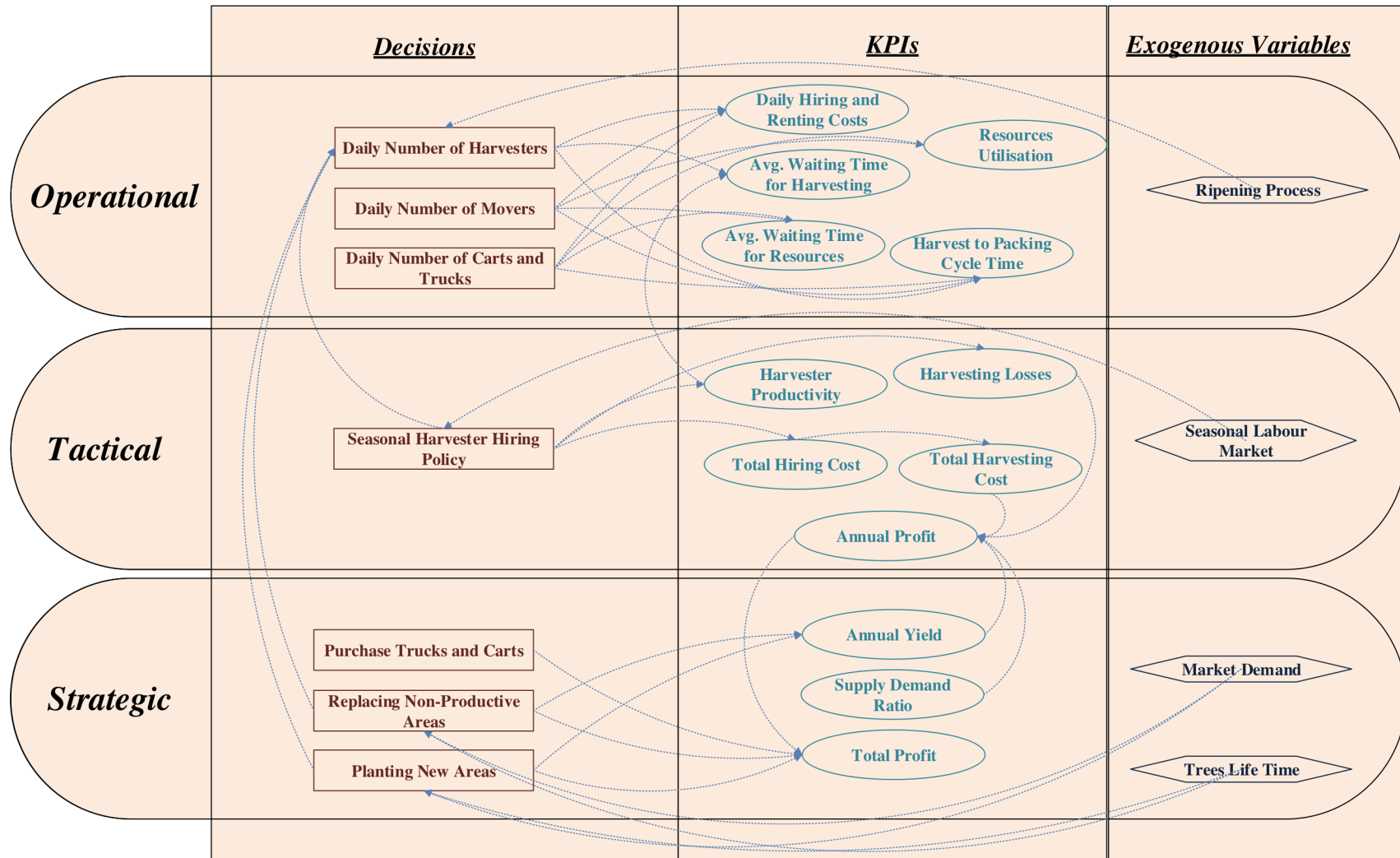
Figure 5-3: Fresh Produce Grower Decision Making Map

5.1.1 *Harvest Operations Component*

Harvesting operations usually rely on products ripeness level in the case of non-climacteric crops. However, the natural ripening process is not homogenous either for a single tree nor the entire orchard. This means that products of a single tree do not become ripe simultaneously. The products of a single tree become ripe gradually over time according to the pattern in Figure 5-4 (Widodo et al. 2006). These patterns may vary from one product type to another, in order to define the fresh produce harvesting point of a particular orchard, the associated ripening or maturation characteristics have to be analysed. Realistically it is quite challenging to identify precisely the amount of produce ready to be harvested in orchard trees. Hence, growers usually rely on examining the ripeness level on samples from the trees to estimate the amount of harvest the next day. So, the starting point in simulating harvest operations in the proposed framework is to simulate the "*estimated harvest quantity*" for the next working days. This can be done by simulating the rate of daily ripening of unharvested units on each tree (Figure 5-4(b)).

(a)   (b)
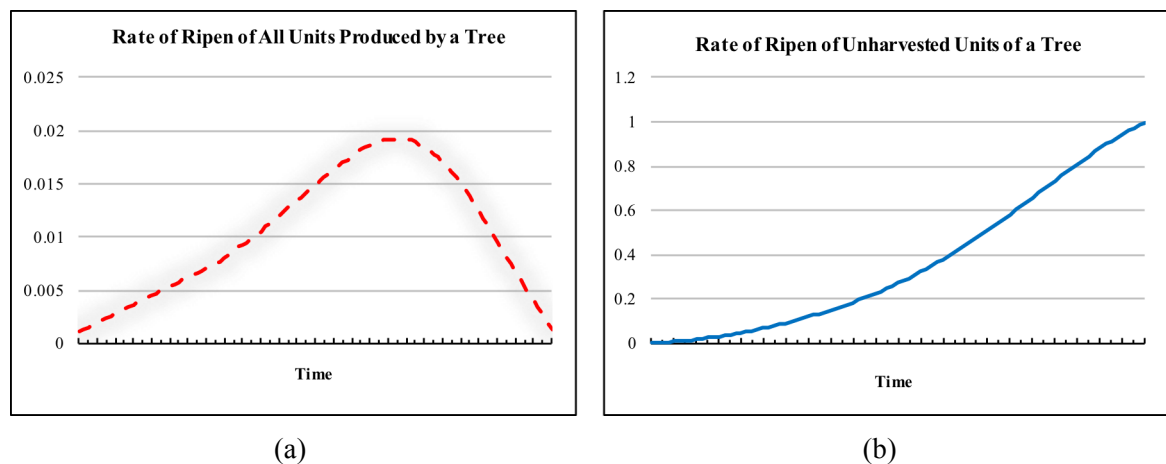
Figure 5-4: Illustrative Curves for Fresh Produce Products Ripening

In the framework, there exist five building blocks for the harvesting operations component (Figure 5-5). The *"Simulate Daily Ripe Units"* block is responsible for generating daily ripeness units on the trees of the farms. These trees are modelled as static agents, and every day a specific number of produce units become ripe on each tree. Based on the ripeness units on all trees of the farm(s) an estimate for harvest quantity of the day is calculated. Accordingly, *"Seasonal Workers Recruiting"* determines the number of workers needed to handle harvesting these volumes. Each worker is modelled as an independent agent with a set of special characteristics that can vary from worker to another in order to reflect experience and skill variations of the seasonal labourers. The recruited workers move to the next block, *"Start Harvest Operations"*, and start harvesting the products following a built-in state chart for each worker agent. Once the harvesting day is finished, a set of variables and performance indicators are updated on both farm and individual worker levels in *"Update Farm Metrics"* and *"Update Worker Metrics"* blocks respectively. Afterwards, another simulated harvest day is triggered if there still unharvested units in farms.

1- Simulate Daily Harvest Units Block: the estimated grower's harvested quantity $(\widehat{Q}_h^G)$ is the main driver for the number of seasonal workers that need to be recruited on any given day. This quantity can be calculated based on simulated ripened units on all the trees in farms using the following equation:

$$\widehat{Q}_h^G(t) = w \cdot \sum_i^n R(t) \cdot U_i(t) \tag{1}$$

Where t is simulation time (days), w is average fresh produce unit weight, n is the number of trees in farms, U is the number of unharvested units on each tree, and R is daily rate of ripening for un-harvested units. This rate can be simulated using the following equation:

$$R(t) = r_1 \cdot e^{r_2 \cdot t}$$

(2)

Where both r_1 and r_2 are positive parameters that can be estimated based on historical figures for harvested quantities from collected data (Section 5.5).
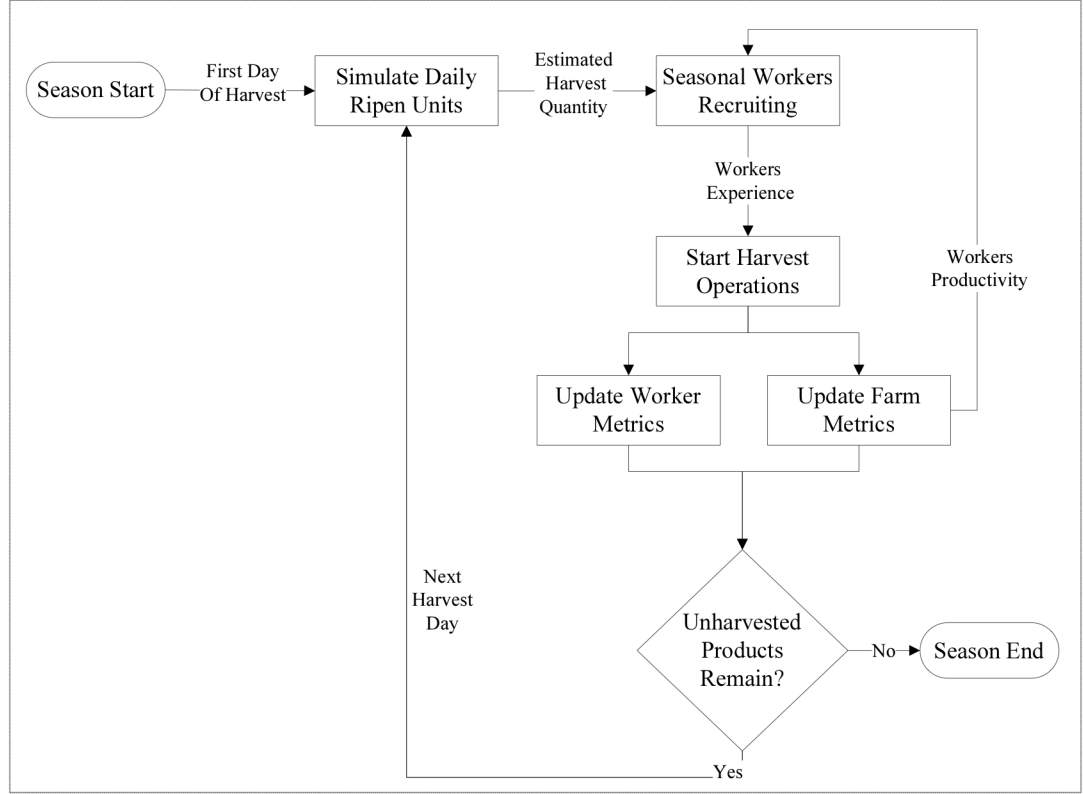
Figure 5-5: Harvest Operations Building Blocks

2- Seasonal Workers Recruiting Block: Once the estimated harvest quantity in the previous block is calculated, this block determines the number of seasonal workers **(D^H)** using the following equation:

$$D^H(t) = \frac{\hat{Q}_h^G(t)}{\bar{P}^H(t)}$$

(3)

Where $\bar{P}^H$ is perceived worker productivity, this productivity represents the manager perceived productivity for a seasonal worker.

3- Start Harvest Operations Block: the operations begin once the recruited workers arrive at farms in the morning at operations start time. Each agent follows the identified state chart for these operations (Figure 5-6). A pool of harvesting agents will be created in the simulation model at the initial state *"Un-Recruited"*. When the number of harvesters (D^H) is determined in *Block 2*, a group of harvesting agents equivalent to that number will be transferred into the state *"Recruited"*. These agents will be picked from this pool in the simulation model according to the planned *recruiting policy* defined by the grower, this policy is discussed later in section 5.1.4. Then recruited agents to move to the state *"Arrived"* waiting for the commencement of operations where they are transferred into *"Looking_Unhandled_Tree"* state. During this state, each agent moves between the farm trees looking for a tree with ripe units. Once an unhandled tree is found, the agents enter the *"Harvesting"* state, which consists of three sub-states representing three different harvesting activities namely: 1) *Checking* unit for ripeness; 2) *Cut* and handle ripe unit; and 3) *Place* picked units into a collecting crate. The transfer between these activities is triggered by the time required for each one of them. The processing time required to conduct any harvesting activity and also resultant products waste (if any), varies from one agent to another according to its experience level. The experience level is a proxy variable used for each agent to reflect seasonal workers' skill variations. An agents experience improves over time if they are recruited for harvesting work in farms as explained in *Block 4*.
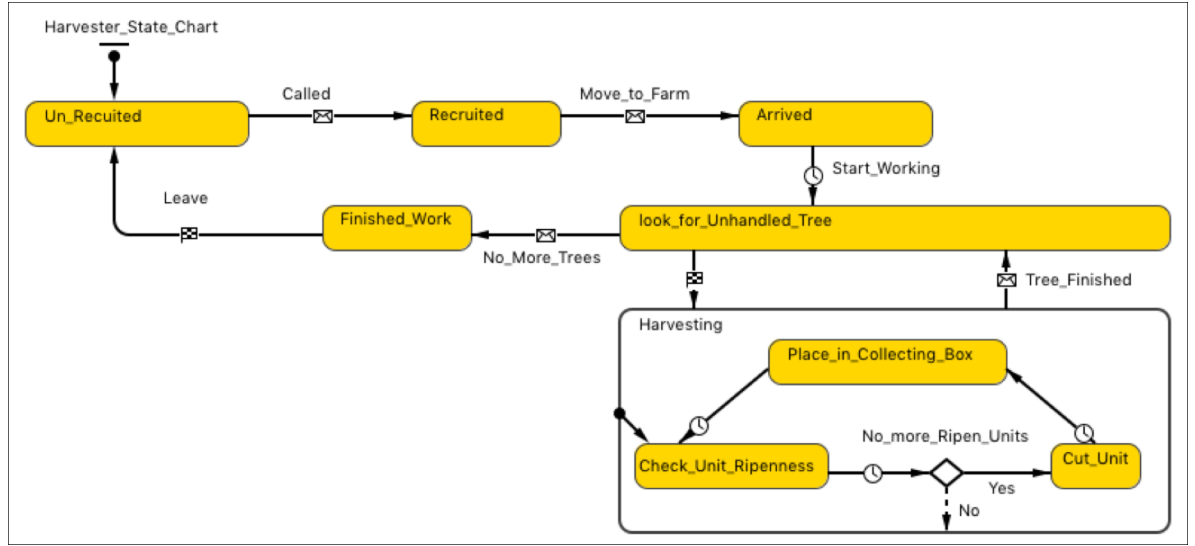
Figure 5-6: Harvesting Worker Agent State Chart

When all ripe units of a tree are picked, the agent moves back to the **_"Looking_Unhandled_Tree"_** state, and then continue switching between the two states until each tree in the farm is handled, or operations finish time is reached. Meanwhile, each agent grabs an empty crate to place picked units into it. Once a crate becomes full, the agents drop it at the current tree and grab another empty one and so on. A discrete event is triggered once a crate becomes available for collection. A DES component that is responsible for crates movements and transportation activities is discussed later in section 5.1.2. When 'work finish time' is achieved or no more unhandled trees exist the agents move into **_"Finished_Work"_** state then they leave work locations moving back into **_"Un-Recruited"_** state.

4- Update Worker Metrics Block: When all ripe units are picked from trees, all harvesting agents are released from the farm, and then a set of metrics are updated for each agent. These metrics are 1) number of working days (K^H) and 2) experience level (E^H). The number of working days (K^H) for each worker is updated as follows:

$$K_i^H(t) = \begin{cases} K_i^H(t-1) + 1, & \text{if worker } i \text{ is recruited at day } t \\ \\ K_i^H(t-1), & \text{Otherwise} \end{cases} \quad \forall\, i = 1,2,..,S^H \quad (4)$$

Where S^H is the size of all seasonal harvesting agents pool.

The experience level variable is updated based on the concept of continuous improvement and learning curves introduced by Zangwill and Kantor (1998) using the following equation:

$$E_i^H(t) = \min\left(E_{max}^H, E_i^H(0) \cdot e^{r_3 \cdot K_i^H(t)}\right) \quad \forall\, i = 1,2,..,S^H \quad (5)$$

Where r_3 is a positive learning curve parameter, $E^H(0)$ is the initial experience level, and E_{max}^H is the maximum experience level. Improving this variable for each agent is reflected on its processing times for the harvesting activities which alter its harvesting productivity that will ultimately enhance harvesting productivity on farm level. The relationship between experience level and harvesting processing time is discussed in detail in section 5.1.4.1.

5- _Update Farm Metrics Block:_ This block updates a set of metrics on the farm level, including 1) harvested quantity (Q_h^G), 2) wasted quantity (Q_l^G), 3) average worker productivity (P^H) and 4) perceived worker productivity $(\overline{P}^H)$. Actual harvested quantity is the sum of harvested quantity by each worker. Similarly, wasted quantity is the sum of loss resulted by each worker during harvesting activities. Average worker productivity is calculated using the following equation:

$$P^H(t) = \frac{Q_h^G(t)}{D^H(t)} \quad (6)$$

The perceived productivity is modelled using a first order delay function ($\boldsymbol{Delay_1}$) introduced by Sterman (2000) as follows:

$$\bar{P}^H(t) = Delay_1 \left(P^H(0), P^H(t), a_1\right) \tag{7}$$

Where $\boldsymbol{P^H(0)}$ is the initial value for the perceived worker productivity and $\boldsymbol{a_1}$ is time to adjust perceived worker productivity Sterman (2000). The main reason for relying on perceived worker productivity for identifying the number of seasonal workers instead of the average is that variations between seasonal workers – subject to their experience levels and skills besides high turnover during the season in many situations – results in inconsistent productivity over the time.

5.1.2 Transportation Component

While harvesting operations are taking place, simultaneously the movement and transportation operations for full crates are carried out. Harvesting agents drop full crates inside the farm; meanwhile, another set of workers, namely **movers**, carry these crates and move them to specific collecting points. The crates are then pulled by electric tractors from the collection points, to the loading point, where crates are loaded onto trucks to move them directly to the packing-house. The framework employs a DES model to model this component based on the process map in Figure 5-7.

Most of the fresh produce products are vulnerable to quality decay if they are exposed to environmental conditions such as humidity and elevated temperature. Hence the key success of fresh produce transportation is to reduce "Harvesting to Packing" cycle time. This encounters the movement time from tree to cart collection point and the waiting times for

these required resources. Therefore, a set of performance indicators are tracked within transportation component including average waiting times for mover, car or truck. This block is also responsible for calculating daily production by monitoring the number of crates collected and weight of trucks' load.
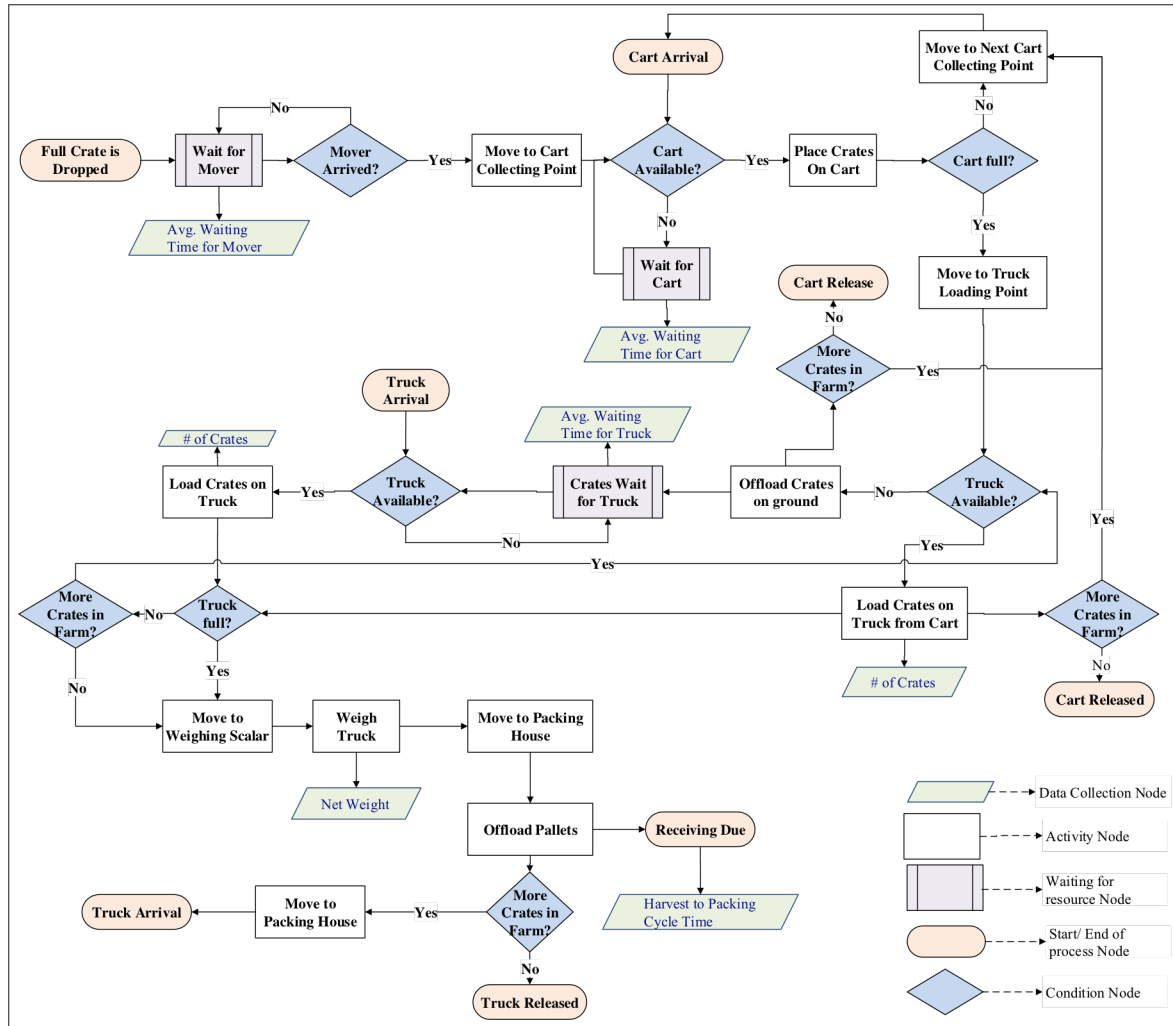
Figure 5-7: Process Map for Raw Fresh Produce Transportation Component

The overall performance of this component is derived by the quantity of harvested products from one side and available resources on the other side. The three operational decisions

identified in Figure 5-3 control resources availability. However, trade-offs between reducing operational times and costs of acquired resources complicate the planning process.

5.1.3 *Farm Dynamics Component*

Perennial crops have long gestation intervals between initial planting, their first harvest season, and an annual yield for an extended period of productivity. This productivity is usually lower than normal during the early and late seasons of trees' lifespan. During the last season, strategic decisions to remove or replace the old trees or the planting of other crops should be taken. Therefore, growers have to carefully plan for these decisions because of the high costs involved in planting new trees and the delayed impact on the supply, either when new planting take place or when trees are getting old. A system dynamic modelling paradigm is employed to model the farm dynamics component in the proposed framework to handle the complexity and long-term impact of alternative scenarios.

It is assumed that there are five groups of planted areas in the farms: 1) New Planted areas, 2) Early Productivity areas, 3) Normal Productivity areas, 4) Late Productivity areas and 5) Dead areas. The relationships between the five areas and the overall yield of farms are presented in a causal loop diagram (CLD) in Figure 5-8. There are many feedback loops which drive the dynamic behaviour within this component. Loops 1 to 4 represents an age chain that reflects the dynamics of trees life cycle. A "newly planted" tree after some delay (i.e., growing time) becomes an "early productivity" tree, then after another delay, it becomes a "normal productivity" tree and so on until it becomes a "dead" tree. Thus, all the arrows in this direction carry "delayed positive" impact signs while the reversed arrow carry "negative" impact signs.
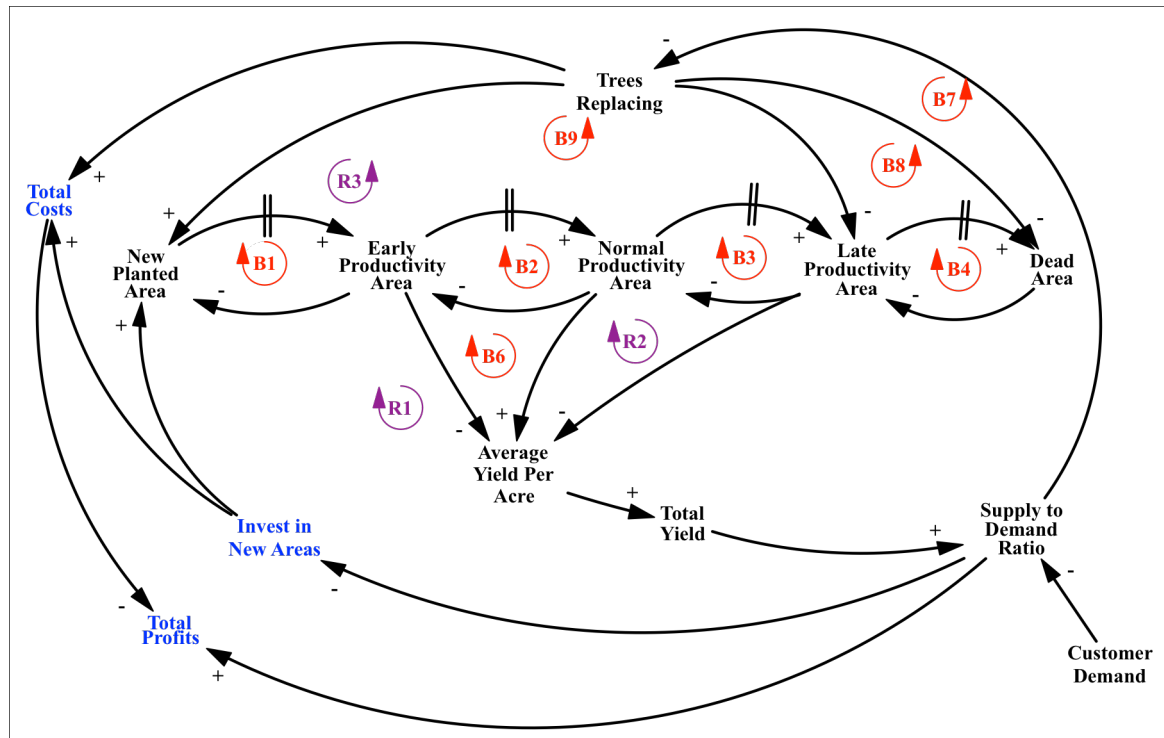
Figure 5-8: Farm Trees Dynamics Causal Loop Diagram

The total yield of the farm relies on the productive areas (i.e., early, normal and late). As indicated in Causal Loop Diagram (CLD) the average yield per acre is decreased when both early and late productivity areas are increased. The total farm yield alters the ratio between grower's supply and customer demand. This ratio is the driver for the grower to either replace the trees of late productivity or dead areas or invest in new areas. The low value for this ratio puts pressures on downstream echelons to decide whether to reject new customer orders or outsource the stock-out quantities. However, both situations negatively impact the relationship between the growers and their partners in the supply chain who are seeking for stable suppliers. On the other hand, if the supply to demand ratio is high (i.e., more than one), the exceeding quantities will be marketed domestically with a way lower prices. Therefore, the growers have to design their farm dynamics in a way that sustain a supply to demand ratio to avoid over or under yield capacity.

