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Exploration of the effects of postharvest handling of fruits and vegetables along fresh produce chains using logistics and computer modelling: A case study in Zimbabwe

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A thesis

submitted in partial fulfilment

of the requirements for the Degree of

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by

Antonetta Tsitsi Zisengwe

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Exploration of the effects of postharvest handling of fruits and vegetables along fresh produce chains using logistics and computer modelling: A case study in Zimbabwe

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Agriculture is not only a significant export earner for many economies but is the largest employer globally. Horticultural produce such as fresh fruit and vegetables are key commodities on local and international trade markets. However, approximately 3 billion tonnes of food that is intended for human consumption is lost or wasted along the agri-fresh supply chains. These losses imply a decline in revenue and deprivation of income for some households. Identification of the sources and causes of these losses is an essential postharvest management strategy that is key in enhancing food and nutrition security and livelihood sustainability in developing countries.

The goal of the study was to characterise postharvest losses in banana, orange, pea and tomato supply chains in Zimbabwe. The study also identified possible mitigation strategies for the losses within the context of operation they were occurring. Three approaches were made use of in the study. Firstly, a literature review of similar studies carried out in other countries aided in the development of questions for a semi-structured interview-based questionnaire. The instrument was used to map the supply chains from the producer (farmer) to the retail store or the point from which customers purchased their produce. Results showed that the key chain participants were producers, traders, retailers, marketers, exporters and wholesalers. Producers or farmers were further subdivided into large-scale commercial, small-scale commercial and small-scale subsistence farmers. Large-scale commercial farmers exported most of their produce whilst small-scale commercial and small-scale subsistence farmers mostly supplied the domestic market.

Secondly, observations were made following interviews. These aided in corroborating the information gathered from the interviews with the activities that were taking place at different points of the supply chain. Unsanitary activities were observed at the small-scale subsistence farmers level and at the traders' market stalls. Thirdly, simulation models were developed for the orange supply chain, using information gathered from the interviews and the observations.

In conclusion, the results obtained in the study indicated that there is need for enhancement of agricultural training and extension services to educate traders and the small-scale subsistence farmers on proper postharvest handling of produce. They form the largest group of farmers in

Zimbabwe, with the least farming space and limited knowledge on postharvest handling. Quality of road and public farmers markets infrastructure requires for the intervention of relevant ministerial and national governing bodies. On matters relating to public health, there is need to educate the public on the dangers of using chemicals not meant for fresh-produce in dealing with nuisance pests and insects. The simulation study highlighted the need for all players in the agri-fresh supply chain to record and keep data on movement of produce. This information should incorporate volumes traded and lost, waiting times, delays for them to be able to identify where they are losing produce and attempt to minimise the losses as best as they can. Sensitivity analyses of the orange model showed that increasing entity arrival to 2 resulted in a doubling of throughput and increased resource utilisation. This proved that simulation models can be used to test alternative modelling scenarios without tampering with the actual system.

Key words: postharvest, agri-fresh supply chain, simulation modelling, fruits and vegetables, food loss, food logistics

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List of abbreviations

APHLIS	African Post Harvest Losses Information System
ASC	Agri-fresh Supply Chain
CSAM	Commodity Systems Assessment Methodology
FAO	Food and Agriculture Organisation
F and V	Fruit and Vegetable
FBS	Food Balance Sheets
FTLRP	Fast Track Land Reform Programme
GDP	Gross Domestic Product
KPI	Key Performance Indicator
LSCF	Large-Scale Commercial Farmer
PHL	Postharvest Loss
QCL	Quality Controlled Logistics
SCM	Supply Chain Management
SSA	Sub-Saharan Africa
SSCF	Small-Scale Commercial Farmer
SSSF	Small-Scale Subsistence Farmer