The CLD presented in Figure 5-8 is translated into a stock and flow diagram (SFD) (Figure 5-9). The five groups of planted areas are presented as stock variables where flow rates transfer areas from stock to another according to trees age advances or planting new areas and replacing old areas decisions. There are a set of alternatives that are identified for these decisions and discussed in the following section.
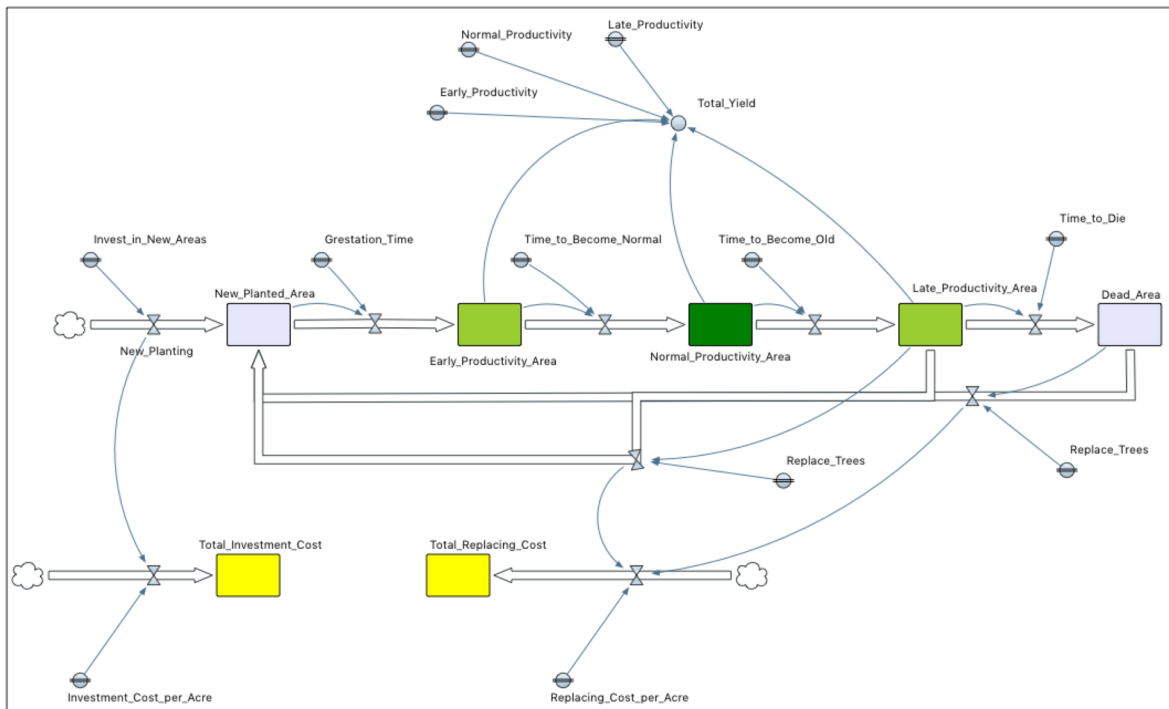
Figure 5-9: Farm Dynamics Stock and Flow Diagram

5.1.4   Grower Decisions Dashboard

A range of decisions, policies, and sets of alternatives are identified in the grower control dashboard (Figure 5-10). The first decision is related to transportation policies on the farm and their parameters. The framework allows decision makers to investigate the impact of several carts, trucks, and movers on system's utilisation. It also helps to select the most

efficient business model for employing these resources. Carts and trucks can be either rented against rate per working hour or purchased and owned by the grower.

Harvesters recruitment policy is considered a significant business decision which has an impact on the three management levels of the farm (i.e. strategic, tactical and operational). The number of the harvester is calculated in "Harvesting Components" based on 1) the identified volume of harvested products (vary from day to day) and 2) total workers' productivity which is determined by their level of experience and skills daily. Three hiring policies are defined to explore how by reducing labourers' variations and retaining their experience, harvesting efficiency can be improved. In the first policy, workers are hired through local hiring agencies who cannot guarantee to supply the same group of labourers every day. This is due to the seasonal nature of operations, high turnover of seasonal labourers, and fierce competition with other local growers. The second policy, similar to the first, requires an extra hiring rate which is paid to secure the estimated number of harvesters where priorities are given to those who worked previously on the farm. Finally, the last policy aims to hire and retain a fixed number of harvester along the entire season.

The last two decisions are related to farm dynamics. Decision makers can choose between four different policies for replacing "late productivity" and "dead" areas. It may be decided that no replacement will take place. Alternatively, trees replacement can occasionally occur once an area becomes "dead" or "late productivity". The last alternative is to conduct trees replacement subject to changes in customer demand to bridge the gap between demand and supply. Similarly, one of the other options for the new investments policy is to match

changes in demand trends. The other two alternatives for this policy is to plant a fixed quantity every year or stop any investment in newly planted areas.

Figure 5-10: Fresh Produce Grower Decision Making Dashboard

5.2 Fresh Produce Packing House Modelling

The key role of packing stations is to transform raw products into final products that comply with customer requirements. The proposed framework includes a set of planning variables for packing station managers along with a wide variety of KPIs (Figure 5-12).

5.2.1 Packing House Operations Component

Packing stations receive raw products from growers in pallets of crates loaded on transport trucks. These pallets are offloaded in air-conditioned receiving areas, then moved to packing lanes where products are packed into bags, punnets, or boxes. Packed products are then

moved to ground services area where packages are lined up onto pallets, wrapped, moved to cooling facilities (if needed) and finally stored in cold storage.

The operation is triggered by the arrival of raw products, then, through a series of processes, these products are moved from a facility to another within the packing house (e.g., from receiving area to packing lanes). DES is employed in the framework to represent this process (Figure 5-11). It is vital for all products to be packed as quickly as they are received at the packing house. Hence, it is found that tracking products' waiting time in the receiving area is a crucial performance indicator. A set of various KPIs which reflect these waiting times is reflected in the employed DES model. It is concluded that the overall performance of the packing house is wholly linked to resource capacity planning and scheduling decisions.
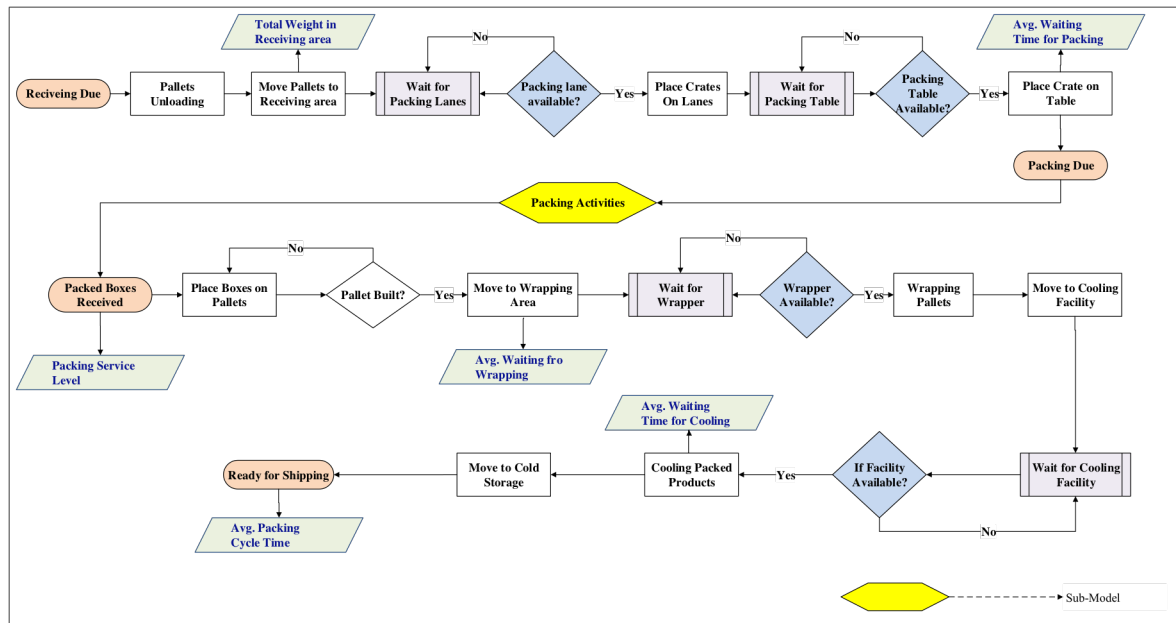
Figure 5-11: Process Map for Fresh Produce Packing Operations
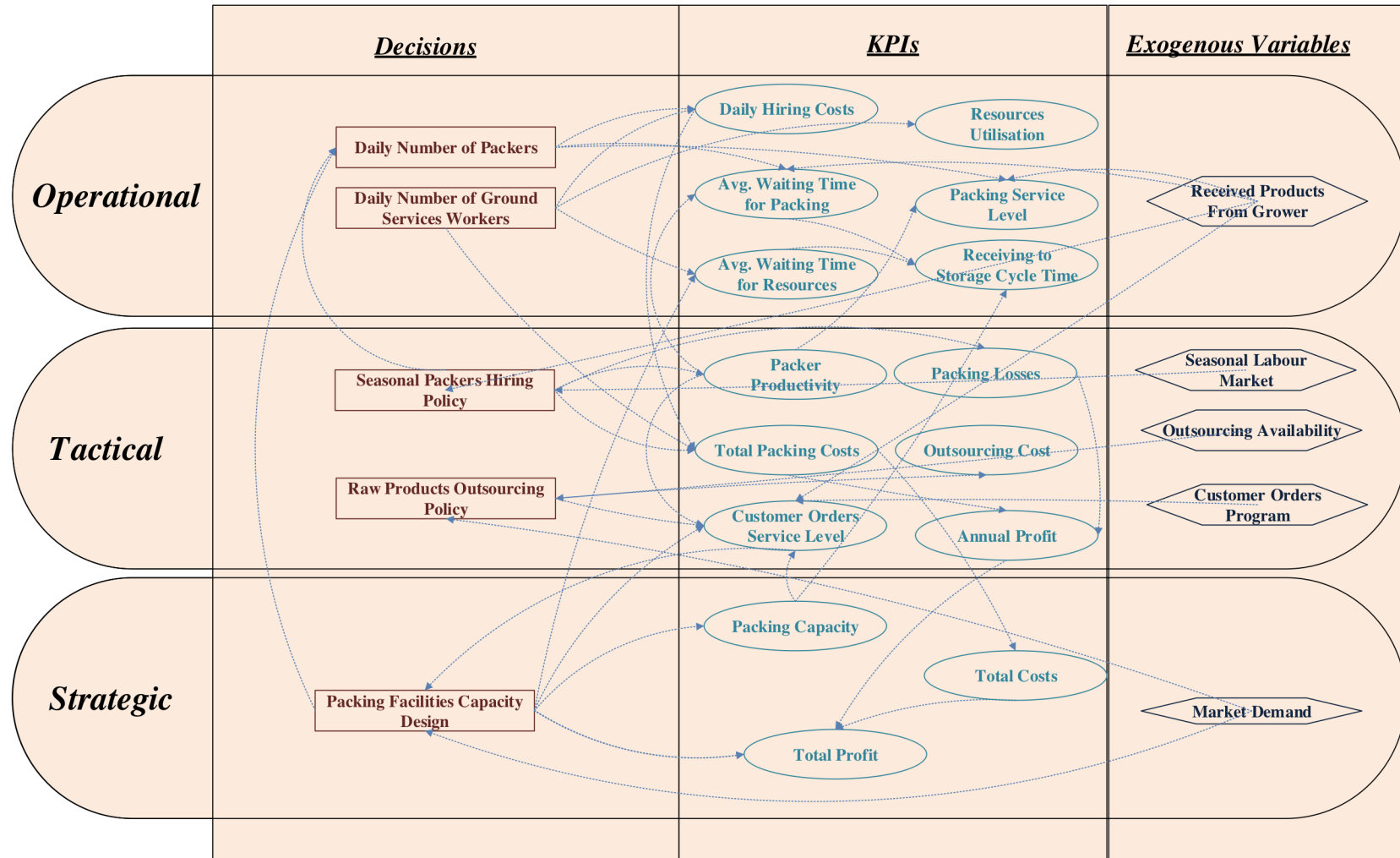
Figure 5-12: Fresh Produce Packing House Decision Making Map

Similar to harvesting, packing activities rely entirely on the seasonal packing labourers who usually work in groups of two to three on packing tables. Therefore, packing activities are modelled using ABM to address labourers' variations on activities performance. This model is integrated with the main DES model of packing operations.

5.2.2 *Packing Activities Component – subcomponent of the previous one –*

The packing process contains various activities including 1) visual inspection of the product, 2) removing defective items, 3) adjusting products weight subject to designated packing units (e.g., bag, punnet etc.), 4) placing products into boxes and 5) wrapping boxes. The boxes are then moved, manually or by conveyors, to the pallets. These tasks are manually executed by seasonal workers hired daily. The level of labourer's experience, skills, and productivity have a significant impact on packing line productivity, product wastes, and quality of the final product. Each worker is modelled as an independent agent with a set of unique characteristics reflecting their experience and skills variations.

Figure 5-13 presents the building blocks of packing activities. At the beginning of the season, packing station managers receive rough estimates of the expected harvest quantities that would be received at the station. The products that need to be packed on any given day is estimated by *"Simulate Daily Quantities at Receiving Area"*. The number of packers is then simulated based on this quantity and the productivity of packers. The *"Seasonal Workers Recruiting"* block simulates the hiring process of the packers. They are then moved and distributed on the packing tables waiting for the raw products to commence packing *"Start Packing Activities"*. Once the crate is placed on the packing table, packers follow the state chart that is defined for each agent (Figure 5-14). At the end of the day, a set of variables

and performance indicators are calculated for the packing house and the individual worker in *"Update Packing House Metrics"* and *"Update Worker Metrics"* blocks respectively.
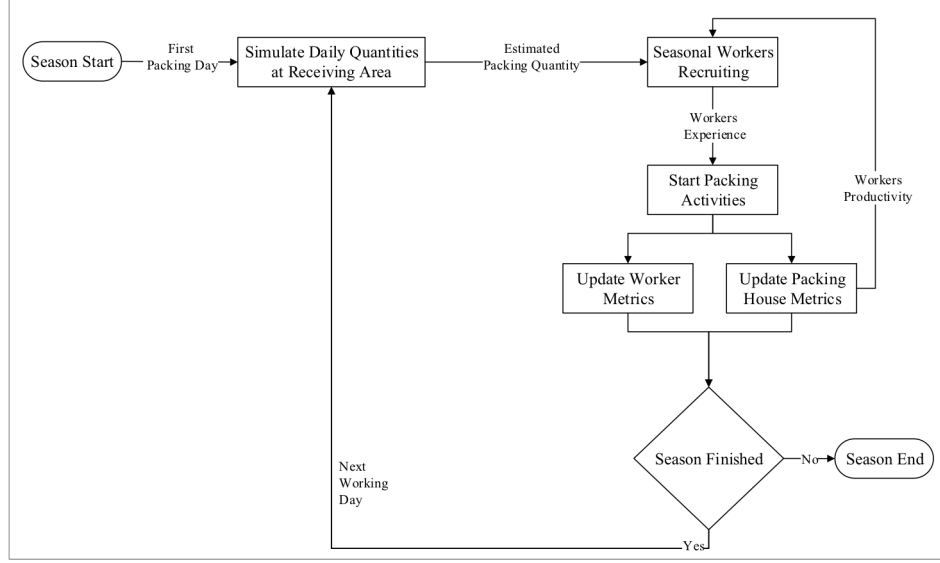
Figure 5-13: Packing Activities Building Blocks

1- Simulate Daily Quantities at Receiving Area Block: The estimated quantity of raw produce at the receiving area $(\widehat{Q}_r^P)$ is the main driver for the number of seasonal workers to be hired on any given day. This quantity is a sum of 1) estimated harvest quantity $(\widehat{Q}_h^G)$, 2) unpacked quantity of previous day (Q_u^P) and 3) outsourced quantity Q^O, the following equation expresses this summation:

$$\widehat{Q}_r^P(t) = \widehat{Q}_h^G(t) + Q_u^P(t-1) + Q^O(t) \tag{8}$$

The unpacked quantity is calculated using the following:

$$Q_u^P(t) = Q_r^P(t) - Q_h^P(t) \tag{9}$$

Where Q_r^P is the actual quantity in receiving area and Q_h^P is the actual packed quantity handled and processed at day t.

2- *Seasonal Workers Recruiting Block:* after estimating product quantity, the number of seasonal workers is determined using the following equation:

$$D^P(t) = \frac{\hat{Q}_r^P(t)}{\bar{P}^P(t)} \qquad (10)$$

Where $\bar{P}^P$ is the perceived worker productivity, which is determined by the manager.

3- *Start Packing Activities Block*: packing operations begin when crates are placed on the packing tables. Packers are assigned to the tables based on the built-in state charts which control the sequence of packing operations (Figure 5-14). A pool of packers is available for hiring and initialised at ***"Un-Recruited"*** state. When the number of packers (**D^P**) is determined in ***"Seasonal Workers Recruiting"*** Block, the status of the packers is transferred into ***"Recruited"***. The recruited packer status is then changed to***"Arrived"*** while waiting for the commencement of operations. By beginning packing operations, packers are assigned to packing tables, and their status is transferred into ***"At_Packing_Table"*** state. Meanwhile, raw products pallets are supposed to be moved to packing lanes where these tables are attached, and crates are placed on tables for processing and packing raw products.

At packing table state, every packer is assigned to one of the three states. In ***"Preparing_Product"***, packers inspect the raw products and dispose of any defected or unqualified items. The inspected products are then adjusted, weighted and fitted into designated packing unit (e.g., punnets or plastic bags), ***"Placing_in_Packing_Units"***. The packed products are then placed in a bigger boxes or packages ***"Wrapping_Packed_Box"*** *state*.

It is noticed that packing waste and losses mostly occur in the first two stages. The packing processing time and rate of loss vary based on packers' experience level. Similar to harvesters, packers experience level is a proxy variable that is used to reflect skill variations. Packers experience improves over time if they are recruited for the next working day as explained in **Block 4**. When all available quantities in receiving, area are packed or work finish time is reached, packing agents stop receiving more crates on tables and finish all available work on the table, then move into **"Work_Finished"** state before they turn again into **"Un-Recruited"** state.

4- Update Worker Metrics Block: At the end of working day, all packers are released from the packing house, and a set of metrics are updated including 1) number of working days (K^P) and 2) experience level (E^P). The number of working days for each worker is updated as follows:

$$K_i^P(t) = \begin{cases} K_i^P(t-1) + 1, & if\ worker\ i\ is\ recruited\ at\ day\ t \\ K_i^P(t-1), & Otherwise \end{cases} \quad \forall\ i = 1,2,..,S^P \quad (11)$$

Where S^P is the size of all seasonal packing agents pool.

Packers' experience levels are updated based on continuous improvement and learning curves by using the following equation:

$$E_i^P(t) = \min\ (E_{max}^P, E_i^P(0) \cdot e^{r_4 \cdot K_i^P(t)}) \qquad \forall\ i = 1,2,..,S^P \qquad (12)$$

Where r_4 is a positive learning curve parameter, $E^P(0)$ is the initial experience level, and E_{max}^P is the maximum experience level. Improving this variable for the packers is reflected on the packing processing times and products waste.
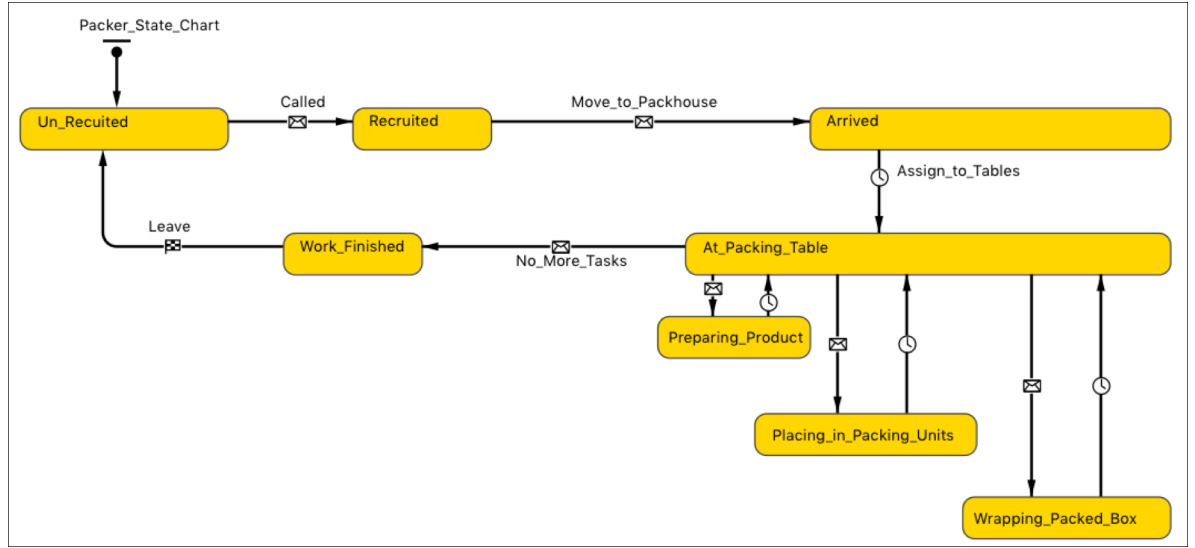
Figure 5-14: Packing Worker Agent State Chart

5- Update Packing House Metrics Block: This block updates a set of metrics including 1) handled quantity (Q_h^P), 2) packed quantity (Q_p^P), 3) wasted quantity (Q_l^P), 4) average worker productivity (P^P) and 5) perceived worker productivity $(\overline{P}^P)$. Handled quantity is simply the sum of weight for all pallets moved from receiving area to packing lanes. Similarly, the daily packed and wasted product quantities are the sums of the packed and disposed boxes during packing activities respectively. Average packer productivity is calculated using the following equation:

$$P^P(t) = \frac{Q_h^P(t)}{D^P(t)} \tag{13}$$

The perceived productivity is modelled using a first order delay function $(Delay_1)$ introduced by Sterman (2000) as follows:

$$\overline{P}^P(t) = Delay_1\left(P^P(0), P^P(t), a_2\right) \tag{14}$$

Where $P^H(0)$ is the initial value for the perceived worker productivity, and a_2 is time to adjust perceived Packer productivity.

5.2.3 *Packing House Decisions Dashboard*

A range of decisions which are usually addressed by packing house managers are identified in the packing house dashboard (Figure 5-15). The number of packing agents is determined according to the employed packers recruiting policy. Three different hiring policies are defined in the dashboard to examine the impact of labourers' variation and the retaining of labourers' experience on packing house efficiency. In the first policy, packers are randomly hired through local hiring agents from the available seasonal packers in the region. The second policy is designed to resolve the variation in packers' performance by offering increased hiring rate per packer to the hiring agency under a condition of providing the priority to the packers who worked previously in the packing house. In the third policy, the managers recruit a fixed number of packers over the season (i.e., D^P will be constant over time). In this case, the recruiters have to bring same people every day for packing operations.

Product outsourcing is another critical decision in fresh produce packing houses particularly when customer demand exceeds the received supply. It has a direct influence on customer satisfaction level and the efficiency and cost-effectiveness of packing operations. For example, outsourcing increases products quantities in the receiving area which could lead to hiring more packers and a delay in packing products to the next working day. For outsourcing decision, the user can choose between three different policies; (1) A daily outsourcing quantity is calculated based on customer orders' dispatching schedule. In this case, a daily outsourcing quantity (Q^O) can be calculated using the following equation:

$$Q^O(t) = \left[Q_p^E(t) - \hat{Q}_h^G(t) - Q_u^P(t-1) \right] * OAF(t) \tag{15}$$

Where Q_p^E is exporter's planned quantity that should be ready for dispatch in day t and OAF is outsourcing availability fraction of that day (see section 5.4.3). Under the second policy, the manager predicts any shortage in supply (i.e., a gap between grower's expected yield and agreed orders by exporter) and attempts to outsource total quantities at the start of the season. Packing house managers in the third policy divide outsourcing quantities evenly on the season weeks. All outsourcing policies would have implications on packing operations efficiency, customer satisfaction and the number of recruited packers.

Figure 5-15: Fresh Produce Packing House Decision Making Dashboard

The framework also considers the capacity expansion decisions inside packing house facilities (e.g., receiving area or cooling facility). It is crucial to plan for such long-term investments in the light of products inflow, from the upstream grower, and outflow to customers aiming to optimise the trade-off between resources utilisation and customer

service level. By considering capacity design decisions, the framework can advise packing house managers when those changes occur which impact the entire system performance. This would also be beneficial in the planning of the capacity of all supply chain entities concurrently. For example, packing house capacity can be designed based on grower's expansion plans for the planted areas and the transportation capacity and dispatching schedules in the exporter's side.

5.3 Fresh Produce Exporter Modelling

After the beginning of harvesting season, exporters collect information about customer orders and grower's expected yield to decide which orders can be served and to plan for dispatching and shipping program that comply with customer's preferences of delivery dates. The fierce market competition leads exporters to maintain an elevated level of customer satisfaction to ensure sustainability of demand. The proposed framework offers a set of planning tools which enable exporters to optimise various business decisions and improve process performance. Both decisions and KPIs are presented in the decision-making map for fresh produce exporter along with the key exogenous variables that affect the business (Figure 5-16).

5.3.1 Receiving Customer Orders

The framework simulates customer orders which are attributed to; 1) ordered quantity, 2) delivery week and 3) delivery day. The customer order component generates random values for these three attributes depending on a statistical distribution derived from historical data of customer orders as illustrated in section 5.5. The flowchart for creating customer orders is presented in Figure 5-17.
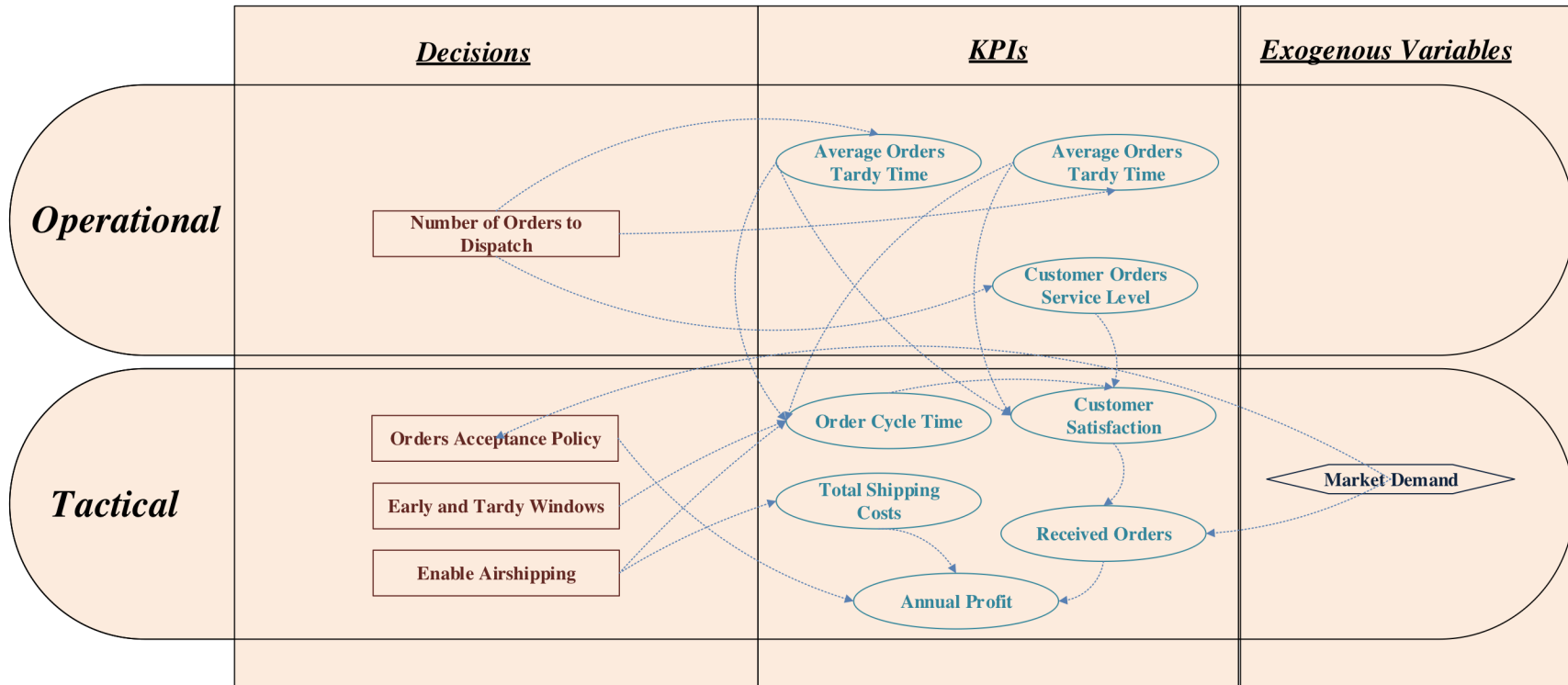
Figure 5-16: Fresh Produce Exporter Decision Making Map
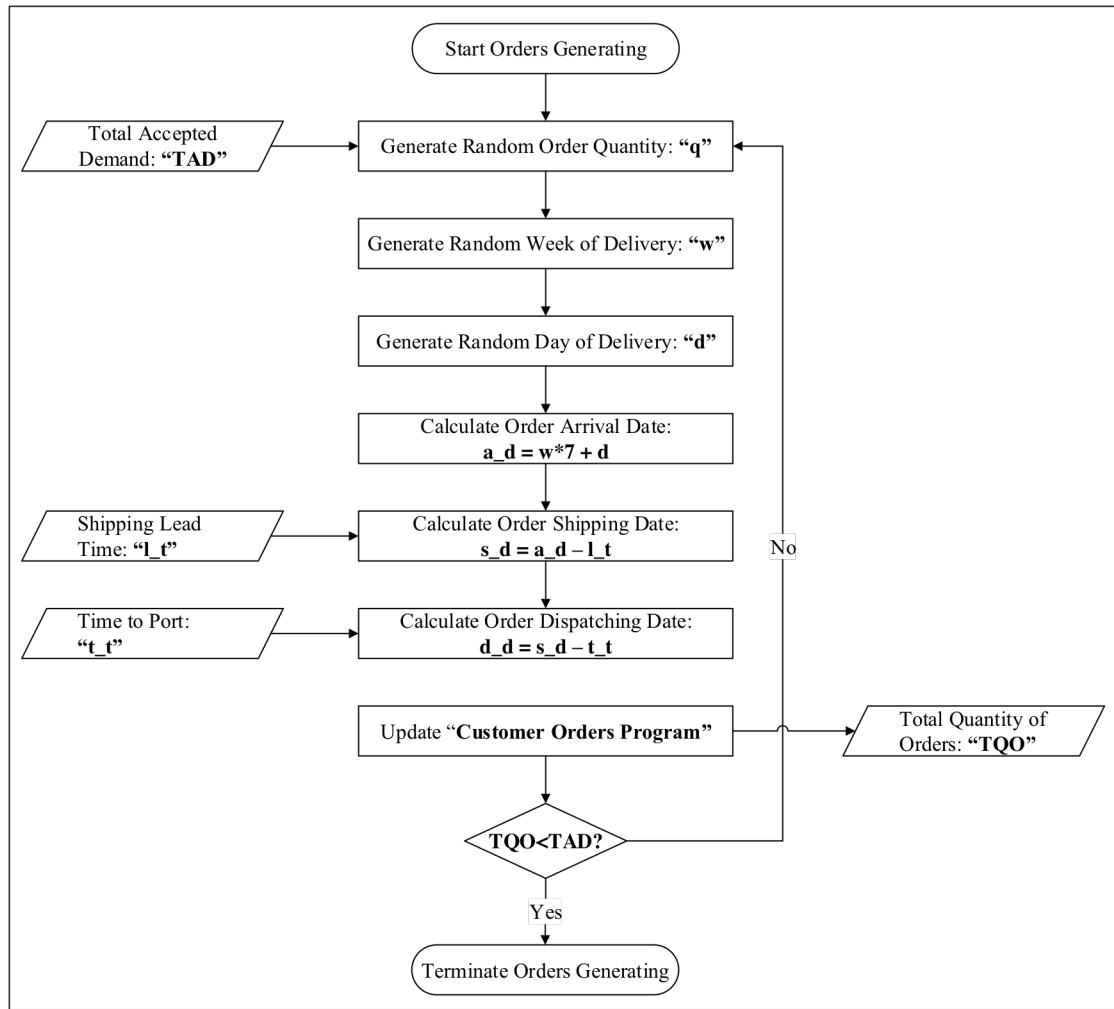
Figure 5-17: Customer Orders Generation Process

The ultimate output of this components is *"Customer Orders Program"* where three more attributes are added to each customer order namely: 1) order arrival date, 2) order shipping date and 3) order dispatch date. This program is important for the packing house as products outsourcing are planned according to orders dispatching dates. Furthermore, arrival, shipping and dispatch dates also affect harvesting, packing, and shipping performance indicators *"customer orders service level"*.

5.3.2 Dispatching Customer Orders Component

A DES model is employed to simulate dispatching customer order processes based on the process map in Figure 5-18. The orders releasing events are triggered based on dispatching due dates. On any dispatching day, according to customer orders program, product pallets are withdrawn from the cold storage area and then loaded into shipping containers. However, sometimes the number of stored pallets will not be sufficient to fulfil all outstanding orders. In this case, orders can be partially dispatched (i.e., dispatch whatever available in stock) or, postponed to the next dispatching day. If an order is already delayed from a previous dispatching day, it takes a higher priority. When the required number of pallets for an order are available, the actual arrival date is set based on a regular shipping route lead time (i.e. maritime shipping). A faster shipping route using an airship can be selected based on customer requirements or to avoid late delivery. A set of KPIs connected to exporter performance is calculated using the DES model. This includes orders averaging early and tardy times, and customer orders service level.
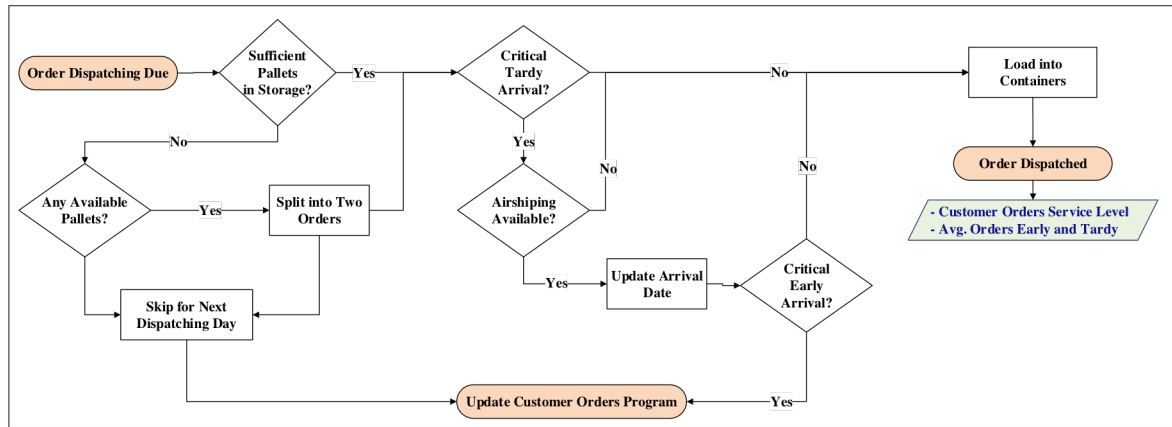
Figure 5-18: Customer Orders Dispatching Process Map

5.3.3 *Customers Satisfaction Impact*

Customer satisfaction is one of the significant metrics that measure fresh produce exporter performance. In the framework, it is assumed that customer satisfaction impacts exporter's profits and influence customer demand for the next season. The latter can have consequences not only on exporters but also on growers and packing stations. Each customer order includes **"customer satisfaction"** attribute which has 100% as an initial value. This value is recalculated when orders are dispatched, and actual arrival dates are determined. A linear relationship is used to map between violating delivery dates and customer satisfaction level for any order (Figure 5-19). To model the impact of customer satisfaction level on exporter's profit, order's revenue will be multiplied by the value of customer satisfaction attribute.
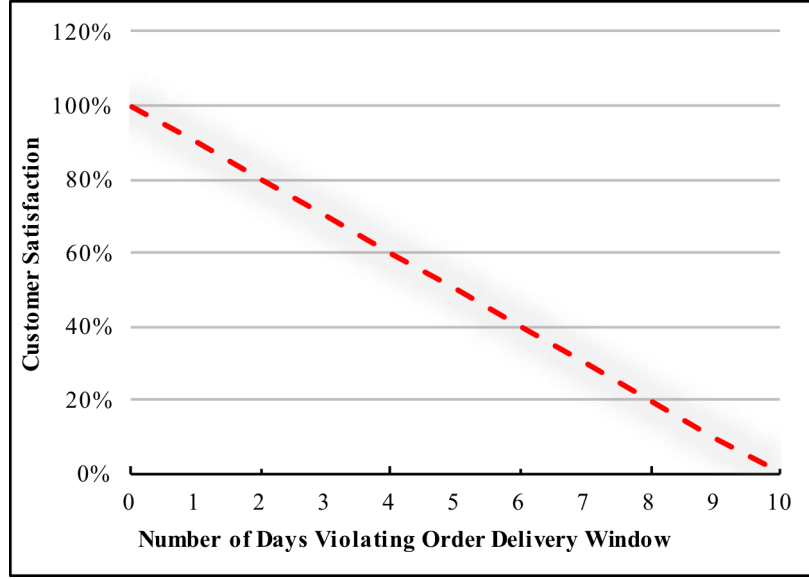
Figure 5-19: Relation Between Customer Satisfaction and Oder Delivery Window Violation

To model that impact, the following equation is used to calculate expected demand (RD) of next season:

$$RD = MD * MS * \max\left(CS, CS_{\min\_eff}\right) \qquad (16)$$

Where MD is the total market demand, MS is exporter's market share, CS is the overall customer satisfaction level and "$CS_{\min\_eff}$" is the minimum effect of customer satisfaction variable.

5.3.4   Exporter Decisions Dashboard

A range of decisions for the exporter is identified at different planning levels (Figure 5-17). For each decision, a set of alternatives is presented in an exporter decision-making dashboard (Figure 5-20). The quantities of accepting orders are the most significant decision in the exporter business and have three possible alternatives as illustrated in the dashboard. The first alternative is to limit the accepted order quantities to the grower's expected yield to avert

the risk of products running out of stock. In contrast, exporters accept all incoming orders in the second alternative to avert the risk of losing potential customers. Finally, in the third alternative, exporters accept customer order quantities which are above expected yield quantity by a certain percentage.

The dashboard also includes a checkbox to identify whether the fast shipping route option will be available or not. In addition, two controls are added to set exporter's critical limits of orders that violate the due dates. Based on these limits it will be decided whether the fast route will be used for a particular order and when it will be used.

Figure 5-20: Fresh Produce Exporter Decision Making Dashboard

5.4 Exogenous Component

5.4.1 Seasonal Labourer

Seasonal workers are hired for harvesting and packing activities. In reality, these workers are characterised by high variations in skills and experience. Many social and economic factors cause high turnover in seasonal labour markets, in addition to the fierce competition between growers on seasonal workers. All these factors together create a sort of inconsistency in seasonal workers on both availability and performance levels. Therefore, seasonal workers are modelled using ABM to address these issues and reflect their impact on the performance. On the other hand, workers' availability is assumed in the framework, which means that

whatever number of seasonal workers is needed, it will be available. It is also assumed that workers involved in harvesting activities differ to packers. Hence, two pools of seasonal workers are created namely: 1) Harvesters Pool and 2) Packers Pool, and the size for each of them is notated as (S^H) and (S^P) respectively. Each worker in these two pools has a set of attributes that impact its performance including;

1- Experience Level (E)

2- Number of Working Days (K)

The number of working days is initialised to be **zero**, where experience levels are randomly initialised between (E_{min}) and (E_{max}) to reflect skills variations. Both attributes are then updated during the simulation runs according to equations (5) and (12) for harvesters and packers respectively. When more than one season is simulated, the number of working days (K) is reset to **zero** for all agents, while experience level (E) is re-initialised randomly for TO% of agents in each pool. Where TO% is a parameter that represents the turnover in the seasonal labour market.

When seasonal workers are hired, they are supposed to perform a set of activities according to agents' statechart. The higher the experience level of workers the better their performance in terms of productivity and product waste will be obtained. Processing time and rate of products' waste are the proxy for agent performance and follow a statistical distribution based on the analysis of the collected data. To reflect the impact of experience level on worker's performance, it is assumed that the mean values of processing times and product waste rates are mapped to agents' experience in a reverse relationship. When agent's

experience improves (i.e., increases) the mean of any activity processing time or losses rate decreases (Figure 5-21).
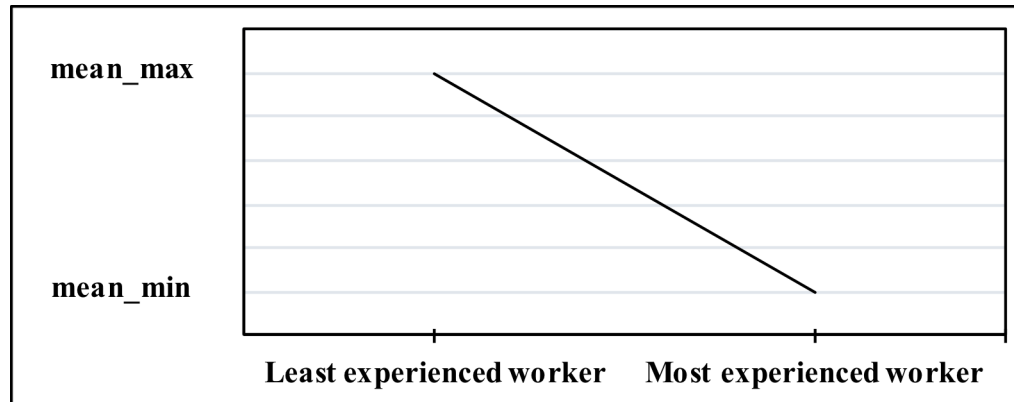
Figure 5-21: Relationship between worker experience and mean of activity time / loss rate distributions

5.4.2 Market Demand

A simple stock and flow diagram are used to model the market behaviour in the model (Figure 5-22). The stock variable, *"Market_Demand"*, can either increase or decrease from season to season according to the *"Change_in_Demand"* variable. This variable can either be constant during the whole simulation runs (i.e., a continuous increasing trend if positive value), or change at certain seasons to simulate demand disruption.
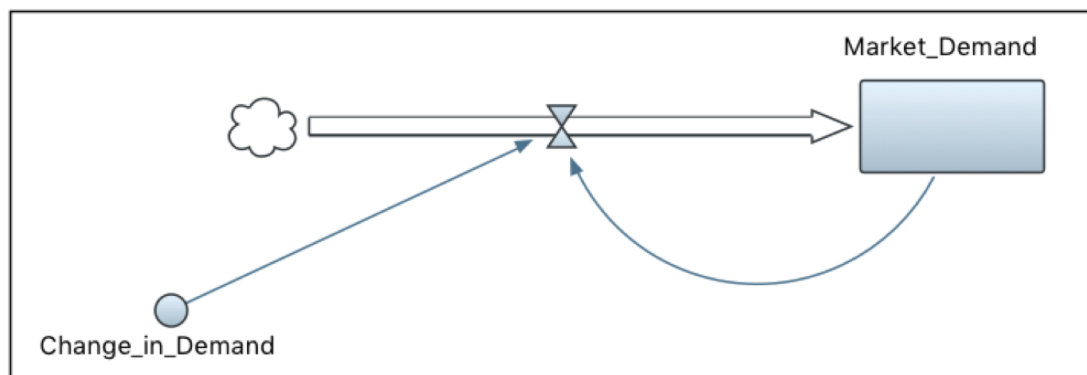
Figure 5-22: Received Market Demand in the Framework

5.4.3 *Outsourcing Availability*

Packing houses outsource additional quantities of raw products if accepted customer orders quantity exceeds grower's expected yield quantity. These products are usually outsourced from other growers within the production region. Outsourcing is available on any day if those growers have harvested quantities that exceed their demand, but if they did not, outsourcing would not be available on that day. Even if outsourcing is available, there is no guarantee that all quantities needed to be outsourced will be available. Hence, in the model, a variable called outsourcing availability fraction (OAF) is used to simulate fraction availability of outsourcing quantity (Q^O) as presented in equation (15). This fraction can be simulated using the following equation:

$$OAF(t) = uniform(OAF_{min}, OAF_{max}) \qquad (17)$$

Where OAF_{min} and OAF_{min} are two positive parameters between **zero** and **1**.

5.5 Data Collection and Analysis

Data collection can be divided into two phases: ***Phase 1*** is data collection for developing the framework components and employed simulation models, and ***Phase 2*** is to collect data that will be processed and analysed to construct the simulation model inputs.

In the first phase, data is collected to gain an understanding of different system components, main processes, the flow of information, and products between them. Then main planning decisions and KPIs are identified. Afterwards, necessary process maps, causal loop diagrams, and agent state charts for the different simulation models are developed before translating them into a simulation model program. Three data sources are used during these

phases. Interviews with both 1) AFPSC members, 2) their staff, and 3) direct observations. Analysis and outcomes of data collected in this phase are discussed and presented in sections 5.1 to 5.3 and their sub-sections as well.

The purpose of the second phase of data collection is to provide all input data and statistical distributions for simulation model parameters and variables. For example, statistical distributions for packing tasks processing times and their parameters (i.e., mean and standard deviation for each distribution). Data is also gathered from three sources: 1) Internal data sources, 2) Data Sampling and 3) external or exogenous data sources.

5.5.1   *Internal Data Sources*

Access to internal data of the three AFPSC entities enables the modeller to gather historical data for customer orders, previous seasons yields, and records regarding packing houses performance. It also provides data regarding grower's farms/ orchards and information on the different planted areas. In addition, information regarding shipping routes used, patterns of orders dispatching, and shipping lead times can be captured. All this data can be analysed to:

1) Drive customer orders pattern which will be used to estimate statistical distributions for orders quantity, delivery week, and delivery days. These distributions will be used to generate customer orders (section 5.3.1). Also, identify lead times of the shipping routes that will be used in orders dispatching simulation model (section 5.3.2);

2) Analyse patterns of daily harvested quantities and generate curves for daily products ripening (Figure 5-4) and fit them into the equation of "daily rate of un-harvested units" (*R*) to estimate its parameters (equation 2, section 5.1.1);

3) Estimate initial values for stock variables that represent the five production areas that were identified for farm dynamics block in section 5.1.3. Also, average yield of each production area will be estimated;

4) Financial data for resources hiring, renting purchasing costs, products shipping costs; outsourcing costs and products selling prices; and,

5) Provide historical figures of behaviour for the three AFPSC entities that can be used at the phase of verifying and validating the simulation model.

5.5.2 *Data Sampling*

The objective of data sampling is to generate data regarding different processing times for the various activities of both DES and ABM model components (e.g., wrapping pallets processing time). These data usually are not tracked and recorded in business internal databases similar to production figures or financial data. Hence, fieldwork has to be conducted, and multiple samples for different processes need to be collected to estimate statistical distributions for their processing times.

Data sampling collection needs to be censored for some processes and activities that are assigned to seasonal agents in the model (e.g. harvesting activities). Samples should be collected for workers with different working experiences to capture the impact of experience variations on performance as explained before in section 5.4.1.

5.5.3 *External Data Sources*

The objective of data is to drive the assumptions regarding exogenous variables in the simulation model. These assumptions are explained in subsections 5.4.1 to 5.4.3.

CHAPTER 6: TABLE GRAPE SUPPLY CHAIN – A CASE STUDY

6.1 Introduction

Grapes are one of the most palatable and widely produced fruits in the world (Fadhel et al. 2005). Countries around the world import and export grape products across borders and continents (Louime et al. 2007). It is estimated that global grape production is 74.49 million tonnes yielding from a total growing area equivalent to 7.12 million hectares in 2014. This represents approximately an 11% increase in production compared to 2004 (FAO 2016). There are many varieties of grapes. However, they are divided into two main categories, 1) table grapes and 2) wine grapes. The latter category accounts for more than 80% of the global production, while table grapes represent 13% (BUNEA and BUTA). Global consumption of table grapes, in particular, has grown at a higher rate amounting to 30% in the past five years and was expected to reach 21.9 million tonnes in 2017, of which 2.9 million tonnes are exported from producing countries to foreign markets (USDA 2017). The main export destinations remain the European Union (EU) and the US who are the world's largest table grape importers – both accounting for nearly half the global trade (Weihua et al. 2013). Table grapes are non-climacteric, perennial crops. They also have the most planning issues and characteristics which is addressed in the proposed framework. For example, table grapes are a labour-intensive industry as it relies mostly on hand operations for harvesting and post-harvesting activities (Meyers et al. 2006). Grape products have a critical shelf life and a high perishability rate of respiration which makes them vulnerable to high post-harvest losses (Blackburn and Scudder 2009). Table grapes also have complex harvesting and post-

harvesting operations that are mostly reliant on seasonal workers (Meyers et al. 2006, Bohle, Maturana, and Vera 2010). Therefore, a table grape supply chain (TGSC) case study is selected for applying the framework and test its validity.

6.1.1 Egyptian Table Grape Industry

The production of grapes in Egypt has existed for more than six thousand years where viticulture was often depicted in the heritage of ancient Egyptians as a source of fruit, drink, and medicine (Nunn 2002). However, the production of table grapes for export only began in the 20th century coinciding with the shift toward desert farming. The employment of drip irrigation and other modern agricultural practices, and the introduction of foreign expertise to facilitate knowledge transfer to the emerging industry. Today, Egypt ranks 15th worldwide in terms of grape production with a total of 1.4 million tons (FAO 2016). Ninety percent of Egyptian production is consumed locally, and close to 120 thousand tons of table grapes are exported each year predominantly to the EU, a figure which has multiplied consistently over the past 10 years (El-Sawalhy, El-Azayem, and Zaghloul 2008). However, the Egyptian table grape industry is challenged by fierce competition from other exporting countries who are rivals in supplying EU retailers.

The Egyptian grape harvest usually commences in mid-May, falling between the Indian supply, which typically ends in early May, and Spanish production which begins in July. This leaves a narrow window of opportunity for Egyptian exporters to supply the market for a period which ranges from four to six weeks depending on an array of climatic, logistical, and market-based factors which influence supply and demand during this period. (Diab et al. 2009). Egyptian growers and exporters, therefore, strive to efficiently plan for their

operations to ensure cost reduction and rapid entry into the market in order to remain competitive.

6.1.2   Ragab Farms – A TGSC Case Study

Ragab Farms is a third-generation producer & exporter of premium fresh produce based in the North of Egypt. Stretching over 1700 acres of reclaimed desert land. The company has more than 300 employees and blends local competence with global expertise through the guidance of international technical consultants. Its main products are exported to Europe, Africa, and Asia and include table grapes, citrus, pomegranates, in addition to ornamentals.

Ragab Farms manages a sizeable scale of operations, which involves the production and management of around ten thousand tons of fruit. The grapes division is one of the most important business units in Ragab Farms. It operates on 300 acres of land and produces 10 varieties of green, red, and black grapes during the Egyptian season which extends from Mid-May until the end of August. Ragab Farms produces 1500 tons of grapes per year, the majority of which are packed and exported through the company's packing house and export subsidiaries. Therefore, its SC consists of grapes *grower*, *packing house*, and *exporter*.

6.2 Data Collection and Analysis

Multiple site visits and meetings took place in 2016 – during harvest season – with the managers, staff of Ragab Farms, and its subsidiaries to collect the required data for the case study. The data regarding operations time, products type, logistics activities and information flow between the three entities were tracked throughout the season. The data was then processed and analysed to estimate the distribution of the input variables of the simulation

model. Data collection and analysis methodologies are discussed in detail in the next sections.