Chapter 1 : Introduction

1.1 Background

World food demand is high and expected to increase due to the expanding global population which is expected to reach approximately 10 billion by 2050 (United Nations, 2017). Impacts of climate change such as shifting weather patterns have affected crop yields in parts of the world (Beddington et al., 2012). This has led to emphasis being placed on the development of sustainable agricultural practices to increase food productivity and minimise food loss and waste along agri-food supply chains (Food and Agriculture Organisation, 2018; 2018). The rapid adoption of agricultural intensification has been observed in developed countries as opposed to extensification (clearing large pieces of land) which is being practised in some developing countries and negatively impacts the environment (Beddington et al., 2012; Bradford et al., 2018; Kader, 2005; Ray, Mueller, West, & Foley, 2013). While this has resulted in a doubling of food production in Europe, Asia, Australasia and both North and South America, a decline has been observed in some countries in Sub-Saharan Africa (SSA) where the majority of small-scale farmers rely on rain-fed agriculture (Ray et al., 2013). This has crippled the agricultural sector which is pivotal in food production, employment creation and economic sustainability (Ray et al., 2013). Reduced food production results in food insecurity, which exists when "people do not have adequate physical, social or economic access to food,'' (FAO, 2003). Globally, the number of food insecure individuals rose from 804 million in 2016 to 821 million in 2017 (FAO, 2018). Slightly more than a quarter of these (about 236.5 million) are from SSA. In Zimbabwe, about 7.5 million people are undernourished with 4 million people facing severe food insecurity (FAO, 2018). To ensure that these people are adequately fed, insufficient local food supplies are augmented with food aid.

1.2 Problem statement

Poor postharvest handling and management practices along the agri-food supply chain (ASC) in developing countries and wastage by the consumers in developed countries account for losses of approximately one-third (about 1.3 billion tonnes) of the food produced (Kader, 2005; Gustavsson et al., 2011; FAO, 2013). Whilst postharvest losses (PHL) are inevitable along the fresh produce chain from farm-to-fork, their magnitude is dependent on several factors. These include seasonality, food commodity, region of production and level of socio-economic development (Gustavsson et al, 2011). Although nearly impossible to eliminate, PHL can be minimised to aid in the conservation of already stressed resources and ensure adequate food and nutrition security. This can be achieved by a number of different methods such as the development of cultivars with enhanced nutritive value, keeping quality and adapted to the current climate conditions; utilisation of crop management regimes that maximise yield without compromising quality; and optimisation of postharvest handling practises. However, this requires an integrated multidisciplinary approach involving coordination of activities among participants along the agri-fresh supply chain, from production to the consumer.

Agri-food supply chains (ASC) encompass all the processes occurring from farm-to-fork (Fredriksson & Liljestrand, 2015). Management of ASC is difficult due to the highly perishable nature of fresh produce and seasonal fluctuations in supply, demand and prices. ASC also differ from other supply chains and are affected by intrinsic and extrinsic factors such as biological variance, climate variability, technological innovations, trade agreements, consumer awareness, globalisation, food safety and concerns relating to human health (Shukla & Jharkharia, 2013). Globalisation has led to the development of interconnected logistic networks. Logistics is key in ensuring the delivery of consistent quality and quantity of food and feeding the global population (Fredriksson & Liljestrand, 2015). Furthermore, research on ASC networks aimed at improving efficiency by using tools such as modelling has increased.

Although linear programming is the predominant modelling technique used (Soto-Silva, Nadal-Roig, González-Araya, & Pla-Aragones, 2016), other authors have used simulation modelling methods in their studies (Borodin, Bourtembourg, Hnaien, & Labadie, 2016). Simulation tools are not only popular for modelling biological and environmental systems, but also find use in manufacturing and supply chain systems (Van Der Vorst, Tromp, & Zee, 2009). Simulation models can integrate food quality models with chain design as well as analyse systems with insufficient data (Borodin et al., 2016).