All financial data which is related to 1) Human Resources hiring cost; 2) Non-human resources renting/ purchasing costs; 3) Planting a new vineyard cost; 4) Replacing a vineyard cost; 5) shipping costs; and 6) selling prices, are presented in **Appendix 3**.

6.2.1   *Data Collection for Grower Entity*

Grapes are picked and placed in crates which take around 16 bunches, with an average weight 0.5 Kg. To collect the full crates of grapes, carts with a capacity of 100 crates, are used throughout the vineyard. Carts are then moved to the loading points and loaded on transportation trucks of the average capacity of 300 crates. Analysing grower data was essential for estimating:

1) Parameters of equation (2) – chapter 5 – that simulates daily rate of ripening for unharvested units (R). Since the framework is applied in this study on vineyards, "units" will be replaced here and after by "bunches".

2) Statistical distributions for seasonal harvester times and loss rate for harvest activities.

3) Statistical distributions for times of the resources used for transporting harvested produce to packing house (i.e., movers, carts trucks).

4) Parameters and initial values for variables and stocks of the SD model of farms (also called vineyards in table grapes context).

6.2.1.1 *Grapes Ripening*

Patterns of grape ripening can be extracted from the actual data of daily harvested quantities (Figure 6-1.a). The daily ripening rate of unharvested quantities can then be calculated

following the same pattern illustrated in Figure 6-1.b. This rate represents a fraction of bunches on a tree that reaches the desired ripe degree, and hence ready for harvesting. Based on historical data figures of daily harvested quantities from season 2015 and 2016, it is noticed that ripening patterns across all vineyards are much the same. This became more obvious when a comparison is conducted on "daily ripening fraction of un-harvested quantity" as well (Figure 6-1.b).

(a)   (b)
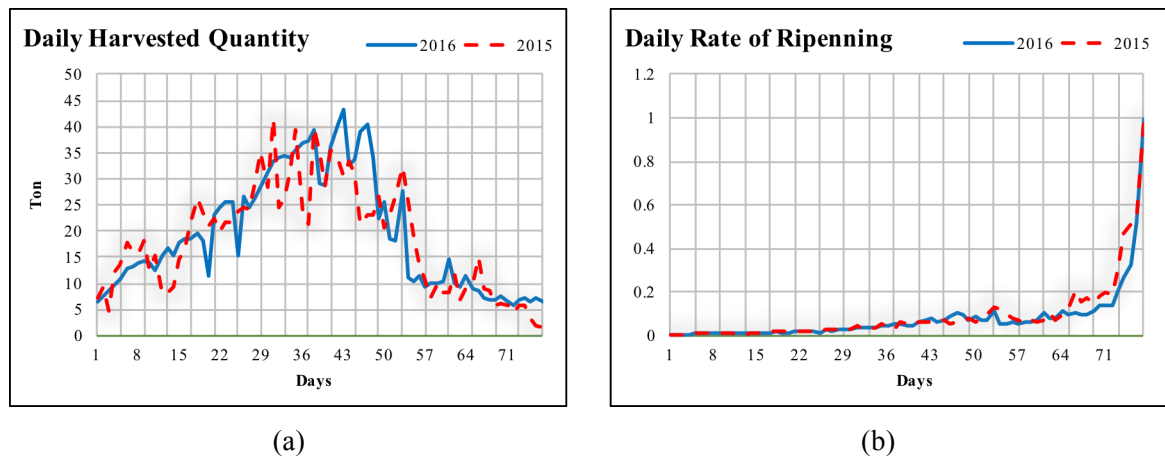
Figure 6-1: Daily Harvested Quantities (a) and Daily Ripening for Un-Harvested Bunches (b) for 2015 and 2016 seasons.

The parameters of equation (2) are estimated, by curve fitting as presented in Figure 6-2. It worth to notice that curve fitting works fine over the whole season except for the last week where the big discrepancy between actual and fitted curves can be noticed. This discrepancy resulted in some variations in the simulation outcomes compared to the actual figures. To overcome this problem, two fitted curves will be used, one for the period from day 1 to 70 and the other from 70 to end of the season. The results for this solution is presented in Figure 6-3. Therefore, equation (2) will be modified in the simulation to be:

$$R(t) = \begin{cases} r_{11} \cdot e^{r_{12} \cdot t}, & t <= 70 \\ r_{21} \cdot e^{r_{22} \cdot (t-70)}, & Otherwise \end{cases} \qquad (18)$$

Where r_{11}, r_{12}, r_{21} and r_{22} are the parameters of the new equation with estimated values

0.0069, 0.0442, 0.0796 and **0.3239** respectively.
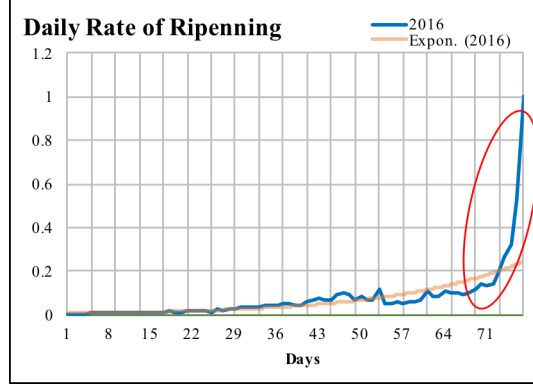
Figure 6-2: Curve Fitting for Daily Rate of Ripening in 2016

(a)　　　　　　　　　　　(b)　　　　　　　　　　　(c)
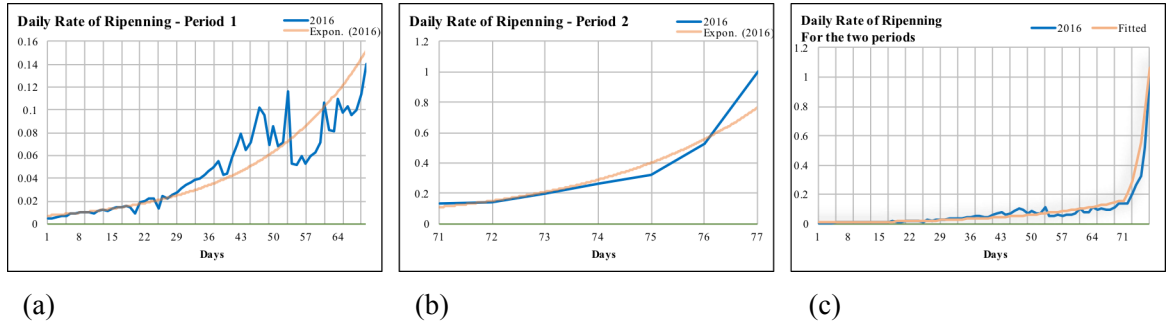
Figure 6-3: Two Periods Fitting for Daily Ripening Rate

6.2.1.2 Seasonal Pickers

During grape harvesting season, pickers are acquired daily according to the predicted harvest

volume of next day. Labour contractors usually recruit seasonal pickers from nearby rural

areas. The existence of many grape farms in Egypt creates high competition on hiring trained

seasonal pickers. This competition affects the consistency of the hiring process. In addition,

the high turnover of seasonal labourers also affects picker supply which causes experience loss. The turnover could be 2 or 3 years in some situations due to social factors connected to Egyptian rural socioeconomics.

It is crucial to understand the relationship between the worker's experience in grape picking and their performance during harvesting activities. To achieve this the behaviour and motion of the pickers during harvesting operations is closely monitored. These observations were collected for two groups of pickers, (1) pickers who didn't participate in any grapes harvesting activities before (Least Experienced Pickers) and (2) pickers who participated in grapes collection for three seasons prior to the current one (Most Experienced Pickers). The purpose of these observations was to capture the behaviour of the pickers during harvesting and to analyse the processing times and losses rate of the two groups of pickers. The data were processed using statistical analysis techniques to estimate their statistical distributions and their parameters (Table 6-1).

6.2.1.3 Transportation Activities

Once a crate becomes full of grape bunches, it is ready to be moved by cart to the collection point. Afterwards, carts are moved to trucks' collection point where they are loaded and then transported to the packing house. The waiting time of the raw grapes at these different collection points is critical for the quality and safety of the crop. The longer the waiting and moving times, the more vulnerable the crop become for aspiration, water loss, and consequent damage. Multiple in-field measuring cycles were performed to collect and statistically analyse them. The statistical analysis is conducted for the two major transportation activities namely: 1) Loading Crates on carts and 2) Offloading crates to

trucks. However, times of movements for the crates by the three resource types (movers, carts and trucks) are also considered in the model. These times are calculated during run time depending on the distance of movement and employed resource speed (Table 6-2). The fitted distribution graphs against actual data are also presented in **Appendix 4**.

6.2.1.4 Vineyards SD Model Parameters

The primary stock variables for the SD model of farms are derived using grower's information on the vineyard areas. Also, growing expert judges were used to estimate parameters of annual yield per acre for the different age groups of vineyards alongside with growing and transition times (Table 6-2).

6.2.2 Data Collection for Packing House
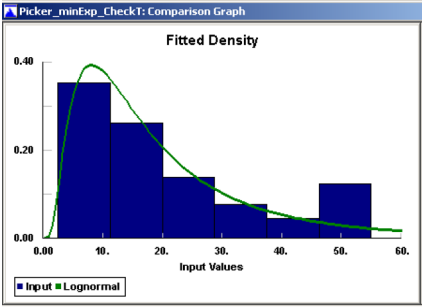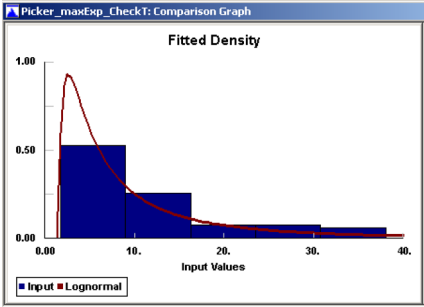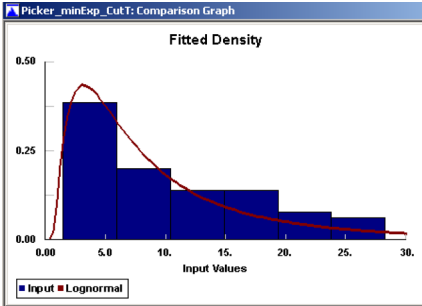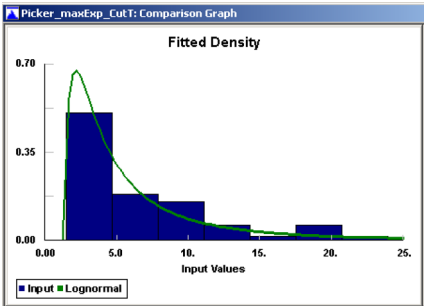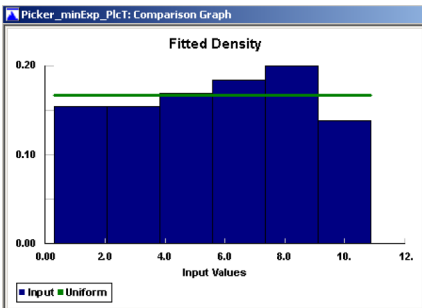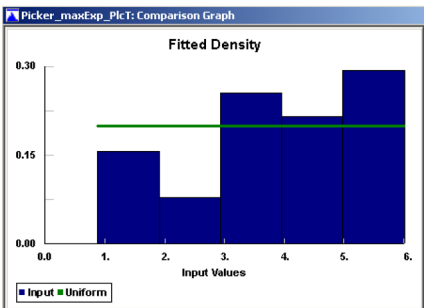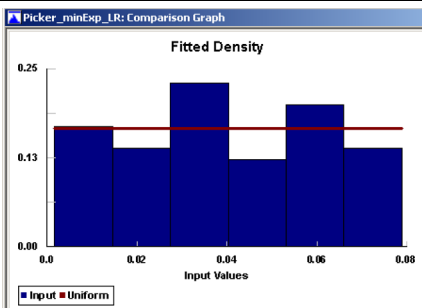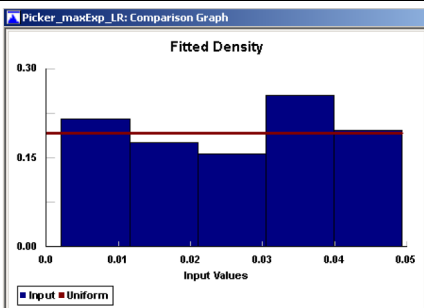
Once trucks arrive at the packing house, the pallets of raw grapes are offloaded in an air-conditioned receiving area to preserve grapes quality. Pallets are then moved to the packing lanes to be packaged into 0.5 kg punnets which are ultimately sold to retail consumers. Punnets are placed in larger boxes with a capacity of 10 punnets and carried by conveyors to the ground services area where they are lined onto pallets of 120 boxes. Pallets are then wrapped and moved to a 'fast cooling' facility for dropping grapes temperature from 16/17 Celsius to -2 Celsius while they wait for exporter's dispatching orders.

Some historical figures for packing house operations times and product quantities (e.g. total packed quantity over the season) were collected to conduct simulation validation phase. Further analysis of the packing house data is conducted to estimate:

1) Statistical distributions for seasonal packer times and loss rate during packing activities.

2) Statistical distributions for times of other packing house resources.

3) Input values for different capacities of the packing house.

Table 6-1: The Fitted Statistical Distribution for Seasonal Pickers Data

	**Least** Experienced Pickers	_**Most**_ Experienced Pickers
Time for "_**Checking**_ Bunches Ripeness" (Seconds)	$\mu = 3.04 \qquad \sigma = 0.925$	$\mu = 2.38 \qquad \sigma = 0.925$
Time for "_**Cutting**_ Ripen Bunches" (Seconds)	$\mu = 2.32 \qquad \sigma = 0.649$	$\mu = 1.83 \qquad \sigma = 0.649$
Time for "_**Placing**_ Bunch in A Crate" (Seconds)	$min = 0.9 \qquad max = 10.84$	$min = 0.9 \qquad max = 5.97$
**Loss Rate** During Harvesting	$min = 0.002 \qquad max = 0.078$	$min = 0.002 \qquad max = 0.048$

Table 6-2: Grower Model Parameters

	Parameter Distribution	Value(s)	Unit
SD Model Parameters			
Initial "New Planted Area"	Constant	0	Acre
Initial "Early Productivity Area"	Constant	50	Acre
Initial "Normal Productivity Area"	Constant	200	Acre
Initial "Normal Productivity Area"	Constant	50	Acre
Initial "Normal Productivity Area"	Constant	0	Acre
Time to Grow	Constant	2	Years
Time to Become Normal	Constant	16	Years
Time to Become Old	Constant	2	Years
Time to Die	Constant	2	Years
Early Area Yield	Constant	3	Ton/ Year
Normal Area Yield	Constant	65	Ton/ Year
Late Area Yield	Constant	3	Ton/ Year
Other Parameters			
Seasonal Pickers Pool Size	Constant	1000	picker
Loading Crates on Cart	Log-Normal	$\mu = 1.83$ $\sigma = 1.15$	Seconds
Offloading Crates from Cart to Truck	Log-Normal	$\mu = 0.947$ $\sigma = 0.859$	Seconds
Crate Mover Speed	Constant	1.4	M/Second
Cart Speed	Constant	0.5	M/Second
Truck Traveling Time	Constant	20	Minutes

6.2.2.1 Seasonal Packers

Similar to the harvester, seasonal packers in the packing house are characterised by an inconsistent supply, high turnover, and fierce competition between growers. Therefore, the data regarding packer performance in the packing house is collected using similar methodologies used in collecting the data related to harvesters. The estimated statistical distributions for the most and least experienced packers' groups are presented in Table 6-5.

Table 6-3: Packing House Model Parameters

	Parameter Distribution	Value(s)	Unit
Seasonal Packers Pool Size	Constant	800	packer
Raw Pallet Unloading from Truck	Triangular	$min = 25,\ avg = 64,\ max = 140$	Second
Raw Pallet Moving to Receiving Area	Triangular	$min = 28,\ avg = 70,\ max = 116$	Second
Raw Pallet Moving to Packing Area	Triangular	$min = 39,\ avg = 74,\ max = 144$	Second
Moving Raw Boxes to Tables	Uniform	$min = 5,\ \ max = 15$	Second
Place Packed Boxes on Pallets	Triangular	$min = 3,\ avg = 11,\ max = 20$	Second
Moving Pallet to Wrap	Triangular	$min = 30,\ avg = 50,\ max = 164$	Second
Wrapping Pallet	Triangular	$min = 6,\ avg = 12,\ max = 18$	Minutes
Moving Pallet to Temporary Storage	Triangular	$min = 36,\ avg = 73,\ max = 118$	Second
Moving Pallet to Cool Fans	Triangular	$min = 46,\ avg = 64,\ max = 140$	Second
Fast Cooling Time	Constant	8	Hours
Moving Pallet to Cold Storage	Triangular	$min = 33,\ avg = 50,\ max = 78$	Second

6.2.2.2 Ground Services Resources Data

Several other activities other than packing grapes take place within the packing house. For example, offloading pallets from received trucks, moving them to receive area lining up packed boxes onto pallets…etc. Multiple measuring cycles were conducted inside the packing house for all these activities to collect processing time and generate their statistical distributions (Table 6-3).

6.2.3 Data Collection of Exporters
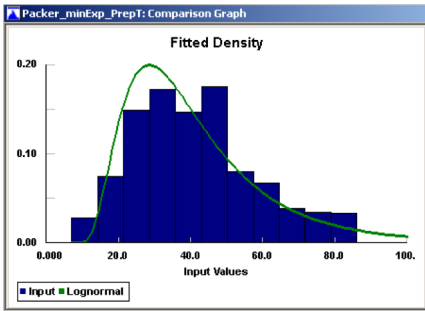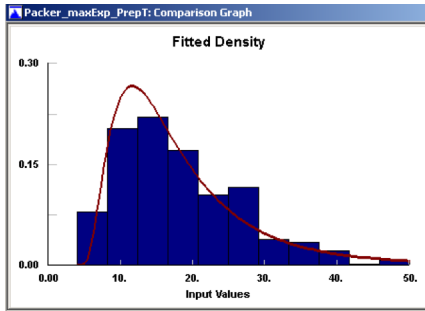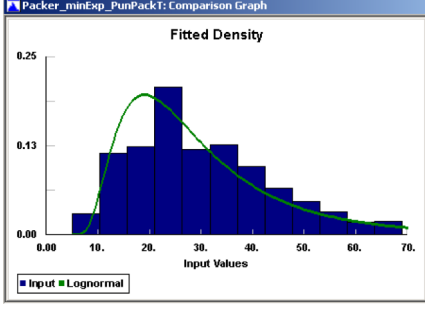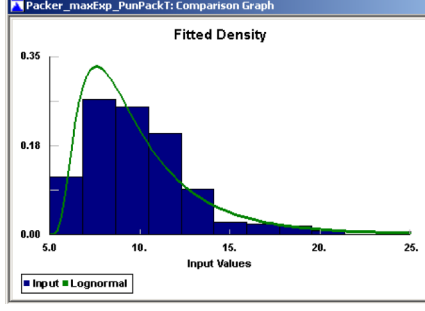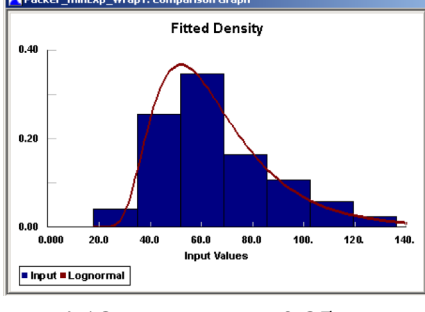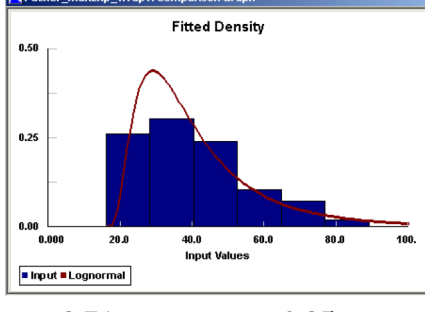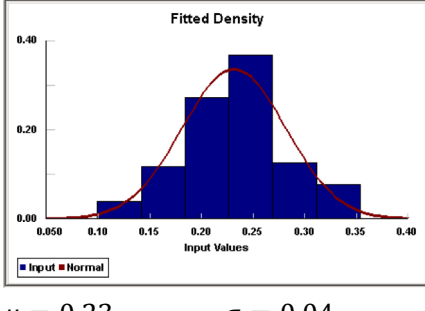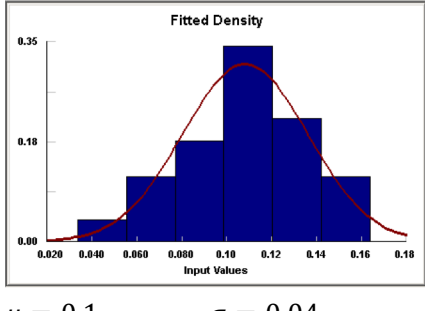
Exporters receive orders a few weeks prior the beginning of harvesting season. Each order comprises of 1) order quantity, 2) expected delivery week and, 3) expected delivery day within this week. Multiple orders might be received from the same customer over different delivery weeks to comply with targeted market requirements. The most valuable information which needs to be collected for the simulation model of this entity is customer orders records and the timing of orders dispatching from the packing house. The former was used to estimate customer orders attributes such as product quantity and delivery dates, while the latter was used to validate model behaviour.

Table 6-4: Probability Distribution for Customer Orders Delivery Week

Week number	1	2	3	4	5	6	7	8	9	10	11	12
Probability	0.03	0.15	0.23	0.16	0.14	0.04	0.02	0.02	0.12	0.04	0.02	0.02
Cum. Probability	0.03	0.18	0.41	0.57	0.71	0.75	0.77	0.79	0.91	0.96	0.98	1.00

Table 6-5: The Fitted Statistical Distribution for Seasonal Packers Data

	Least Experienced Packer	**_Most_** Experienced Packer
Time for "**_Preparing_** Bunch" (Seconds)	$\mu = 3.72 \qquad \sigma = 0.5$	$\mu = 2.9 \qquad \sigma = 0.5$
Time for "**_Packing_** Punnets" (Seconds)	$\mu = 3.4 \qquad \sigma = 0.5$	$\mu = 1.8 \qquad \sigma = 0.5$
Time for "**_Wrapping_** Box" (Seconds)	$\mu = 4.18 \qquad \sigma = 0.25$	$\mu = 3.71 \qquad \sigma = 0.25$
Loss Rate During Packing	$\mu = 0.23 \qquad \sigma = 0.04$	$\mu = 0.1 \qquad \sigma = 0.04$

The received orders are requested to be delivered over 12 weeks from season commencement. The probability distribution for receiving an order during any of these weeks is presented in Table 6-4. In the simulation model, orders delivery dates are generated randomly between three days of the week: Monday, Wednesday, and Friday (i.e., days 2, 4, and 6). Similarly, order quantities would have possible values that are increments of between 5 and 40 pallets. Other parameters that belong to exporter actor are presented in Table 6-6.

Table 6-6: Exporter Model Parameters

	Parameter Distribution	Value(s)	Unit
Air Shipping Lead Time	Constant	1	Days
Sea Shipping Lead time	Constant	8	Days
From Farm to Shipping Lead Time	Constant	2	Days
Weekly Dispatching Days		1, 3 and 6	
Customer Window for Early Delivery	Constant	7	Days

6.3 Table Grape Supply Chain Simulation Model

6.3.1 Model Assumption

The harvest season is assumed to commence at 15th of May every year and ends either by dispatching all customer orders or on the 31st of August. The following set of assumptions are considered regarding the exogenous variables in the model:

1- The human resources managers have stated that usually half of the seasonal workers they recruit for operations over one season will not be available for the next one. Therefore, the turnover of the seasonal workers is assumed to be 50%; this means that

half of available workers during a particular season may not be available next season and may be replaced by new ones.

2- Market demand for the initial season is assumed to be 14334 tons, and Ragab Farms share of this demand is 10%. Also, the market demand is assumed to grow by 7% every year.

3- Outsourcing availability of the grapes is estimated to be 70%.

6.3.2 Model Construction

Relying on the system understanding obtained and the conceptual modelling developed for the AFPSC in chapter 5, a comprehensive hybrid simulation model was constructed for Ragab Farms using "AnyLogic v.7" simulation package. Simulation modules were connected to resemble AFPSC business model, where the blocks are connected based on the conceptual framework flow charts, process maps, agents state charts and stock and flow diagrams. An object-oriented programming approach was used to customise pre-defined blocks and agents. A Microsoft Excel workbook was also used to save the measured KPIs and other behavioural data after each simulation run (i.e., replicate), followed by exporting most important behavioural data in graphical form for future analysis and validation.

6.3.3 Model Verification and Validation

Model verification is the process of ensuring whether the conceptual framework in terms of modelled components behaviour is reflected correctly in the hybrid model. Validation is also concerned with whether the developed model is an accurate representation of the real system. The simulation model is, therefore, verified and validated using the following steps. *First*,

process maps, agent state charts, and causal loops diagrams were verified through multiple discussions held with the managers and staff in Ragab Farm before and during the model development process. This allowed participation in the modelling process which increases confidence in the framework outcomes. It also provided users with the opportunity to question and criticise the conceptual models and process maps. *Next*, the model output was examined for the feasibility under a variety of settings of input parameters. For instance, the model was tested under the assumption that no demand is received in any given season. The model is logically reached as all grower production was marketed locally and no operations had taken place at the packing house or exporter entities. *Last*, the model outcomes of the baseline case were validated against the actual data of the real system.

To reduce the model development cycle time and to increase the confidence in the simulation model results, the verification and validation activities were carried out through the whole development phases of the hybrid simulation model. The model was developed over three phases starting with modelling grower business, followed by modelling packing house and exporter entities. After each development phase, the model was verified and validated with respect to the outcomes of previously completed phases. The model logic was verified to ensure that agent and object statuses followed the correct reasoning during simulation runs. This was conducted by applying visual tracking using simulation animation capabilities.

6.3.4   *Baseline Case Validation Results*

Model validation process indicates the model ability to represent reality. The most conclusive test of model validation can be held in the simulation model which represent current system

state (i.e. As-Is situation) and its outcomes. Simulation outcomes, in this case, can then be compared with the actual results of the studied systems. The simulation runs of the current system state are called "*baseline case*" simulations run. This baseline case is supposed to reflect the real system performance during last season (i.e., 2016 season) where all planning decisions are set to their default values. A set of performance metrics and system variables were selected to form the comparison criteria between baseline simulation and real system actual outcomes (Table 6-7). The simulation and agent-based models were run for 20 independent replications to obtain independent and identically distributed outputs, with each replicate re-initialised by different pseudo-random number seed.

Validation was conducted by using a visual comparison between simulation models and real system behaviour. For each system variable, a validation process was applied using a time series graph that consists of three datasets; 1) historical data, 2) average values of the simulation output (based on 20 replications) and 3) the output of a single replication. The graphs of all validation processes are presented in Table 6-8. The visual comparison between models output and the actual data suggest that the simulation and agent-based models behave in the same manner as the real system and can be considered as a valid representation of the genuine business (i.e., TGSC).

Table 6-7: AFPSC Validation Variables

Grower Variables	1- Daily Harvested Quantity
	2- Total Harvested Quantity
	3- Daily Number of Pickers
	4- Picker Productivity
Packing House Variables	5- Daily Outsourced Quantity
	6- Total Outsourced Quantity
	7- Daily Received Quantity
	8- Total Received Quantity
	9- Daily Packed Quantity
	10- Total Packed Quantity
	11- Daily Wasted Quantity
	12- Total Wasted Quantity
	13- Daily Number of Packers
	14- Packer Productivity
Exporter Variables	15- Daily Dispatched Quantity
	16- Total Dispatched Quantity
	17- Daily Planned Dispatched Quantity
	18- Total Planned Dispatched Quantity
	19- Total Delayed Quantity
	20- Customer Service Level

Table 6-8: Simulation Model Behaviour Versus Real System Behaviour

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

(j)

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(o)

(p)

(q)

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(t)
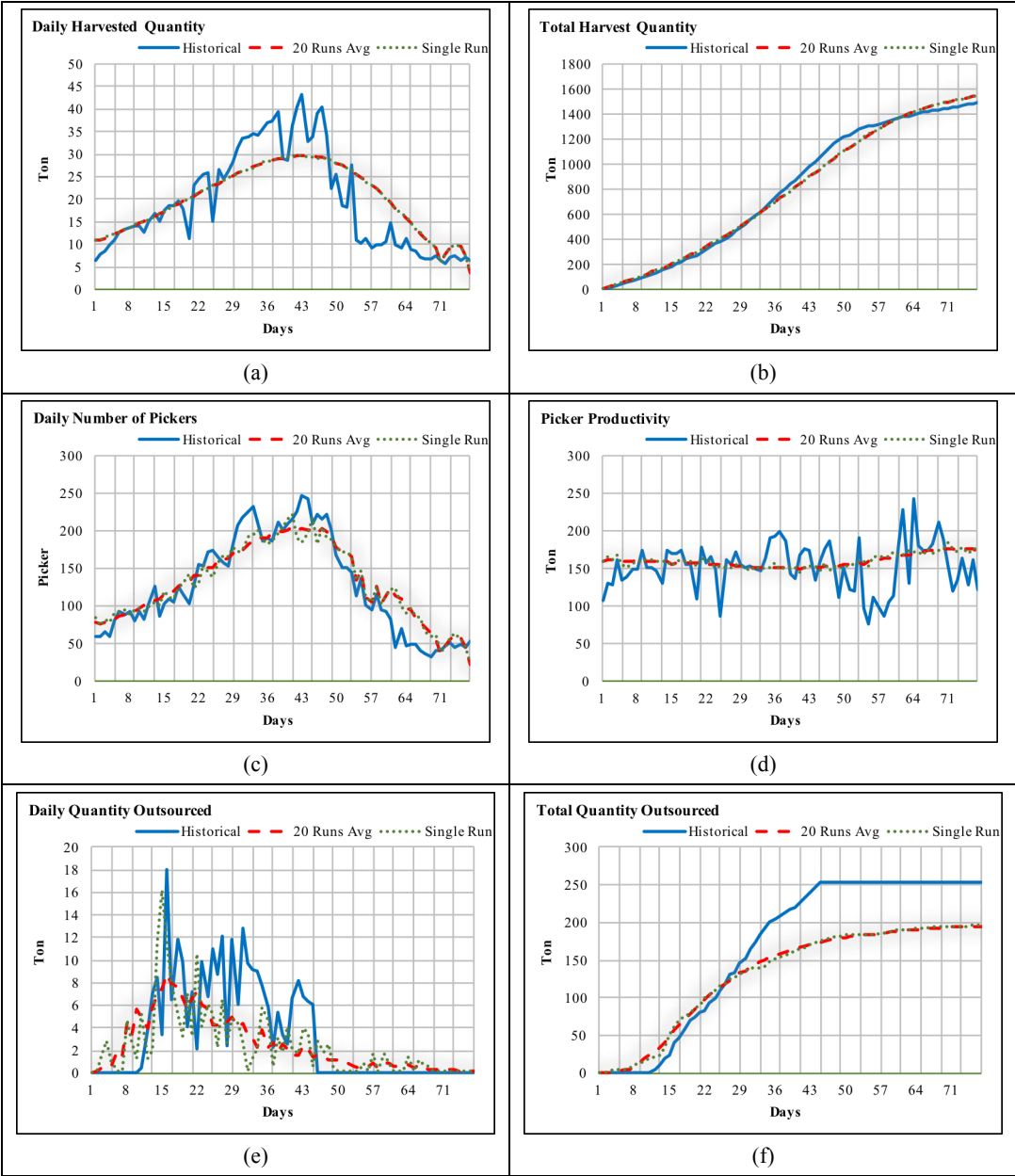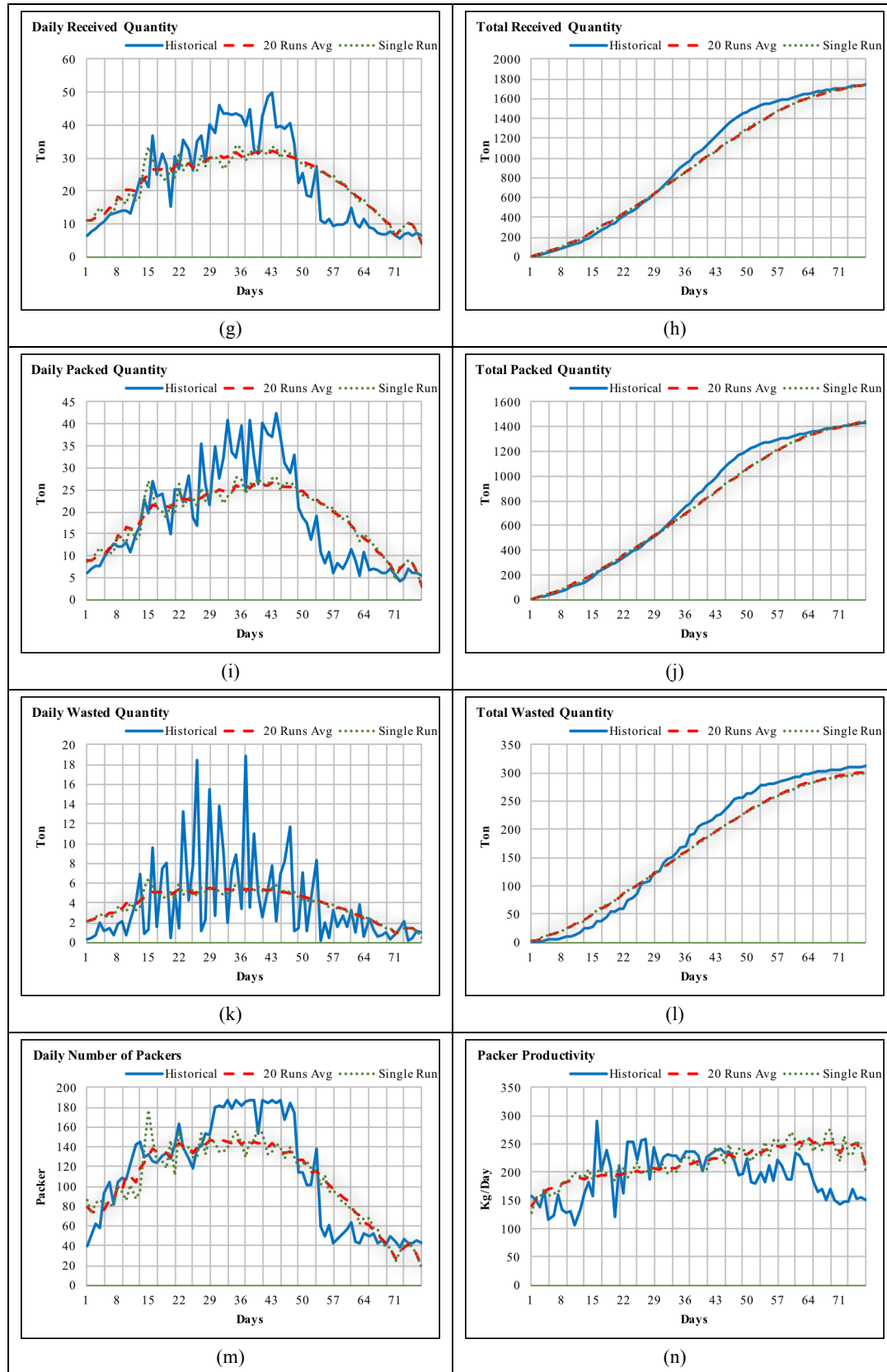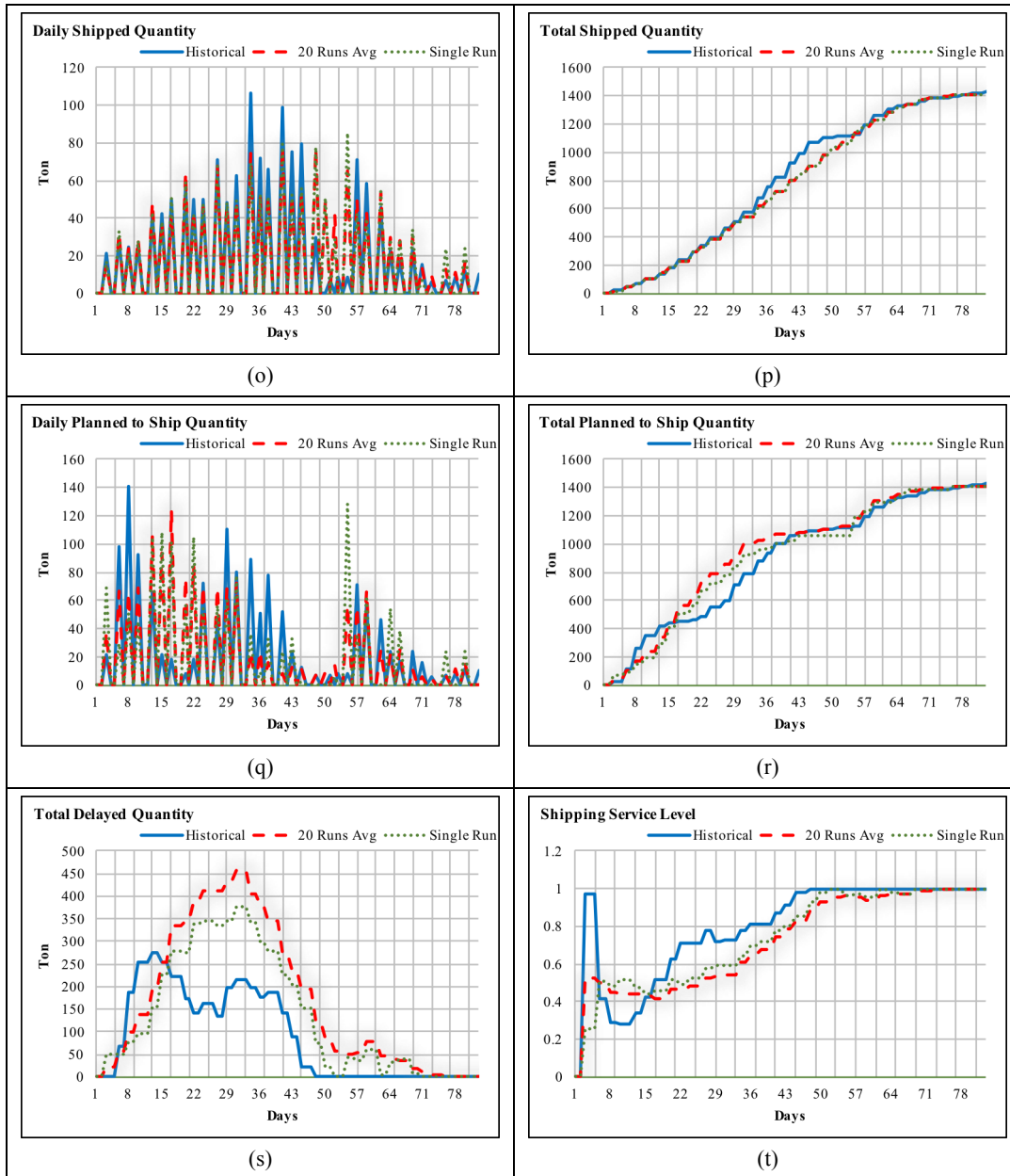
The validation results have also proven the model's ability to accurately simulate the

behaviour of the two main components that drive dynamics of the TGSC supply and demand

as illustrated in figures (a), (b), (q) and (r) (Table 6-8). Although some variables have high

fluctuations over time that are not fully captured by the model (e.g., Figure (a), (i) and (k)),

their accumulated variables (e.g. Figure (b), (j) and (l)) show that their behaviour over time is identical with real system accumulated behaviour. Hence, the confidence in the overall model behaviour is more important than its ability to capture unique variations of some variables, primarily when the model is used to address tactical and strategic planning issues.
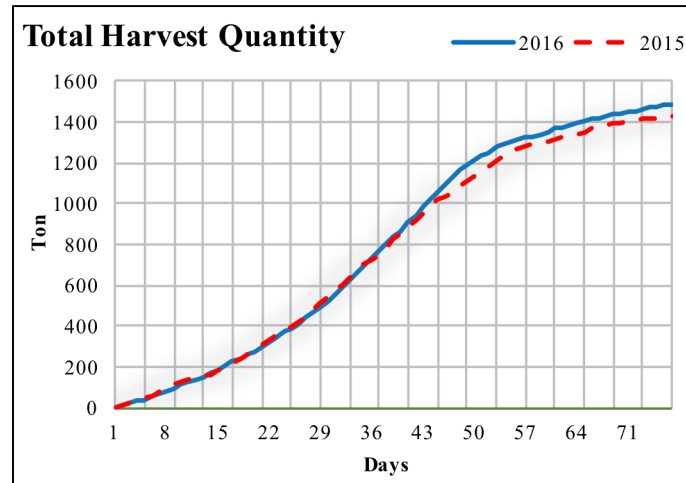
Figure 6-4: Total Harvested Quantities for 2015 and 2016 seasons

Finally, the deviations between simulated and actual data are statistically examined by calculating the mean absolute deviations (MAD) for each system variable (Table 6-9). The MAD is a commonly used measurement to evaluate simulation models accuracy (Kobayashi and Salam 2000). It is adapted for the forecasting and simulation applications, particularly in situations where enough data are available. The values for MAD of each variable is quite acceptable if it is compared to its values range. MAD values of all simulation variables in the studied TGSC case are close enough to the MAD values of the actual data to support the conclusion that the developed simulation models represent real system performance (Table 6-9).

Table 6-9: AFPSC Validation Variables

Validation Variable	MAD for Single Run	MAD for 20 Runs Avg.
Daily Harvested Quantity	4.9	4.9
Total Harvested Quantity	38.3	38.5
Daily Number of Pickers	18.6	18.0
Picker Productivity	25.6	25.1
Daily Outsourced Quantity	2.6	2.3
Total Outsourced Quantity	42.1	42.0
Daily Received Quantity	6.9	6.6
Total Received Quantity	62.3	62.6
Daily Packed Quantity	5.6	5.5
Total Packed Quantity	44.5	45.1
Daily Wasted Quantity	2.8	2.7
Total Wasted Quantity	17.8	17.0
Daily Number of Packers	24.6	22.0
Packer Productivity	41.0	40.8
Daily Dispatched Quantity	6.6	6.2
Total Dispatched Quantity	33.3	33.6
Daily Planned Dispatched Quantity	15.1	11.7
Total Planned Dispatched Quantity	58.9	68.5
Total Delayed Quantity	72.5	99.2
Customer Service Level	0.1	0.1

6.4 Modelling TGSC Planning Decisions and Business Scenarios

The next stage after model verification and validation is to test its efficacy as a planning and decision-making tool for AFPSC. Different planning decisions and business scenarios are developed cooperatively with the TGSC managers to examine models' ability to support decision makers in planning activities. Some scenarios consider planning decisions on either the operational, tactical or strategic levels, while others focus on the integration between the

two or three management levels. The business scenarios and their results are discussed in the following sections. The baseline case will be referred here by business as usual scenario *(BAU)* where all decisions are set to their default values.

6.4.1 *Seasonal Workers Recruiting Scenarios (Operational & Tactical Planning Level)*

During grape harvesting season, both harvesters and packers are recruited daily based on managers' demand. The recruiting process is reliant on the seasonal workers from nearby rural areas. The fierce competition for skilled workers affects the consistency of labourer supply. In addition, recruiting agencies cannot guarantee to supply the same group of labourers every day because of the high variations in the needs of growers and packing houses alongside with the high turnover rate among seasonal labourers. However, managers believe that hiring same workers every day reduces training efforts and reflects positively on operations efficiency and total cost.

Hence, the rationale behind examining different recruiting scenarios is to envisage how by hiring the same workers over the season and retaining their work experience operations efficiency would be improved in terms of productivity, minimal product waste, and total cost (Table 6-10). Three scenarios are tested relating to the seasonal hiring policies scenarios; the first scenario represents the business as the usual situation (*BAU*) where labourers are hired subject to the expected work volumes. While seasonal workers are selected randomly in the *BAU,* in the second scenario (*S11* scenario) workers are hired according to the number of days they were hired in the farm previously – where the highest priority is given to the workers who are recruited most often. The third scenario (*S12*)

proposes hiring a fixed number of workers, but the same group (i.e., same persons), every day over the season.

Table 6-10: Seasonal Workers Scenarios

	Scenarios Controls	
Scenarios Code	*C1: Grower Hiring Policy*	*C2: Packing House Hiring Policy*
BAU	Variable (D^H) – Random Agents	Variable (D^P) – Random Agents
S11	Variable (D^H) – Selected Agents	Variable (D^P) – Selected Agents
S12	Fixed (D^H) – Selected Agents	Fixed (D^P) – Selected Agents

It is assumed that for **S11** and **S12** scenarios, increased hiring rates (25%) will be paid for the recruiting contractors to motivate them into fulfilling the scenarios' requirements. All other controls and parameters are set similar for the three scenarios. Also, a fixed random generator seed is used for the simulation runs to ensure same demand and supply settings. The three scenarios will be simulated for one harvesting season. Various metrics are presented and explored out of the simulation runs to investigate system's performance under the three scenarios (Table 6-11).

The preliminary results suggested that system's performance under S11 and S12 scenarios, where worker's experience is retained, outperform the BAU scenario where workers supply is inconsistent (Figures (e) and (f) in Table 6-11). The development of harvester and packers experience – when consistently hired over season – has positively impacted their productivity and skills (Figures (c) and (d) in Table 6-11). Having said that number of pickers and packers were fixed over the season for **S12** scenario explains the drop in their productivity from day 57 as the quantities to be processed were decreasing. The improvement of workers' skills has led to a significant improvement in the grape wasted

quantities (Table 6-11 g and h), particularly at the packing house. It also resulted in a noticeable reduction in the number of recruited workers, mainly in **S11** scenario (Figures (a) and (b) in Table 6-11).

Table 6-11: Simulation Results for Seasonal Workers Hiring Scenarios

(a)　　　　　　　　　　　　(b)

(c)　　　　　　　　　　　　(d)

(e)　　　　　　　　　　　　(f)

(g)

(h)

(i)

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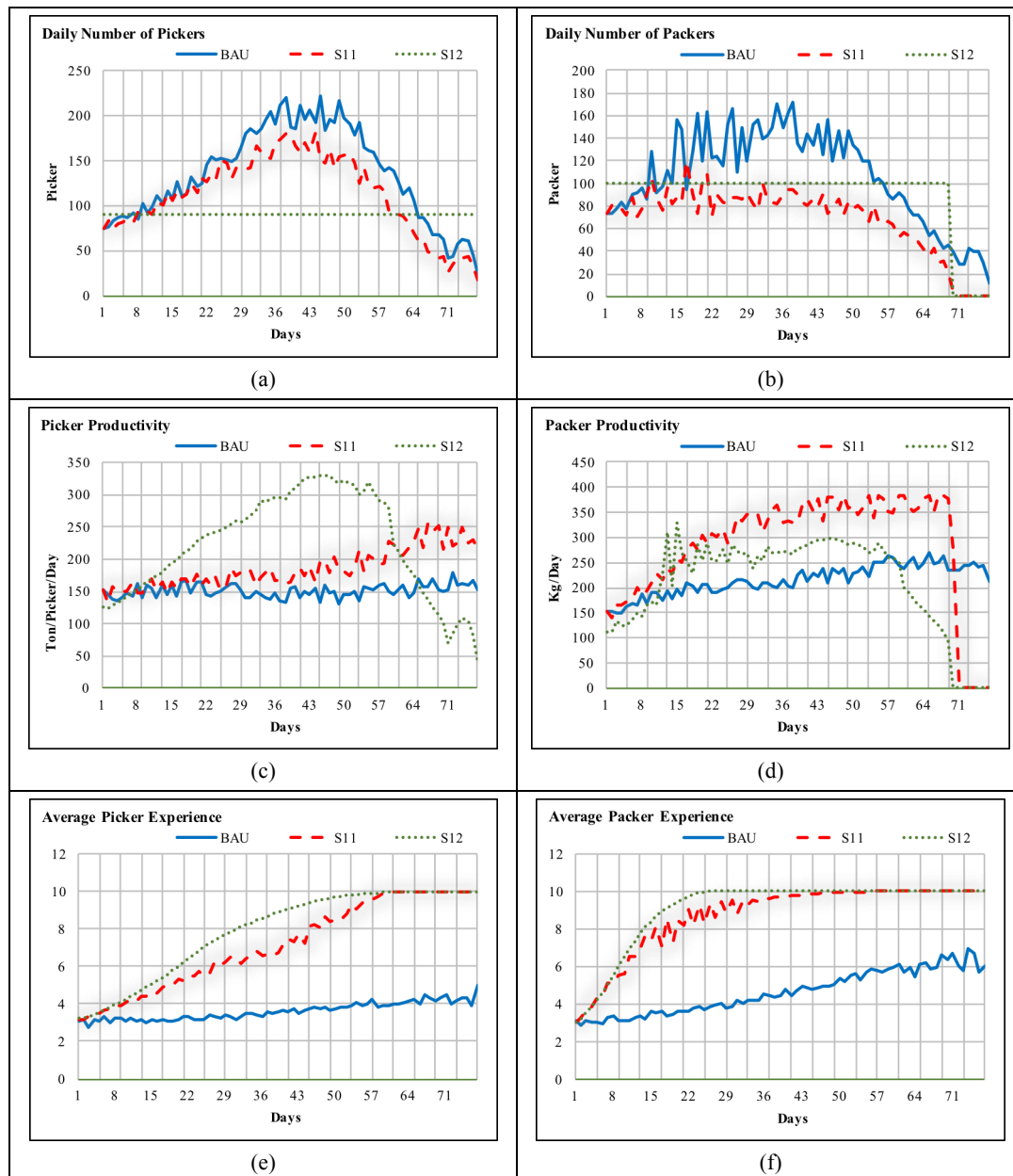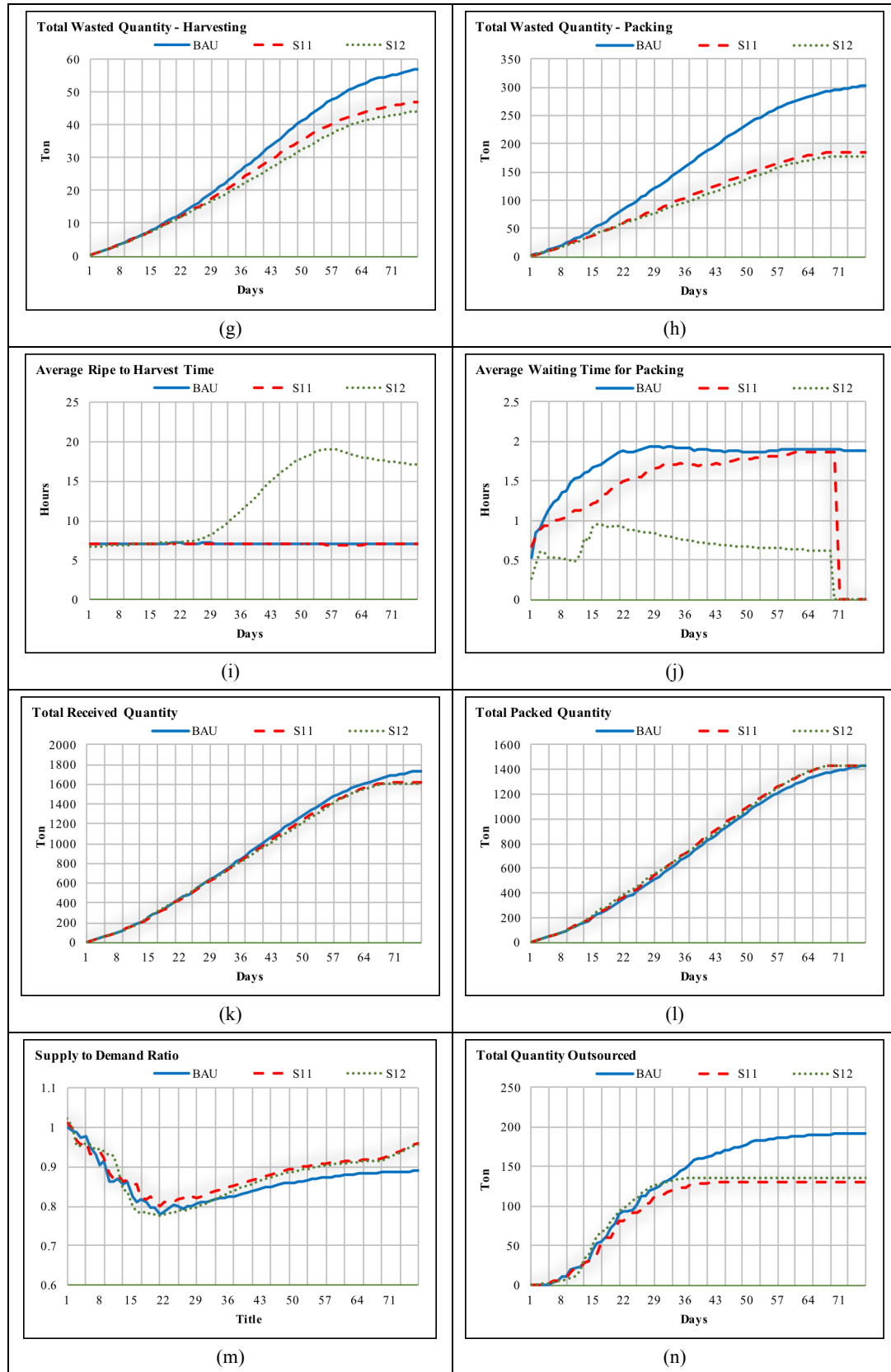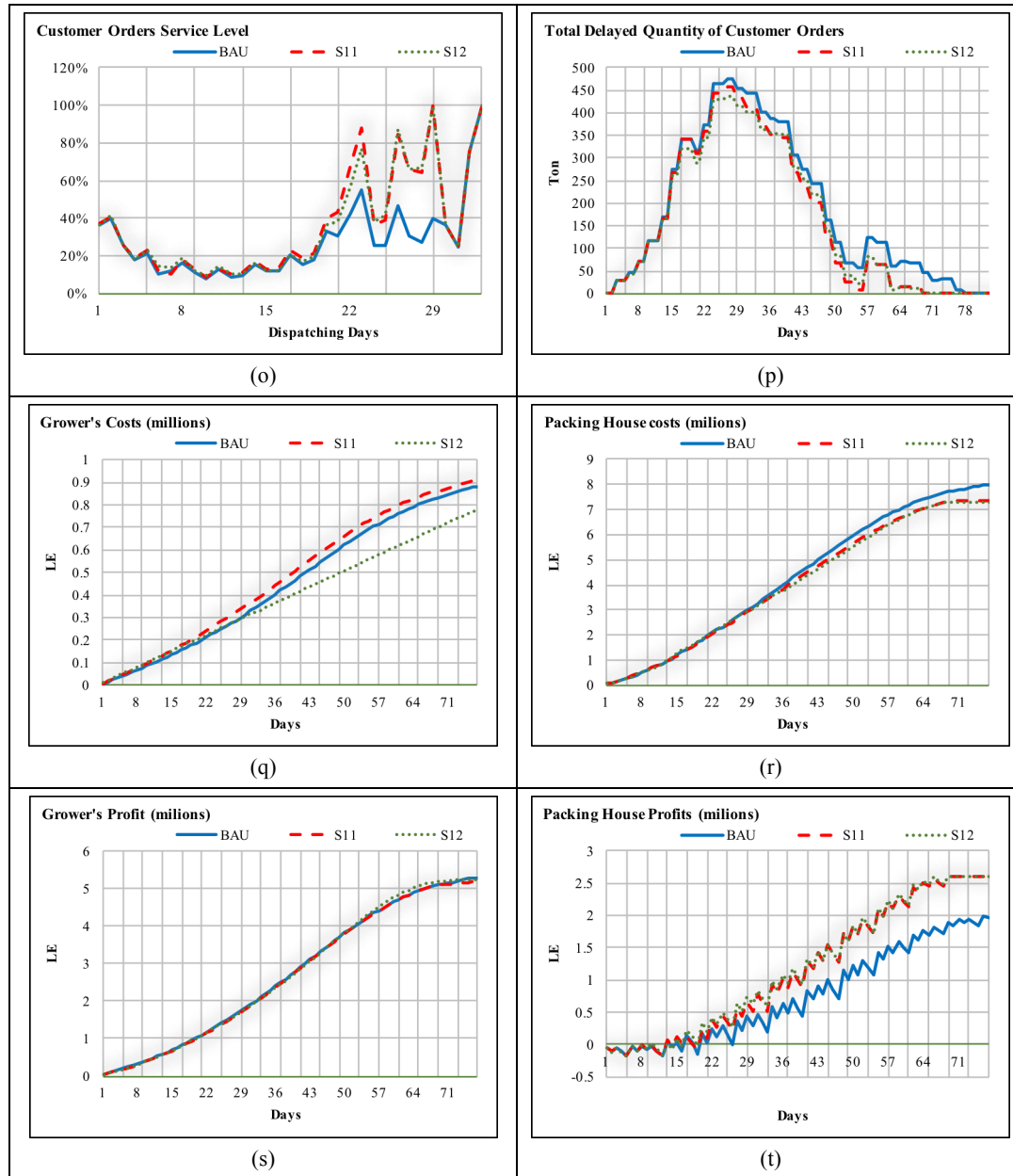
More insightful operational implications can be observed. For instance, reducing wasted products during packing activities has decreased outsourcing quantities significantly (Figure (n) in Table 6-11), and consequently, the risk of products quality and outsourcing availability are mitigated. The reduction in grapes wasted in the packing station also decreased packing