Studies carried out on agricultural commodities such as the tomato (Ghezavati, Hooshyar, & Tavakkoli-Moghaddam, 2017; Macheka, Spelt, van der Vorst, & Luning, 2017; Macheka, Spelt, Bakker, van der Vorst, & Luning, 2018; Rocco & Morabito, 2016; Underhill & Kumar, 2015), mango (González-Aguilar, Zavaleta-Gatica, & Tiznado-Hernández, 2007), banana (Mvumi, Matsikira, & Mutambara, 2016), oranges (Musasa et al., 2013), cereals and grains (Mwangi, Mutungi, Midingoyi, Faraj, & Affognon, 2017; Tefera, 2012) have highlighted the problems associated with postharvest loss and the demand for the development of viable solutions to ensure adequate food and nutrition security. Cereals and grain studies have been extensive as they form the staple food of most Sub-Saharan Africa households (constituting 10-55% of the diet). An African Postharvest Losses Information Systems (APHLIS) framework was developed for the analysis and quantification of PHL in cereals under varying climatic conditions for Eastern and Southern Africa (Rembold, Hodges, Bernard, Knipschild, & Léo, 2011), with plans underway to develop a system to incorporate fruit and vegetables.

1.3 Justification

A review of current literature on PHL in fruits and vegetables showed a scarcity of studies within the Zimbabwean context highlighting the need for such studies to be carried out. PHL contribute to the high dependence on vegetable imports which are sourced to meet local demand. Furthermore, increasing the quantity of food produced is more costly in comparison to reducing the amount of food lost in the agri-food supply chain. Peas and oranges are significant export earners in Zimbabwe whereas bananas and tomatoes are key commodities on the domestic trade markets. This thesis will not only add to the body of knowledge on postharvest handling studies along fresh produce chains in Zimbabwe and developing countries but in addition, attempts to use discrete event simulation modelling of fresh produce chains in the Zimbabwean context.

1.4 Aims and Objectives

The overarching aim of the study is the reduction of postharvest losses along fresh produce chains from farm-to-fork.

1.4.1 Research aims

I. To map the agri-food supply chains

II. To identify postharvest handling practises carried out by participants in the mapped pathways that contribute to postharvest losses

III. To identify possible mitigation strategies and measures to minimise postharvest losses within the context of operation they are occurring

1.4.2 Research objectives

I. Using semi-structured interview-based questionnaires, map fresh produce chains of fruit and vegetables under study from farm-to-fork

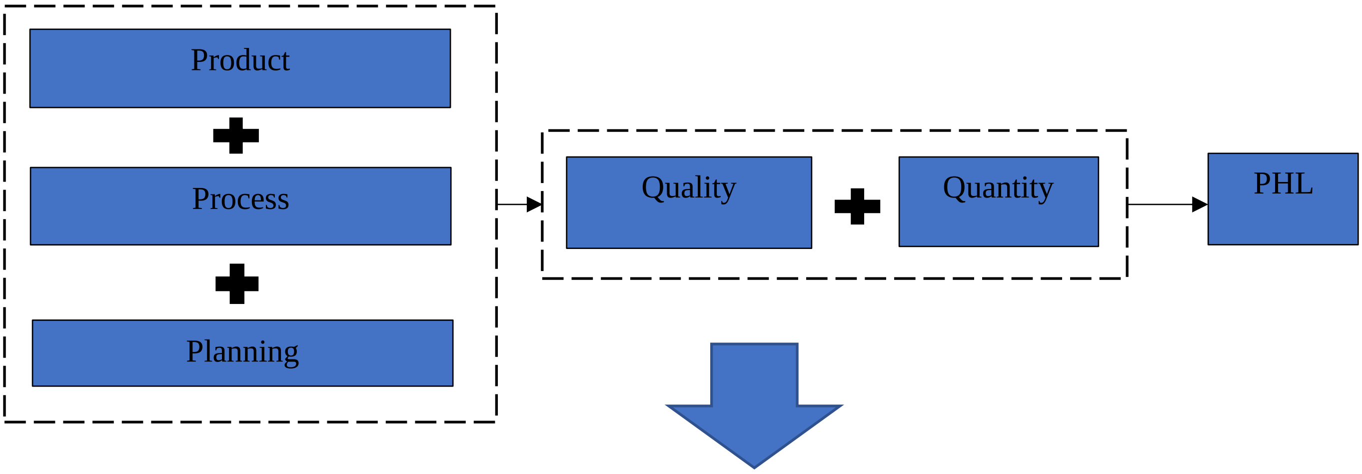
II. Using semi-structured interview-based questionnaires and observation techniques, determine the source and nature of postharvest losses in the chain