houses demand for grapes from growers. This caused a surplus of grapes on the growers' side, which growers can sell it to the local market to increase their revenue.

Exporters in TGSC have also been affected by these results. Customers service levels are improved, and the number of delayed customer orders is reduced (Figures (o) and (p) in Table 6-11), which enhance the trust of the farm and increase received orders for next season. On the other hand, although reducing outsourcing quantity should be beneficial for the grower, as the share of supply from the total demand is increased (Figure (m) in Table 6-11), it does not reflect grower's total revenue (Figure (s) in Table 6-11).

Financially speaking, S11 and S12 scenarios have shown significant improvements in operational costs and total profit (Figures (q), (r), (s) and (t)), especially for the packing house. From product quality perspective, the S12 scenario has negatively affected the average time for harvesting ripe bunches, which has increased significantly (Figure (i)). However, the same scenario has contributed to reducing raw products waiting time in the packing receiving area by almost 50% (Figure (j)). The step-like behaviour for the waiting time in the packing receiving area can be explained in light of accelerated improving in packers' experience (Figure (f)) for all of them concurrently during the first two weeks. The waiting time has increased, then, as a response to the increased in-flow of products while the number of packers is fixed. But after a while when packers experience and skills have improved further, the waiting time has declined again.

In conclusion, the outcomes of the two investigated hiring policies at Ragab farms, and their subsidiary packing house showed the utmost importance for managers to exert more effort in retaining the experienced labourers and attempts to reduce high labourer turnover

which impacts farm performance. In return, this will result in positive implications for customer satisfaction, system productivity, and total supply chain revenue.

6.4.2 *Outsourcing Policies (Operational – Tactical Planning Level)*

On many occasions, customers demand is found to be higher than expected farm yield. Packing house managers in such cases have to outsource the deficit; otherwise, order delays may be experienced, which in turn detrimentally impacts customer satisfaction and their demand behaviour for future seasons. Raw grapes are usually outsourced from other farms within the same geographical region. However, many factors undermine the ability of the packing house to secure outsourcing quantities. These include fierce competition between farmers and short in supply for the overall production region. Hence, outsourcing decisions have to be planned wisely to bridge the gap between supply and demand on one hand, and avoidance of excessive purchasing and outsourcing costs on the other hand.

Three different outsourcing policies are explored, among them the current policy as the base for comparison (i.e., *BAU*) (Table 6-12). By using this policy, the manager attempts to bridge the gap between the expected product quantities which are shipped from growers, with the product quantities to be dispatched. In other words, outsourcing will take place only when the quantities to be packed on a given day do not match the planned dispatched quantities. The second policy, *S21*, attempts to bridge the estimated gap between supply and demand at the beginning of the season. Product outsourcing will take place on daily until this gap is filled. In the third policy, *S22*, the supply and demand gap will be estimated and outsourced over a few weeks during the season instead of outsourcing all at once. The

proposed framework is utilised to simulate the three different scenarios and investigate their operational and financial implications.

Table 6-12: Outsourcing Policy Scenarios

Scenarios Code	Outsourcing Policy
BAU	Occasionally to meet orders dispatching schedule
S21	All estimated quantities are outsourced at season beginning
S22	Distributing estimated quantities over season

The simulation runs for the three scenarios will utilise a fixed seed for a random number generator to ensure same demand and supply settings. Only one harvesting season will be simulated. Various KPIs are used to reflect the performance resulted under the three scenarios (Table 6-13).

The results of simulation models suggest that outsourcing all product quantities at an early stage of the season outperforms the policy of outsourcing products over the season (Figures (c), (f), (g), (h) and (i) in Table 6-13). The performance of the third scenario *(S22)* is dominated by other two scenarios for all measurement indicators. Therefore, the policy is excluded from the study.

From the packing house manager's perspective, there is no significant difference between (*BAU and S21*) policies, although S21 policy is able to secure more quantities at the beginning of the season (Figures (a) and (b) in Table 6-13) which reduce the number of delayed orders (Figure (g)) and as result increase customer satisfaction levels (Figures (f) and (h)). On the other hand, it can be deduced that both policies have the same impact on grower's performance (Figure (e)).

Table 6-13: Simulation Results for Outsourcing Scenarios

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

(j)
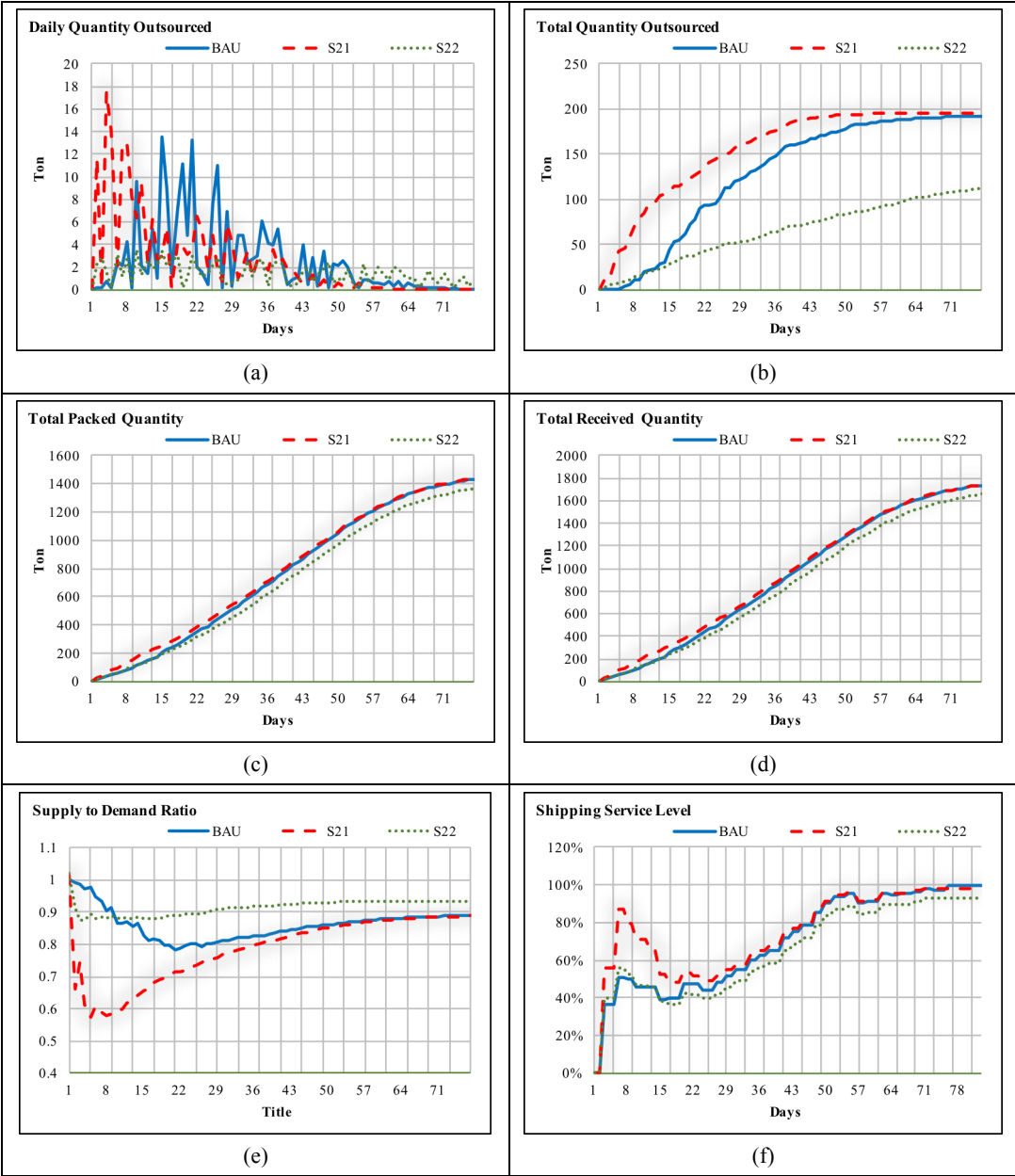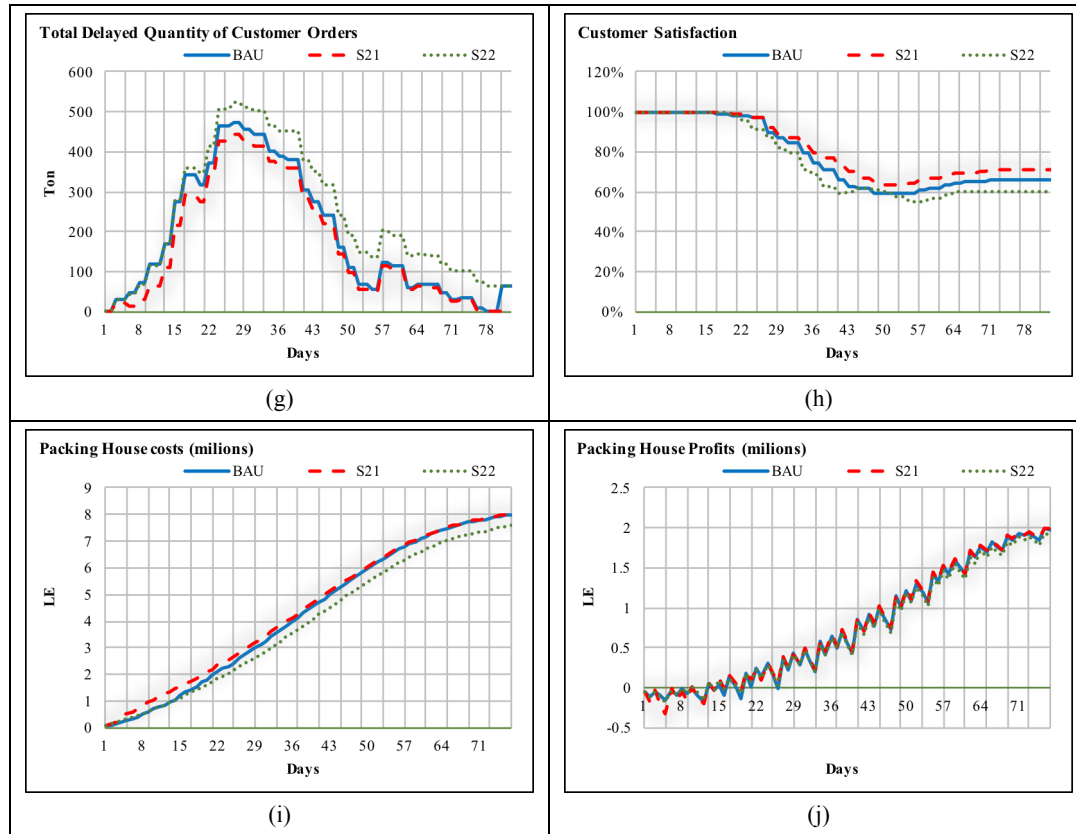
6.4.3   Vineyards Investment Scenarios (Strategic Planning Level)

One of the most critical decisions for agri-fresh produce farmers is the investment in growing new areas to increase production. Growers are usually motivated to plant new areas when they spot a growing market demand, and they aim to achieve higher business profits. In some situations, long growing and production lead times – the case for many fresh produce products – undermine efficient planning for such decisions. Therefore, a long-term investment scenario is investigated using the proposed framework.

In Ragab farms, they usually replace trees of vineyards when their production declined. The new trees take two to three years of growing and gestation before they start

regular production. If market demand is quite stable, this policy would be sufficient with the aid of few outsourced quantities in some cases. However, the whole SC would be challenged if the market demand increases, customers will ask for more quantities and if the SC fails to secure their needs they might consider looking for other suppliers. Accordingly, two scenarios are tested in this case, the first (i.e. **BAU**) assumes that only low productivity trees are replaced, while the second scenario (i.e. **S3**) will consider planting new vineyards in addition to replacing low productivity trees. Meanwhile, the market demand is assumed growing at a constant rate for the five years and then stabilised at the last year, Table 6-14.

Table 6-14: Vineyard Investment Scenarios Policy Scenarios

Scenarios Code	Vineyards Investment	Market Demand
BAU	Only trees replacement is considered	Grows annually by 7%for five years
S3	BAU + Planting new areas to meet demand	

When strategic decisions are examined, multiple successive harvesting seasons are simulated to allow sufficient time for the investigated policies to affect system's dynamics. Both scenarios are simulated for 15 years (i.e., 15 harvesting seasons) with the same random generator seed for each run. Other controls and parameters in the model are set to their default values. Various KPIs are used to reflect the performance resulted from the two scenarios (Table 6-15).

The overall market demand is assumed to be increasing by 7% annually for 5 years, and the "***received demand***" (i.e., total customer orders quantities) is expected to follow the same pattern (refer to eq. 16). However, received demand is found to be quite stable in both

scenarios (Figure (c)). At the end of the first season, the growth in market demand had a positive impact on the received demand of the next season. However, the reduction in *"customer satisfaction"* level (Figure (d)) have eliminated that positive effect. The excessive delay of customer orders arrival in some seasons (Figure (h)) explains the poor customer satisfaction level.

Hence, improving *"customer satisfaction"* is necessary for the whole SC to keep "received demand" at the same level for future seasons, and also allows growth in conjunction with total market demand. Therefore, another scenario was explored to investigate the impact of improving customer satisfaction on the TGSC performance (section 6.4.4).

Economically speaking, grower's profits were negatively affected due to significant investments required to develop a new vineyard (Figure (e)). However, return on investment (i.e., ROI) have compensated the cost of investments in addition to the growth of land capital value (i.e., planted space is increased). On the other hand, while exporter's profits have not been affected (Figure (f)), packing house revenues are slightly improved (Figure (g)). This could be explained due to the reduction in outsourcing costs because of the increase in farm supply.

Table 6-15: Simulation Results for Vineyard Investment Scenarios

(a)

(b)

(c)

(d)

(e)

(f)

(g)   (h)
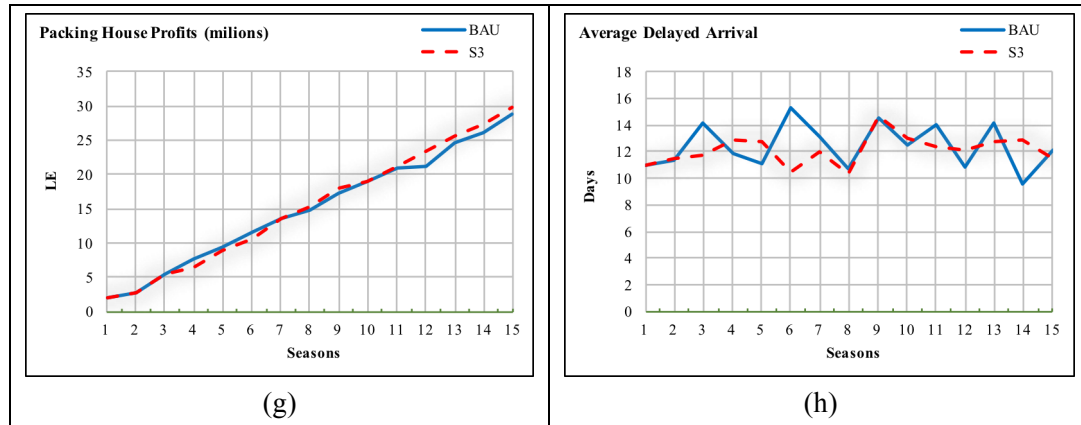
6.4.4 *Market Demand Growth, Vineyards Investment, and Air-shipping Scenarios (Strategic Planning Level)*

Although there is a relatively long shipping lead time required in maritime transportation, exporters prefer them due to the significant difference in shipping cost compared with air-shipping. However, in some situations the delay in packing operations, disruption in raw grapes supply, or delays in orders, dispatchers consequently have to opt for the air-shipping option.

As indicated in the previous section, although market demand is growing the TGSC is not positively affected by that growth due to low *"customer satisfaction"* levels. Therefore, a new customer order shipping policy is investigated in this section to explore its impact on customer satisfaction and the ultimate effect on the entire supply chain performance. Under this policy, orders are shipped as normal using maritime routes, as long as their dispatching dates are within certain limits (i.e., allowed limits for early or tardy dispatching date). Otherwise, the air shipping route will be used to reduce order arrival delays. Meanwhile, the same assumptions for market growth and grower's investments in

new vineyards will be considered. Therefore, two scenarios are presented here to test the efficacy of employing fast shipping routes for delayed orders. These scenarios are presented in Table 6-16.

Table 6-16: Vineyard Investment Scenarios Policy Scenarios

Scenarios Code	Vineyards Investment	Market Demand	Shipping Policy
S3	Trees replacement + Planting new areas to meet demand	Grows annually by 7%for five years	No Air routes
S4	Trees replacement + Planting new areas to meet demand		Use Air routes for orders with potential delays

Two limits are assumed to control whether an order will be shipped by maritime or air routes. On any dispatching day, if a customer order arrival date(using regular shipping route,) will exceed **5** days it should be shipped using the air route. If an order dispatched on the same day, using the air route, will cause early arrival that exceeds **5** days it will not be dispatched, and an alternative dispatching date will be set. The overall objective of the two limits to avoid both early and delay arrivals that exceed customer windows for early and tardy orders arrival.

Two scenarios will be simulated for 15 years. Similar assumptions for random generators seeds are also applied. Other model controls and parameters are set to their default values. Various KPIs are used to reflect the performance resulted under the two scenarios (Table 6-17).

The excessive delay of customer orders and consequently low customer satisfaction are the main reasons for limiting received demand from growing. When shipping performance has improved, positive implications have resulted. Many KPIs in Table 6-17

refers to the improved shipping performance. For instances, overall order cycle time (Figure (d)) has improved by the impact of reducing orders arrival delays (Figure (e)). Consequently, customer satisfaction (Figure (c)) has significantly improved and received orders (Figure (b)) have increased as it should be.

The increase in received demand was also perceived by the growers and called for more investments in new vineyards as presented in Figure (a). This trend is expected to continue for a while as supply to demand ratio is still below one (Figure h) which indicates that there are still shortages in demand.

Increased demand downstream of the TGSC has increased the flow of raw grape products from upstream. Therefore, larger workloads took place, and more packing throughout happened. This was reflected in improvements in packing capacity in *S4* compared to *S3* as indicated in the Figure (j). This has led to another interesting point, in which it is apparent that the current physical capacity of the packing house is not fully utilised and the manager will now consider increasing this capacity.

Economically speaking, the results were satisfactory for the packing house managers. However, there was a negative impact on exporter's profits (figures i and f respectively). Although more investments costs were incurred by the grower, their earnings have witnessed slight improvement due to increased demand and therefore increased revenues. Again, if the value of the increased land capital is considered beside this small growth in total profits, the outcomes of *S4* scenario are also satisfactory for the grower.

Table 6-17: Simulation Results for Vineyard Investment and Shipping Policy Scenarios

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

(i)

(j)
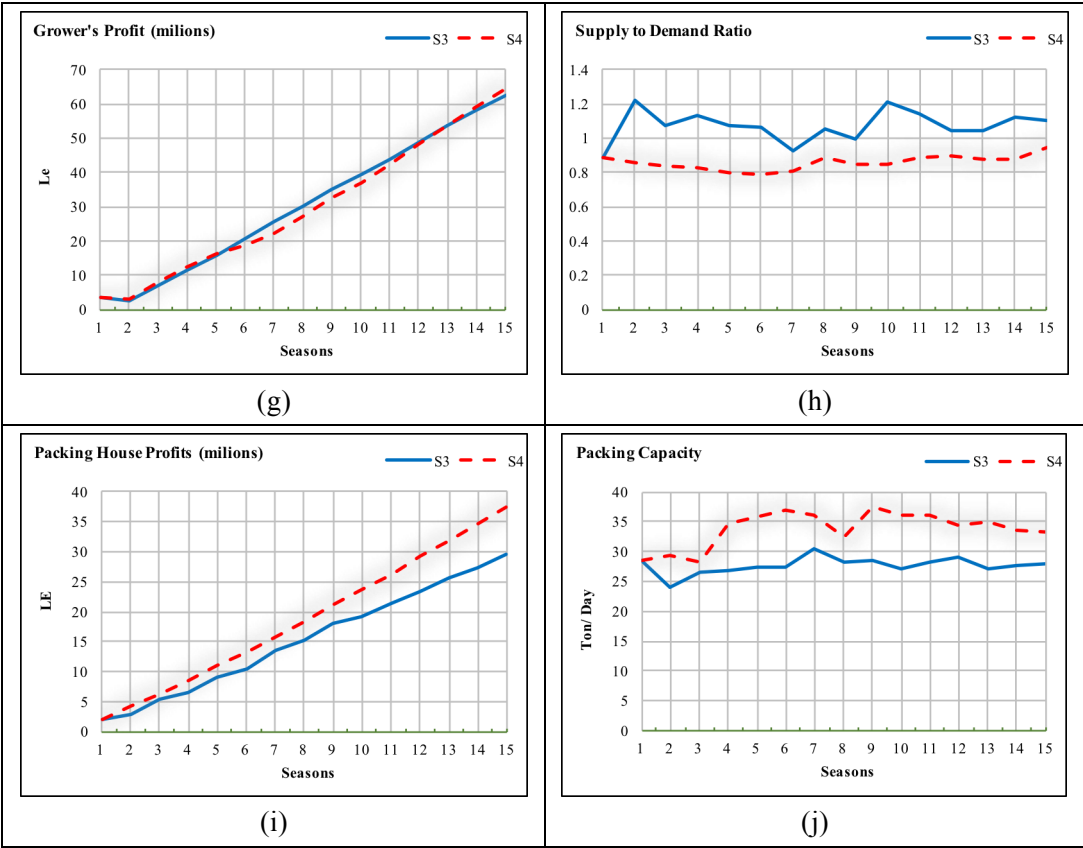
CHAPTER 7: CONCLUSION AND FUTURE WORK

7.1 Introduction

Recent globalisation and increasing competitive markets along with advances in technology have led to changes in lifestyle and dietary preferences of consumers. There is a significant demand for healthy fresh products. They are also expected to be available year-round at affordable prices. Therefore, these products are always exported from production areas to consumption locations. On the other hand, agri-food businesses are currently under scrutiny and are subject to various legislative and regulatory pressures which undermine effective management and planning. This calls for the development of innovative strategies, smart planning, and decision-making support tools which should resolve the industry challenges.

Given the various types of agricultural products, fresh produce crops are the most problematic. Consumers' demand them in at certain ripeness and freshness with minimal levels of processing (mostly handling and packing) before they reach their plates. These products also have a short shelf-life and are vulnerable to many environmental stresses which threaten their safety and edibility. All these factors result in the classification of AFPSCs as complex business systems. Moreover, considering seasonality and the labour intensity of production, harvesting, and post-harvesting operations, along with precautions needed during transportation and logistical activates, add to agri-fresh produce complexity.

Considering the broad spectrum of decisions in AFPSC and their intricacies, traditional decision-making and planning tools are less than optimal as they have limited abilities in modelling complex, multi-firm, multi-dimensional relationships. Alternatively,

simulation and modelling approaches can address planning and decision-making problems in complex systems. Additionally, smart implementations of these approaches combined with innovative ideas for integration and collaboration, add more to their capabilities in addressing higher levels of complication. Therefore, the main purpose of this research was to utilise ideas of the previous statement to introduce an integrated framework for efficient planning and decision-making support for AFPSC managers. The core component of the proposed framework is a comprehensive hybrid simulation model developed for complex AFPSC systems. The following sections summarise the stages of this research to address the gaps in the existing knowledge domain and develop a practical, yet robust framework for AFPSC planning. Subsequently, a discussion of the main research findings is provided which is followed by the main contributions to existing knowledge. Research limitations are then highlighted, and finally, directions and guidelines of future work conclude this chapter.

7.2 Research Contribution

The work carried out in this thesis has contributed to both knowledge and application of AFPSC planning and decision-making.

> **Literature review on modelling and simulation approaches employed for agri-fresh produce supply chain planning problems**

- This contribution adds to the knowledge domain by looking at the first research question of the study; *"How are modelling and simulation techniques currently employed in AFPSCs?"*

- The study provides a comprehensive review of methods that are used for planning and decision-making problems of AFPSC. A new three-dimensional framework was utilised to explore the AFPSC characteristics, the nature of decisions, KPIs, planning modes and types, and properties of employed models. Reading and reviewing over than 900 articles has resulted in a dataset of 94 articles on M&S application for AFPSC planning problems.

- Extensive analysis of applications in these articles has provided useful insights into how various models are used for AFPSC planning. It shows that there is a growing trend acknowledging the potential impact of existing models, but a set of dominant characteristics were found such as:

    - Lack of integration between AFPSC actors in planning activities;

    - Focus on financial KPIs;

    - Paucity of models that are used for strategic and long-term planning; and,

    - The absence of studies which have considered seasonal labourer behaviour.

- This study also provides a roadmap for future research and identifies areas that require further attention from researchers.

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Exploratory Study: AFPSC Conceptual Models

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- This contribution addresses the second research question; *"What are the main planning decisions and performance indicators that AFPSCs' managers should consider?"*. This contribution adds to both knowledge and application of the field.

- An exploratory study is conducted in a set of agri-fresh produce organisations including growers, processors, traders, and exporters. The data was collected through in-depth interviews with twelve managers involved in different operations of agri-fresh produce business such as harvesting and packing operations. The outcomes of the exploratory study have contributed to the design and engineering of the integrated planning framework.

- Exploratory study findings were significant in understanding the AFPSC system structure and highlighting the vital components their connections. Decision-making challenges and various KPIs were also identified from collected data.

- The outcomes have confirmed that system components alongside with planning and decision-making process have similar characteristics as per literature (e.g., seasonal labourers hiring). Hence, the findings of both the literature review and the exploratory study were engaged in developing a planning, and conceptual decision-making model for AFPSC focused on the upstream part of the SC (e.g., growers,

processors and exporters). In addition, two other conceptual models were developed for the structure of AFPSC offering both upper and inner views of the SC entities and their activities.

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Developing a hybrid simulation-based integrated planning framework for AFPSC managers.

</div>

- This contribution is believed to add value to both knowledge and application by addressing research questions 3 and 4, and part of the second research question.

  - RQ3: *"How can a modelling and simulation-based framework be developed for AFPSCs planning?"*

  - RQ4: *"How far would a developed framework be useful for decision-making in AFPSC and to what extent can it be applied?"*

- The developed integrated framework has included the managers' views and understanding which certainly will add value to the framework and increase opportunities of implementability. Introducing an advanced hybrid simulation model for AFPSC planning and decision-making problems is a contribution.

- The framework addressed the high level of complexity for real-life AFPRSC systems via a robust three paradigms model based hybrid simulation. Each paradigm captured a different level of complexity. ABM model components were successfully used for addressing heterogeneous characteristics of seasonal labourers who are extensively

involved in major operations for agri-fresh produce production. DES model components were developed to address the complex daily activities within these operations such as post-harvesting and packing activities.

- SD was used to model the dynamism involved in planting and replacement decisions which have both delayed and long-term impact on both AFPSC demand and supply. SD modelling is also used in other components of the model. For example, it is used to model worker perceived productivity.

- On the top of the developed simulation model, the framework offers a graphical user controls dashboard which enables various planning options for either short or long runs planning and for centralised and decentralised modes of AFPSC.

- Implementation of the proposed framework in real life AFPSC case study was decided to test its validity and efficacy for supporting AFPSC decision makers. An Egyptian TGSC was selected for that purpose, and multiple site visits and meetings were conducted to collect the required data for implementing the simulation model. Then, various real planning scenarios were derived jointly with managers to explore the framework capabilities

7.3 Results Discussions

The proposed framework was developed by studying the internal decision-making mechanisms, rules and control procedures through the development of a hybrid simulation-based planning framework for AFPSCs. Managers and staff of agri-fresh produce business played a significant role in guiding the researcher throughout system exploring, developing

and validating conceptual models and ultimately the framework. It was designed mainly to support managers of AFPSC in planning at different planning levels of decision making.

Through the development of a detailed and comprehensive *hybrid simulation model* that replicate multiple components and operations of the real system, the researcher and managers used a *'what if'* analysis approach to examine various policies and scenarios to explore the framework capabilities. In this way, they can enhance the decision-making process by simulating situations which are too complicated to anticipate their outcomes relying on their experience no by other types of models (e.g., mathematical models). Furthermore, at operational and tactical levels, the integrated framework provides a safe and non-disruptive planning tool to assess potential decisions without unnecessary disruption to the operations during the season. On a strategic level, it also offers cost-free planning and decision-making environment that can assess likely plans and strategies and/ or anticipate consequences of unexpected disruptions which both have long-term implications on the AFPSC business. Consequently, potentially expensive unsuccessful strategies can be detected prior to their actual implementation.

The outcomes of simulated scenarios using the integrated planning framework have successfully provided useful insights to the TGSC managers. For instance, there was a belief that seasonal labourer supply inconsistency and the high turnover affected the business. However, the magnitude of that effect is not tangible and cannot be evaluated. Simulation results for multiple scenarios where seasonal labourers turn over and supply inconsistency are eliminated, have highlighted the utmost importance of retaining workers experience during harvesting and packing seasons. The results showed significant products waste

reductions (around 24 % and 58% during harvesting and packing respectively) and improved financial indicators (e.g., 25% improved profit at packing house). These outcomes have encouraged the management to seriously revise their current hiring policies to retain workers experience and skills gained during the season.

Anticipating changes in supply and demand of the TGSC supply chain were also insightful for the three managers. The simulation results have demonstrated how TGSC did not benefit from growing market demand until shipping orders performance was improved and customer satisfaction had increased. The inefficiency of internal business processes may undermine the whole business from gaining benefits of market growth opportunities. Therefore, investments in production capacities at upstream will not receive a satisfactory return on investment unless the downstream operations are improved.

Simulation outcomes of supply and demand scenarios have also reflected on the complexity of the relationships between SC entities. Although investment decisions are made by growers, while shipping policies are controlled by the exporter, the packing house benefitted the most from these decisions on both operational and financial levels. Operationally, the manager of the packing house discovered that current capacities of packing facilities are not fully utilised, while financially, the packing house was the entity obtaining the highest profits. The essence of the integrated planning framework is clearly demonstrated here. It enables managers to anticipate outcomes of their decisions not only on their own business but also on other partners of the SC. Hence, the results can be utilised as a reference for any potential negotiations between the SC members for future decisions or collaboration.

Finally, being profitable within the current business environment does not mean that the current policies and decisions are efficient. There are always opportunities for improvement and better performance; however, many business managers fear the consequences resulting from change because they cannot anticipate them. Even when a change is decided, the delayed impact of unwanted outcomes might be a disaster if not adequately studied and predicted before taking the decision. The proposed framework offers such anticipation tools for AFPSC business managers and stockholders.

7.4 Framework Generalisability

Despite a few attempts to use simulation models for AFPSC systems, such a sophisticated and comprehensive simulation model like the one presented in this thesis has not been used before in relation to these systems. The detailed explanation of the different conceptual models and how they are developed and connected to building the ultimate framework can guide other researchers in constructing efficient modelling for complex agri-business systems. From biologically and business stands, non-climacteric and perennial crops – which are the base for framework component – are one of the most complex agri-food systems. This supports the generalisability and applicability of the framework for other agriculture businesses. Appropriate changes to few components or disabling them will make the framework valid for other crops. For instance, if products do not require manual handling during packing activities the ABM model used for packing workers would be altered, and the resources which are used in this case will be modelled, homogeneous agents.

7.5 Limitations and future work

This research contributes towards integrated planning frameworks for AFPSC systems. Although it has attempted to cover all the various aspects of the decision-making process and involved operations, the researcher does not claim to have exhausted this area. The framework is limited only to upstream entities for AFPSC (i.e., the first three echelons). Downstream entities, such as distribution centres and retailers are also crucial for the business. The framework needs to be extended to include them.

The framework is designed for AFPSC that facilitate one type of products. The fact that many growers and other agri-fresh produce organisation produce more than one kind or a variety of products makes the system more complicated. The source of added complexity is the potential overlap between various production operations. This would motivate researchers to embrace the current design of the framework to increase its capability to handle added complexity.

The hybrid simulation model presented in this thesis was designed to be used as an exploration tool which anticipates impact and consequences of potential decisions or disruptions on the overall AFPSC performance. However, this can be complemented by optimisation modelling to add more capabilities to the framework. When the optimisation component is added, the framework will not only be able to test manager's plans and strategies but also offer and propose them.

Although the outcomes of this research make significant contributions to the AFPSC planning and decision-making tools, the implications of the research are confined to a single case study. For future work, incorporation of further implementations of multiple of case

studies will help improve the framework and learn more about the implementation

challenges.

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APPENDIX 1: OVERVIEW OF MODELLING APPROACHES

The main challenge of complex system integrated planning is, the incorporation of various planning levels into the decision-making process. This is a result of the multiple actors often exist within the SC. Modelling approaches can support complex decision-making process for such systems. Employing these approaches for decision making support is a quite mature research area (Holland 2000). Models are built to represent real systems to either investigate or improve their behaviour. Such models are frequently employed in operation research (OR) and Management Science (MS) problems. These models facilitate the exploration and implementation of more effective solutions to problems that involve complex interactions among system entities and within a rapidly changing environment (Altay and Green 2006). An overview of the main modelling techniques is given in this appendix.

i.   *Mathematical Models*

A mathematical model is a set of mathematical equations that represent the relationships between system elements, mainly the decision variables and objective functions (i.e., targeted performance indicators). Mathematical Models include: linear programming (LP); integer programming (IP), mixed linear integer programming (MLIP); non-linear programming (NLP); dynamic programming (DP); goal programming (GP) and stochastic programming (SP). (Jordan and Smith 1999). In context of SC, mathematical models are employed to optimize performance of SC functions such as production and distribution (Xu, He, and Gen 2009). For example, LP model is used for robust optimization of multi-site procurement,

production and distribution decisions (Kanyalkar and Adil 2010). Hamedi et al. (2009) used MLIP model for planning distribution of natural gas SC.

Mathematical models can usually optimise one performance indicator (i.e., single objective function) or more (multi-objective functions). A multi-objectives MLIP model is used for integrated production and distribution planning of perishable products (Amorim, Günther, and Almada-Lobo 2012). The model investigates optimal production sequencing and volumes that minimise the total costs simultaneously with maximising products shelf-life. Similarly, Chen, Wang, and Lee (2003) introduce a multi-objective NLP model for planning multi-product, multi-period production and multi-enterprise SC network.

SC chain inherent multiple sources of uncertainties such customer demand and products supply. However, most of the mathematical modelling techniques are deterministic and do not take these uncertainties into account. Instead, uncertain parameters are assumed to be represented as constant values and known for certain in the model. Only stochastic mathematical models are the exception, where probability distributions of uncertain parameters (e.g., random demand) are expressed in the models. Lin and Chen (2003) introduced an SP model for distribution centre to mitigate supply uncertainty by optimal supplier selection policy to minimise customer demand violations. Hsu, Hung, and Li (2007) presented another SP model for vehicle routing problem of perishable food distribution under delivery time uncertainty. The objective of the model is to minimise the different logistics costs while avoiding violations of delivery time windows. For more mathematical modelling applications of in the context of SC, see (Abo-Hamad and Arisha 2011)

It is evident that mathematical modelling approaches are widely used for SC planning problems (Mula et al. 2010). However, there exist some issues that restrict the adoption of mathematical modelling for complex real SC planning problems. In practical SC problems, complexity imposes existence of an enormous number of variables and constraints. Hence, developing mathematical equations to consider all these constraints and variables becomes a difficult mission (Pidd 2004). Therefore, mathematical modelling approaches are only suitable for small to medium planning problems and when limited number of variables and constraints are considered (Méndez et al. 2006). Another drawback of mathematical models is that they are static and ignore the dynamism resulted from changes of endogenous and exogenous variables over time. Hence, the large number of problems cannot be addressed by these approaches, especially in situations where high complexity degree exists in the system as the case of AFPSCs.

ii.   *Simulation Models*

While mathematical modelling has limitations on the level of complexity they can handle, simulation models can be employed for any level of detail of the complex system. Simulation approaches are used to support decision-making in supply chain where uncertainties exist, building on their intrinsic modelling flexibility (van der Vorst, Tromp, and van der Zee 2009). In agriculture systems, simulation modelling has gain popularity due to its ability to address the complex, dynamic and stochastic nature of their problems. It can be used for conducting large-scale virtual experimentation on these systems rather than physical experiments that might be very expensive and need a long time as in the case of fresh produce crops, such apples and grapes (Hester and Cacho 2003). In addition, A simulation is a robust approach

for evaluating different decisions and strategies using set of scenarios based on what-if analysis (Min and Zhou 2002). It can also be used to represent many realistic features of the supply chain along with biological and environmental aspects of fresh produce production (Hester and Cacho 2003).

There exist three primary simulation modelling approaches that are very suited for complex SC modelling: 1) Discrete Event Simulation; and 2) System Dynamics; and 3) Agent-based Modelling (Jahangirian et al. 2010). Discerption, capabilities, advantages, limitations of each approach are discussed in the following sub-sections.

Discrete Event Simulation (DES)

It is an approach that can be employed for complex, dynamic and stochastic systems where variables state change at discrete time advances. The system in the DES model is viewed as queuing networks (Terzi and Cavalieri 2004). There are two dominant 'worldviews' of DES models: "event-oriented" and "process-oriented" views. In the latter view, passive entities (e.g., products or customers) are moving through systems processes, while in the former view the state of an entity is linked to sequence of events assigned to that entity. The process-oriented view is most commonly one used in DES frameworks (Heath et al. 2011). Figure A1-1 presents the necessary steps to conduct a DES study according to (Pidd 2004).

In context of SCM, DES is the dominant simulation approach employed for studying complex SCs including food SCs (Terzi and Cavalieri 2004). For example, A DES model is applied for a complicated automotive SC (Turner and Williams 2005). The model is used to investigate different production and distribution scenarios under uncertainties in demand and consumer behaviour. In context of food SCs, Rijgersberg et al. (2010) present DES model to

quantify the microbial risks of fresh-cut SC under different logistics and storing decisions. Bechar et al. (2007) use DES model to study working practices that reduce labourer involvement in harvesting of greenhouse tomato yards. Similarly, van't Ooster et al. (2014) applied DES to simulate different recruiting scenarios based on the labourer skills for rose harvesting operations. Zhou, Leck Jensen, et al. (2015) developed DES model to evaluate various designs for harvest operations for potato grower to improve resources efficiency and utilisation.
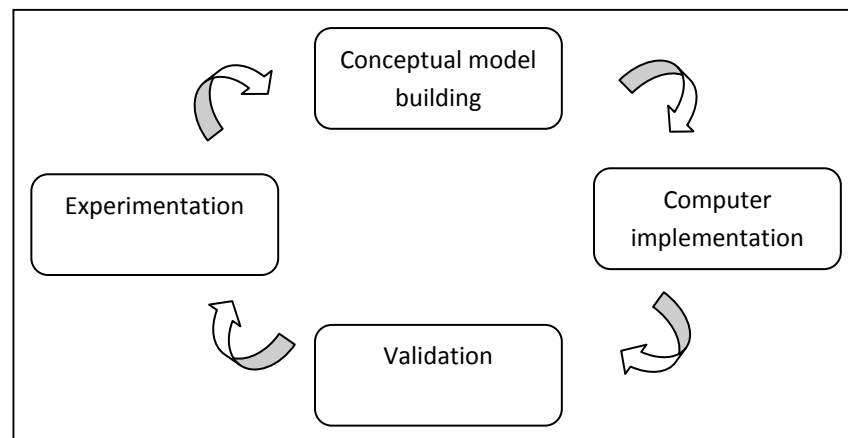
Figure A1-1: The Main Steps for DES Approach (Pidd 2004)

It is believed that DES models are best suited only for operational and tactical decision-making levels (Brailsford and Hilton 2001). Also, the approach comes short in its ability to consider human behaviour and the sociological issues that frequently exist in the agriculture systems, For example, the heterogeneous characteristics of seasonal labourer markets and the significant impact on harvesting operations for many (Whatman and Van Beek 2008). The reason is that DES entities are usually passive objects and their behaviour is dependent on the rules and flowcharts defined by the modeller (Borshchev and Filippov 2004). Finally, DES models are also criticised for demanding a massive amount of data and require multiple

replications runs to understand the actual behaviour of the system, which potentially can lead to long runtimes (Viana et al. 2014).

System Dynamics (SD)

SD is a modelling approach based on causality relationships among the various system entities, expressing these relationships as differential or difference equations, and then use computer to translate these equations into as a simulation model (Sterman 2000). In SD, the system is initially mapped by developing cause and effect links between the variables constructing a set of feedback loops, which ultimately build causal loop diagrams (CLDs). These CLDs are the basic building block for the SD model as they describe the underlying structure of the system. The aggregate behaviour of any particular entity in the system is resulted from interactions between these feedback loops (Borshchev and Filippov 2004). The CLDs are then translated into stock and flow models where the cause and effect links will be formulated mathematically. The dynamics of the system arises from delayed effect of some (or maybe all) of these feedback loops. SD approach is beneficial for studying system response to various policies (Morecroft and Robinson 2005). Figure A1-2 presents the necessary steps for conducting an SD study according to (Sterman 2000).
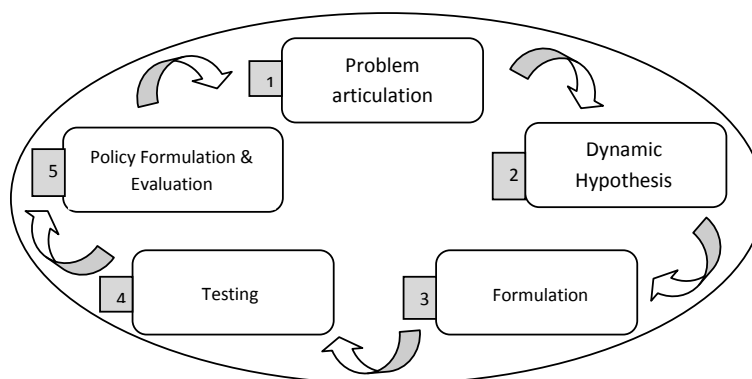
Figure A1-2: The Main Steps for SD Approach (Sterman 2000)

In context of SCM, SD modelling is recommended as useful approach for strategic level of planning for SC (Tako and Robinson 2012). Different areas of SCM have experienced applying SD for strategic decision making, including SC redesign, information sharing, demand amplification, and inventory management (Angerhofer and Angelides 2000). Focusing on food SC, an SD model is used for investigating the behaviour of non-perishable food SC operating in monopolistic environment under variations of demand and supply lead times (Kumar and Nigmatullin 2011). Another SD model is employed for integrated planning of production life-cycle of livestock supply chain (Piewthongngam et al. 2014). Several demand and supply disruption scenarios have been investigated in an SD study for multi-echelon supply chain of fast moving consumer goods (Crowe, Mesabbah, and Arisha 2015). In context of AFPSCs, Teimoury et al. (2013) introduced an SD model to investigate, on governmental level, different import policies impact on the Cherry agriculture industry in Iran.

Similar to DES approach, SD is not a suitable approach to consider human behaviour and the sociological aspects of complex systems. This is mainly because of the continuous and aggregate nature of stock variables and difficulties to distinguish the in and outflows even if they represent different entities in the real system (Borshchev and Filippov 2004). On the contrary to DES, SD models are not well suited for capturing in-depth details of system relationships and, hence, they are not recommended for operational level planning (Helal et al. 2007).

Agent-Based Modelling (ABM)

ABM is relatively a new simulation approach compared to DES and DS approaches. As a simulation paradigm, it was initially developed to overcome the drawback of DES and SD in addressing heterogeneous human behaviour in complex systems (North and Macal 2007). ABM is an individual-centric and decentralised approach where system entities are represented and implemented as autonomous agents (Julka, Srinivasan, and Karimi 2002). Agents interact with each other and with other system entities directly or indirectly as per their behavioural rules, which are defined by the modeller. The overall system behaviour emerges from agents interactions and communications between them and their system environment (i.e., collective behaviour of the agents) (Shen and Norrie 1999). Agents are not used only for representing human entities within the system, but they can also represent non-human components, such as retailer or distribution centre in case of SC system (Julka, Srinivasan, and Karimi 2002). Modeller has to define a set of rules for each agent type; conceptually these rules are mapped in what so agent state charts/ diagrams.

ABM is a robust approach, which can capture heterogeneity and variations among simulated entities and their complex relationships. It allows a more realistic modelling of complex systems with different behaviour patterns (Shen and Norrie 1999). SCs are complex systems full of interactions between various actors, and this makes ABM a suitable approach for modelling SC applications. ABM models are employed in decision-making problems related to SC applications where behaviour of individuals is significant. An ABM model is used to study the impact of information sharing in a distributed make-to-order manufacturing SC (Chan and Chan 2009). Nienhaus, Ziegenbein, and Schoensleben (2006) present an ABM

model that investigates the role of human behaviour in bullwhip effect with the aid of the beer distribution game. In context of AFSCs, (Krejci and Beamon 2015) developed ABM model to explore impact of coordination between growers on the overall FSC performance. Different coordination mechanisms are proposed, including pooling resources and combining yields. Growers (i.e., the agents) evaluate the trade-offs between expected payoffs under coordination policy and their business autonomy. In context of agriculture systems, many studies used ABM for agriculture land use (Matthews et al. 2007). ABM models are developed to address workers' heterogeneous characteristics in terms of levels and types of their skills. For instance, Dawid et al. (2008) introduced a macroeconomic ABM model featuring geographical dimensions, among of them heterogeneous workers, for European policymakers to evaluate a wide range of public policies.

To conduct a successful ABM study sufficient empirical data are needed to model a real-life system accurately. Otherwise, the resulting ABM model may misrepresent the system and create inaccurate and misleading behaviour (Siebers et al. 2010). Similar to DES, ABM requires multiple replications of a simulation run, a single run of the model is not sufficient for the statistical analysis of the results (North and Macal 2007).

The following table summarises the main differences between the three simulation approaches.

Table A1-1: Comparison between the threes simulation paradigms

Aspect	System Dynamics	Discrete Event Simulation	Agent-Based Modelling
Problem Level	Strategic and Policy	Tactical and Operational	Strategic, Tactical and Operational
Model Elements	Stocks flows and causal loop diagrams	Processes, entities, resources	Agents, statecharts
Number and type of entities	Large, homogenous	Small, can be homogenous	Any number, maximum level of heterogeneity
Feedback	Explicit, shown on causal loops, important	Hidden, not important	Function of the behaviour of the agent
Decisions	Modelled as causal loop diagrams	Hidden in the code processes and resources	Modelled in agent statecharts
Behaviours such as proactivity, memory, adaptiveness	Not modelled	Not modelled	Modelled within Agent statecharts
Randomness	No randomness (hidden in delays)	Explicitly modelled and important	Can be built into Agent Behaviour
Interpretation	Structure determines dynamic behaviour	Randomness creates behaviour of entities in process	Relationships and system level behaviour emerges as consequence of entity behaviour
Purpose	Understanding	Problem solving	Exploration

Hybrid Simulation Modelling (HSM)

Fakhimi and Mustafee (2012) suggested that combining different simulation approaches will reduce the limitations of individual methods and increase their capabilities. Having said that none of the three techniques has superiority in addressing the three levels of decision making, and in the light of managers quest for tools and techniques that facilitate integrated planning, several researchers have investigated hybrid models developing (Mustafee et al. 2015). The hybrid simulation also enables leveraging single approach's strength and address higher level of complexity in systems that cannot be modelled using an individual approach (Powell and Mustafee 2014).

Such hybridisation between simulation models is reported in literature in context of SCM. For instance, Venkateswaran and Son (2005) introduced hybrid SD-DES model manufacturing enterprise. The model employs SD for strategic level planning of the enterprise while DES is used to model shop floor operations. In context of food supply chains, Mittal and Krejci (2013) developed a hybrid ABM-DES model for inbound logistics operations of a local food hub. ABM is used to model different producers' tendency to sell their products in that hub. While the DES is used to model the inbound operations of the food hub.

In other disciplines, hybrid simulation has proved the ability to address various aspects of decision-making levels. For examples, see Pena-Mora et al. (2008) in construction, Zhao et al. (2011) in solar energy production, Brailsford et al. (2013) in healthcare, and Zhang, Chan, and Ukkusuri (2011) in transportation.

APPENDIX 2: LITERATURE REVIEW DATASET

SC Actors: A→ Authority; D→Distributer; E→ Exporter; Grower; P→ Processor; and R→ Retailer

SC Analysis Level: C→ Chain; F→ Firm; I→ Industry; and N→ Network;

SC Function: D→ Design; H→ Harvesting; I→ Inventory; L→ Logistics; Pa→ Packing; Pri→ Pricing; and Pro→ Production

Decision Making Level: O→ Operational; T→ Tactical; and S→ Strategic

KPIs: C→ Customer; E→ Environment; F→ Financial; O→ Operational; QS→ Quality and Safety; and S→ Social

Model Type: A→ Analytical; HE→ Heuristics; M→ Mathematical; and S→ Simulation

Model Purpose: D→ Descriptive; and N→ Normative

Parameters: D→ Deterministic; and S→ Stochastic

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
1	(Saedt, Hendriks, and Smits 1991)	LP and MILP models are used for planning greenhouse pot-planting for some horticulture products to maximising total revenues.	G	F	Pro	O, T	F	M	N	D
2	(Vanberlo 1993)	LP model to determine sowing, harvesting and production plans for peas growing with the objective of minimizing costs across the logistical chain.	G	F	H, Pro	O, T	C, F, O	M	N	D
3	(Hamer 1994)	LP model for planning planting and harvesting fresh Brussels sprout crop with the objective of maximizing profits.	G	F	H	O, T	C, F, O, QS	M	N	D

APPENDIX 2: LITERATURE REVIEW DATASET

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
4	(Maia, Lago, and Qassim 1997)	MILP model is used for the postharvest technology selection for fruit and vegetable crops. The objective is to optimise capital investment in products preservation facilities under uncertainties.	D	C	D	S	F	M	N	D
5	(Miller et al. 1997)	LP and fuzzy programming models are used for production and harvesting planning of a packing station with the objective of minimizing costs	G, P	C	H, Pa	O	C, F	M, HE	N	D
6	(Broekmeulen 1998)	A local search algorithm (heuristic) is to find optimal assignment of fresh fruits and vegetable products in cold store. This assignment plan is the evaluated against different temperature control using a simulation model.	D	F	I	O	E, F, QS	S, HE	N	D
7	(Darby-Dowman et al. 2000)	An SP model used to plan Brussels crop harvest and production under different weather scenarios. The objective was to maximise the total revenues	G	F	H, Pro	O, T	F	M	N	S
8	(Romero 2000)	A multi-objective LP model is used to find an efficient harvesting schedule to maximise the revenues and minimise the crop variability	G	F	H	O, T	F, O	M	N	S
9	(van der Vorst, Beulens, and van Beek 2000)	A DES model for a fresh cut vegetables SC to test different scenarios for the SC design.	D, P, R	C	I, L	O, T	F, O, QS	S	D	D
10	(Gigler et al. 2002)	A dynamic programming model is used to plan production, harvest and exports for a banana SC Netherlands with an objective of minimising total costs across the SC while preserving the products quality	E, G	C	H, I, L, Pro	T	F, QS	M	N	D
11	(Faulin 2003)	LP model is used to solve vehicle routing problem for fruits and vegetable distribution centre to optimise the products flow to minimise transportation cost and products travelling distance.	D	N	L	O	F, O	M	N	D
12	(Hester and Cacho 2003)	A dynamic NLP model is used for apply orchard production planning. The model aims to optimise annual thinning decisions to maximise the net profit values over the planning horizon.fr	G	F	H, Pro	T, S	F	M	N	D
13	(Lin and Chen 2003)	An SP model is used to optimise supplier selection and products distribution problems. The objective is to maximise total profit while reducing demand violations	D	N	D, L	O, T	F, O	M, HE	N	S

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
		under different supply uncertainties.								
14	(Vitoriano et al. 2003)	An IP model is used to plan harvest and production resources for a grapes grower to minimise total operations cost and processes times	G	F	H, Pro	O	F, O	M	N	D
15	(Allen and Schuster 2004b)	NLP model is used to plan harvesting and capital investment for grapes production to reduce losses costs due to weather variations and overcapacity production.	G	F	H	S	F, O	M	N	S
16	(Blanco et al. 2005)	A MLIP model used for planning apple and pear packing house. The model objective is to minimise operations cost and packing waste	P	F	Pa	O	F, O	M	D	S
17	(Caixeta 2006)	An LP model used for planning orange harvesting operations in Brazil. The objective is to minimise operations costs while satisfying certain quality and safety constraints.	A, G	I	H	T	F, QS	M	N	D
18	(Kanchanasuntorn and Techanitisawad 2006)	An inventory control model is used to plan the stock out policy for high perishable agricultural products in order to improve inventory cost and service level	R	C	I	T	F, O	A	D	S
19	(Widodo et al. 2006)	DP model to integrate production, harvest and storage of perishable products with growth and loss functions for maximizing demand satisfied	G	C	H, I, Pro	O, T	C, F	M	N	D
20	(Hsu, Hung, and Li 2007)	Stochastic mathematical model to solve vehicle routing problem in order minimise transportation cost and violations of delivery time-windows	D	C	L	O	F, O	M	N	S
21	(Bai, Burke, and Kendall 2008)	A heuristic model for inventory control of fresh produce products of a UK retailer.	R	F	I	O	F	HE	N	D
22	(Cittadini et al. 2008)	Multi-objective model to plan the production of fruit. The model optimises manpower utilisation and maximizes fruit production costs.	A, G	I	H, Pro	T, S	F, S	M	D	S
23	(Ferrer et al. 2008)	MILP model to balance operating costs of the harvesting process with the quality loss effects of the schedule.	G	F	H	O	F, O	M	N	D
24	(Osvald and Stirn 2008)	A heuristic algorithm employed for vehicle routing problem of a fresh vegetable SC to reduce distribution	D	C	L	O	F, O, QS	HE	N	D

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
		costs								
25	(Blackburn and Scudder 2009)	An analytical model for design problem of a watermelon and sweet corn problems in order to preserve products shelf life.	G	F	H, L, Pa	T	F, QS	A	N	D
26	(Nagasawa, Kotani, and Morizawa 2009)	Multiple mathematical models were employed to optimise forms of vertical cooperation between growers. The objective to coordinate harvesting operations to meet customer demand while sustaining market prices	G	N	H	O, T	C, F	M	D	D
27	(Sarker and Ray 2009)	Non-linear multi-objective model for harvesting operations planning on a macro level to secure local country food supply.	A	I	Pro	T	F, O	M, HE	N	D
28	(van der Vorst, Tromp, and van der Zee 2009)	DES model for distribution operations of pineapple SC. The model is used to explore different designs of the SC in order to improve transportation costs and environmental impact of SC.	D, E, P	C	D, L	S	C, E, F, O, QS	S	D	D
29	(Arnaout and Maatouk 2010)	A heuristic model used for harvesting schedule problem for grape growers. The objective was to reduce products waste costs alongside with labourer hiring costs.	G	F	H	O	F, O, QS	HE	N	D
30	(Bohle, Maturana, and Vera 2010)	MLIP model for wine grapes harvesting problem, it incorporates uncertainty in labourer productivity during harvesting operations in order to minimise products waste costs.	G	F	H	O	F, O	M	N	S
31	(Cai et al. 2010)	Analytical game theory model to investigate coordination for products pricing between fresh produce suppliers.	D, P	C	L, Pri	O, T	F, O, QS	A	N	D
32	(Devadoss and Luckstead 2010)	SD model studying apple supply responses for various investment decisions in new orchards.	A, G	I	Pro	S	F	M	D	S
33	(Perez-Mesa, Galdeano-Gomez, and Aznar-Sanchez 2010)	Analytical game theory model for optimising products pricing by tomato retailers in Spain.	G, R	C	Pri	T	F	A	D	S
34	(Rijgersberg et al. 2010)	DES model for green lettuce logistics activities. The model was designed to study microbial infection of the	D, G, R	C	L	T	F, QS	S	D	S

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
		products.								
35	(Ahumada and Villalobos 2009b)	MLIP model developed for harvesting planning tomato and bell shape peppers SC with overall objective of maximising the total revenues.	E, G	C	L	O	F, QS	M	N	D
36	(Ahumada and Villalobos 2011)	MLIP model to optimise different operations performance a Mexican vegetable supply chain in order to control products quality and minimise operational costs.	E, G	C	H, L,	T	F, O, QS	M	N	D
37	(Rong, Akkerman, and Grunow 2011)	MLIP to optimise cooling efforts during production and logistics activities to minimise disposal costs, while preserving the required quality and quantity demanded by customers	D, G	N	L, Pro	O, T	F, O	M	N	S
38	(Ahumada, Rene Villalobos, and Nicholas Mason 2012)	A modification is added to 2011 model, by adding uncertainties for production yield and prices.	E, G	C	H, L, Pro	T	F, O	M	N	S
39	(Amorim, Günther, and Almada-Lobo 2012)	Multi-objective MLIP model for production and distribution functions. The model aimed to minimise costs of production, logistics, and losses of products simultaneously with maximising their shelf life.	P	N	L, Pro	O	F, QS	M	N	S
40	(McKellar et al. 2012)	SD model to explore impact of environment temperature on food safety for a fresh lettuce SC.	D, E, R	C	I, L	T	QS, S	S	D	S
41	(Tan and Comden 2012)	An NLP dynamic model for a tomato grower in Italy. The model is used for planning farming areas and seeding schedule to maximise grower's profits.	G	F	H, Pro	T	F	M	N	S
42	(Yu, Wang, and Liang 2012)	Mathematical modelling for vendor managed inventory system using an NLP model. The main objective was to minimise products deterioration costs.	P	F	I	O	F	M	N	D
43	(Catala et al. 2013)	A MLIP model used for strategic planning for apple and pears orchards restructuring and variety selection. The objective of the model is to maximise net present value for return on investments	G	F	D, Pro	S	F	M	N	D
44	(Sun 2013)	An analytical game theory model for supplier-retailer relationships. It is used to optimise SC coordination	G, R	C	Pri	T	F	A	N	S

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
		decisions under supply disruption scenarios for fresh agriculture products.								
45	(Teimoury et al. 2013)	An SD model used for investigating government imports policy for fruits and vegetable SC. The main objective of the government is to stabilise products price on the macro level.	A	I	Pri	T	F, O	S	D	S
46	(Tsao 2013)	NLP model for facility allocation problem. The objective is to reduce setup and operational costs while achieving highest product quality for vegetable and fruit distributions centre.	D	N	D, L	T, S	C, F, QS	M	N	D
47	(Yu and Nagurney 2013)	An analytical model for exploring food safety and SC members' profits under different disease outbreak scenarios.	G	N	D, I, L, Pa, Pro	T	F, QS	A	N	D
48	(Accorsi et al. 2014)	Use of LCA models to explore impact of different packaging design for fruits and vegetable products. The objective of the design it to reduce Co2 emissions resulted.	D, G, P	C	D, L	S	E, F	A	D	D
49	(Agustina, Lee, and Piplani 2014)	MLIP for vehicle routing and scheduling problems for cross docking operations for fresh fruits and vegetable SC. Reducing orders early and tardy arrivals are the main objective alongside with distribution and operational costs.	D	C	I, L	O, T	F, O	M	N	D
50	(Ampatzidis et al. 2014)	A heuristic algorithm for machine repair during grapes and cherries harvesting operations. The objective of it was improving resources efficiency.	G	F	H	O	F, O	HE	D	D
51	(Atallah, Gomez, and Bjorkman 2014)	An LP model is used to optimise products localisation on macro planning level for broccoli industry in the US in order to reduce water consumption and ensure total local demand is covered.	A, D, G	I	D, Pro	S	E, F, O, S	M	N	D
52	(Aung and Chang 2014)	Simple heuristic model to find optimal temperature for multi-commodity refrigerated storage of retailers and distributors of fruits and vegetable products.	D, R	F	I, L	O	E, F, QS	HE	N	D
53	(Govindan et al.	A mixed metaheuristic and multi-objective	P	N	D, L	O, T, S	E, F	M, HE	N	D

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
	2014)	mathematical model for facility location and vehicle routing problems. To reduce both transportation and logistics costs and CO2 emissions.								
54	(Hu, Chen, and Huang 2014)	LP model to optimise number and locations of new market entry vegetable production areas under different demand scenarios to maximise the total profits of the producer.	G	F	L, Pro	T	F	M	N	S
55	(Lambert et al. 2014)	A fuzzy programming model for planning exporting quantities for Persian lime SC in Mexico.	G	F	H, Pa	T	F, QS	HE	D	S
56	(Manfredi and Vignali 2014)	LCA model for exploring environmental impact of various cultivation and processing decisions for tomato.	D, G	C	H, Pro	T	E	A	D	D
57	(McKellar et al. 2014)	SD model for exploring distribution time and temperature impact on product safety for fresh lettuce SC in Canada.	D, E, R	C	I, L	T	QS, S	S	D	S
58	(Su, Wu, and Liu 2014)	NLP model to select between two model of coordination for fruits and vegetable distribution between retailers and distribution centres to maximise total profits.	D, R	C	L	O, T	F	M	N	S
59	(Velychko 2014)	NLP model for fruits and vegetable post-harvest processing and distribution activities to minimise total costs.	D, R	C	L	O	F	M	N	D
60	(Willem, Roberto, and Jack 2014)	An SD model for exploring different outsourcing policies for an Egyptian strawberry SC. The main objective was to achieve highest freshness levels of sourced products meanwhile minimise total outsourcing costs.	D, G	C	I, L	T	F, QS	S	D	D
61	(Aiello, Enea, and Muriana 2015)	A stochastic programming model to explore efficacy of multiple products traceability systems on fruits and vegetable SC efficiency.	G, R	C	D	T	F	M	D	S
62	(Bouwknegt et al. 2015)	An analytical model to assess contamination risks for lettuce SC in Netherland. Multiple safety precautions policies were tested to investigate impact on products safety	G, R	C	H, L	T	QS, S	A	D	S
63	(Castro Silva, Fontes, and	MCDM model is used to design performance management system of fruits for premium fruit exporter	E	F	D	T	S	A	N	D

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
	Barbosa 2015)	in Brazil. The objective of the system is improving employees' motivation and company image.								
64	(Danloup et al. 2015)	MLIP model for optimising collaboration between retailer and distribution centre to reduce greenhouse gases resulted from transportation activities.	D, R	C	L	T	E	M	N	D
65	(de Keizer et al. 2015)	Mixed MLIP and DES model for optimising food SC network design by addressing food hub allocation and products flow problems. Several KPIs have reported such service level and distribution costs.	G, R	N	D, L	O, S	F, O, QS	M, S	N	S
66	(Etemadnia et al. 2015)	MLIP for facility location and capacity design problem for fruits and vegetable hub. The objective was to minimise total logistics costs.	A	I	D, L	S	F	M	N	D
67	(González-Araya, Soto-Silva, and Espejo 2015)	MLIP model for harvesting operations schedule and labourer recruiting policy of apple orchards on macro level in Chile. The main objective was to minimise products losses and to hire costs.	D, G	F	H	T	F, QS	M	N	D
68	(Keyes, Tyedmers, and Beazley 2015)	LCA model to assess impact of replacing conventional apple orchards by organic ones on environment, mainly resultant emissions and use of fertilisers.	G	F	H, Pro	S	E	A	D	D
69	(Li et al. 2015)	An NLP model for vehicle routing problem for a Chinese banana SC. The model considered delivery time windows and road irregularities for the optimal solution.	D, R	C	L	O	F, O	M	N	D
70	(Marquez, Higgins, and Estrada-Flores 2015)	An analytical model that map transport and distribution operations of fruits and vegetables supply chain in Victoria. It was used to study weather disruption on CO2 emission resulted from the SC activities.	A	I	L	T	E	A	D	D
71	(Nadal-Roig and Plà-Aragonés 2015)	MLIP model for transportation planning of fruits SC in Spain. Product flows and a number of trucks are optimised in order to minimise transportation costs.	D, G	C	I, L	O	F	M	N	D
72	(Santos et al. 2015)	Integer programming model used for vegetable crop rotation problem. The objective of the model is to find optimal crop rotation schedule that minimises land use.	G	F	Pro	T	E	M	N	D
73	(Soysal et al. 2015)	A stochastic mathematical model used for vehicle routing and product flows problem considering demand	D, R	C	I, L	O	E, F, O	M	N	S

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
		and few consumption uncertainties. Objective is minimising total travelling time, travelling cost and CO2 emissions.								
74	(Wang, Chen, and Wang 2015)	An analytical game theory model used for developing cooperation strategy between SC members to improve products quality and safety.	A, D, R	C	D, Pri	T	F, QS, S	A	D	D
75	(Wishon et al. 2015)	MLIP model used for planning harvesting operations seasonal labourers schedule in Arizona.	G	F	H	T	F	M	N	D
76	(Zhou, Jensen, et al. 2015)	DES model for potatoes growing operations. Multiple resources are manipulated to study their impact on operations efficiency and resources utilisation.	G	F	H	O	F, O	S	D	D
77	(Accorsi et al. 2016)	Multi-objective LP model used for potatoes farm infrastructure design. Multiple decisions are considered including land use, crop assignment and facility locations. Objectives are maximising crop yield, reduce logistics costs and carbon gases emissions and sustain food demand on macro level.	A, G, P	N	D, L, Pa, Pro	T, S	E, F	M	N	D
78	(Bortolini et al. 2016)	Multi-objective LP model used for network design for fresh produce products distribution for an Italian fruit and vegetables SC. Objectives include minimising costs, delivery dates violations and CO2 emissions.	D, G, R	N	L	T	C, E, F	M	N	D
79	(Cameron and Aruna 2016)	Multi-objective LP model used to quantify impact of disruptions on spinach SC in Spain. Decisions include products flow and safety stocks while objectives are reducing product wastes and meeting customer demand.	D, G, R	N	L	T	C, F	M	D	D
80	(Chen et al. 2016)	NLP model for inventory control for fresh produce products to optimise products expiry dates while preserving their freshness. Shelf space size, replenishment cycle time and inventory levels are the decision variables.	R	F	I	T	F	M	N	D
81	(Falcone et al. 2016)	LCA model used for studying many wine grapes growing scenarios in southern Italy. Both environmental and economic impacts are considered. Scenarios include using conventional varieties against organic ones.	G	F	Pro	S	E, F	A	D	D

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
82	(Ferreira, Batalha, and Domingos 2016)	An SD model used for citrus SC in Brazil. The model is used to study growing new citrus varieties and employing new evolving technologies.	A	I	Pro	S	F	S	D	D
83	(Grillo et al. 2016)	MLIP model used for customer orders promising by an orange packing house. Orders acceptance and rejections are optimised in order to maximise total profits products freshness.	P	F	H, Pa	T	F, QS	M	N	D
84	(Lamsal, Jones, and Thomas 2016)	MLIP model used for planning the movement of the crop from farm to processing plant. Harvesting starting time and a number of trucks are the decision variables while objectives are minimising costs and processing time.	G, P	C	H, L, Pa	O	F, O	M	N	D
85	(Mateo et al. 2016)	MLIP model used for seasonal supplier selection for tomato retailer in Spain. Objectives are meeting customer demand and minimising purchase costs.	G, R	N	D	T	C, F	M	N	S
86	(Mishra et al. 2016)	NLP model is used to optimise storage temperature for leafy green SC in order to minimise refrigeration costs while preserving product freshness and safety	R	F	I	O	F, QS	M	N	D
87	(Tromp et al. 2016)	DES model used to assess multiple intervention policies' impact on fresh lettuce at Dutch retailer. Ordering and replenishment policies are investigated against waste rates and out-of-stock performance indicators.	R	F	I, L	T	C, F	S	D	S
88	(de Keizer et al. 2017)	Multi-objective integer and nonlinear programming model is used for packing house and cold store traceability design in order to minimise operations and logistics cost and products contamination.	G, R	N	D	T, S	F, QS	M	N	D
89	(Gautam et al. 2017)	MLIP model used for periodical planning of fresh tomatoes distribution in order to minimise logistics cost.	A, D, G	I	I, Pa	T	F, QS	M	N	D
90	(Ghezavati, Hooshyar, and Tavakkoli-Moghaddam 2017)	MLIP model is used for SC network design. The design considers facility locations and links between each other. The objective is to minimising products quality decay.	D, G, R	N	I, L, Pa	O, T	C, F, QS	M	N	D

#	Author	Article's Short Summary	SC Actor	SC Analysis Level	SC Function	Decision Making Level	KPIs	Model Type	Model Purpose	Parameters
91	(Orjuela-Castro, Herrera-Ramirez, and Adarme-Jaimes 2017)	An SD model used to study different packing operations design for mango SC in California. Inventory levels, quality development and transportation time, are the behavioural variable.	G, P, R	C	L, Pa	T	O, QS	S	D	D
92	(Qi et al. 2017)	Analytical game theory model used for planning coordination of contracts and products pricing in order to optimise freshness of products.	D, R	C	Pri	T	F, QS	A	D	D
93	(Soto-Silva et al. 2017)	MLIP model used for grower selection and facility location, and truck acquisition problems of and Chilean apple SC. Objectives are minimising transportation costs and cost of locating storage facilities.	G, P	N	I, L	O, T	F	M	N	D
94	(Wang and Chen 2017)	Analytical game theory model used to optimise grower-distributer contracting and products pricing in order to maximise total profits	D, R	C	Pri	T	F	A	N	S

APPENDIX 3: FINANCIAL DATA OF THE CASE

The following table includes all the values for the financial parameters used for simulation model of the case study. Due to data congeniality, managers refused to put actual economic data, so instead, they suggested using peroxided values for financial data instead.
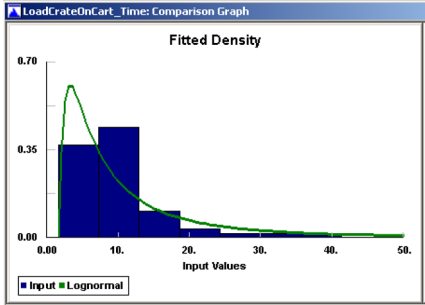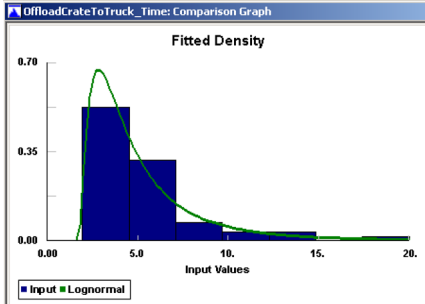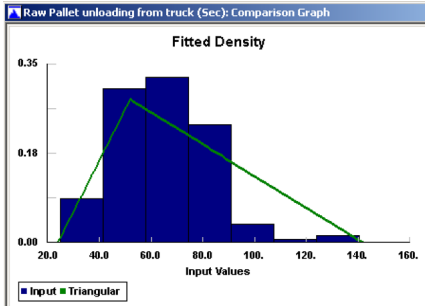
	Value(s)	Unit
Grower Data		
Truck Renting Cost	400	LE/ Day
Truck Purchase Price	400000	LE
Cart Renting Cost	200	LE/ Day
Cart Purchase Price	100000	LE
Selling Price (To the Packing House)	4000	LE/ Ton
Selling Price (To Local Market)	2000	LE/ Ton
Trees Replacement Cost	57000	LE/ Acres
New Vineyards Planting Cost	157000	LE/ Acres
Picker Regular Hiring Rate	60	LE/ Day
Other Workers Regular Hiring Rate	60	LE/ Day
Packing House Data		
Packer Hiring Rate	85	LE/ Day
Other Workers Hiring Rate	65	LE/ Day
Low-Quality Grapes Price	1500	LE/ Ton
Selling Price (Export)	7000	LE/ Ton
Selling Price (Locally)	4000	LE/ Ton
Sourced Grape Cost	5000	LE/ Ton
Electric Unloader Renting Cost	450	LE/ Day
Electric Unloader Purchase Price	300000	LE/ Day
Proposed Cost for new Packing	8000000	LE
Exporter Data		
Air Shipping Cost	6000	LE/ pallet

Selling Price	10000	LE/ Pallet
Containers Data		
Bunch Average Weight	0.5	KG
Raw Crate Size	16	Bunch
Raw Pallet Size	50	Crate
Raw Truck Size	6	Pallet
Packed Box Weight	5	KG
Packed Pallet Size	120	Box
Container Size	20	Pallet

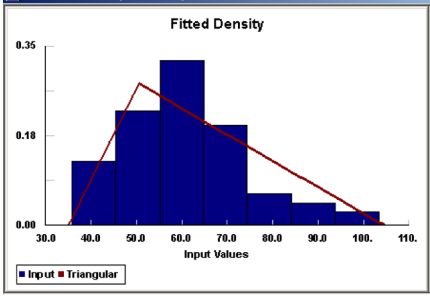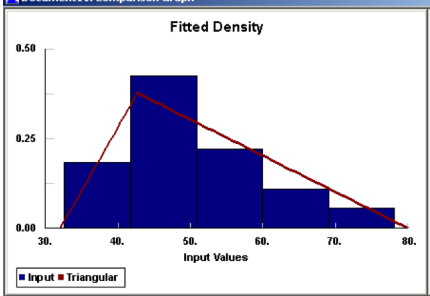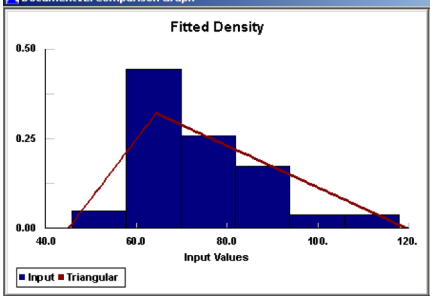## APPENDIX 4: STATISTICAL DISTRIBUTIONS FOR PROCESSING TIMES

Variable Name	Fitted Distribution
Time for "***Loading Crates on Cart***" (Seconds)	$\mu = 1.83 \qquad \sigma = 1.15$
Time for "***Offloading Crates from Cart to Truck***" (Seconds)	$\mu = 0.947 \qquad \sigma = 0.859$
Time for "***Raw Pallet Unloading from Truck***" (Seconds)	$min = 25, \; avg = 64, \quad max = 140$

Time for "***Raw Pallet Moving to Receiving Area***" (Seconds)	$min = 28, \ avg = 70, \quad max = 116$
Time for "***Moving Raw Boxes to Tables***" (Seconds)	$min = 5, \quad max = 15$
Time for "***Place Packed Boxes on Pallets***" (Seconds)	$min = 3, \ avg = 11, \quad max = 20$
Time for "***Wrapping Pallet***" (Seconds)	$min = 6, \ avg = 12, \quad max = 18$

Time for "***Moving Pallet to Temporary Storage***" (Seconds)	**Document10: Comparison Graph** — Fitted Density $min = 36,\ avg = 73,\quad max = 118$
Time for "***Moving Pallet to Cool Fans***" (Seconds)	**Document11: Comparison Graph** — Fitted Density $min = 33,\ avg = 50,\quad max = 78$
Time for "***Moving Pallet to Cold Storage***" (Seconds)	**Document12: Comparison Graph** — Fitted Density $min = 46,\ avg = 73,\quad max = 118$