III. Simulation modelling of mapped pathways

IV. Suggest possible mitigation strategies

1.5 Methodological Approach

1.5.1 Conceptual Framework



1.5.2 Empirical research

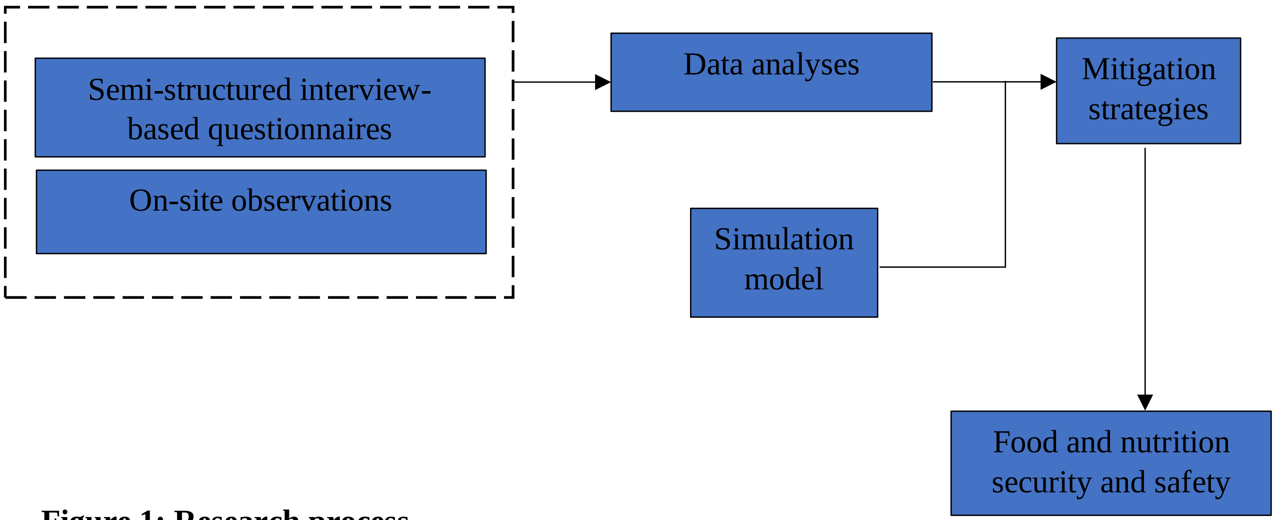


Figure 1: Research process

1.6 Thesis organisation

This thesis is divided into 6 chapters with **Chapter 1** having introduced and given a brief background to the problem, outlining aims, objectives and justification for undertaking the study. **Chapter 2** is a review of relevant literature on agri-food supply chains focussing on the concepts highlighted in the conceptual framework in Figure 1. A combination of product characteristics (physical and chemical attributes), process parameters (postharvest handling) and planning (supply chain management and logistics) are key determinants of fresh produce quality, subsequently influencing postharvest losses and food and nutrition security. **Chapter 3** is a description of the empirical research process outlined in Figure 1, explaining the choice of methodology and instrumentation for data collection and analysis. **Chapter 4** presents the concept of simulation modelling, outlining the model development process and implementation. **Chapter 5** presents and discusses the obtained results. **Chapter 6** is a conclusion of the main findings and recommendations for future research outlook.

Chapter 2 : Literature Review

Chapter 2 is a review of relevant literature related to postharvest handling, postharvest loss, and logistics in the fruit and vegetable supply chains.

2.1 Global Fruit and Vegetable Production and Trade

Fruit and vegetable (F and V) consumption is integral for the maintenance of a balanced diet. Fresh fruits and vegetables are known to provide essential nutrients needed to lead an active and healthy lifestyle. Research has shown that regular consumption of fruits and vegetables may aid in longevity and prevent the development of degenerative diseases (Kaur & Kapoor, 2001; Sibomana, Workneh, & Audain, 2016). World fruit and vegetable production estimates currently stand at nearly 2 billion tonnes with bananas, oranges, peas and tomatoes amounting to approximately 390 million tonnes (Figure 2) (FAOSTAT, 2018). The Asian region is the largest producer globally. India, China, USA, Brazil, and Mexico are the leading producing countries in the world.

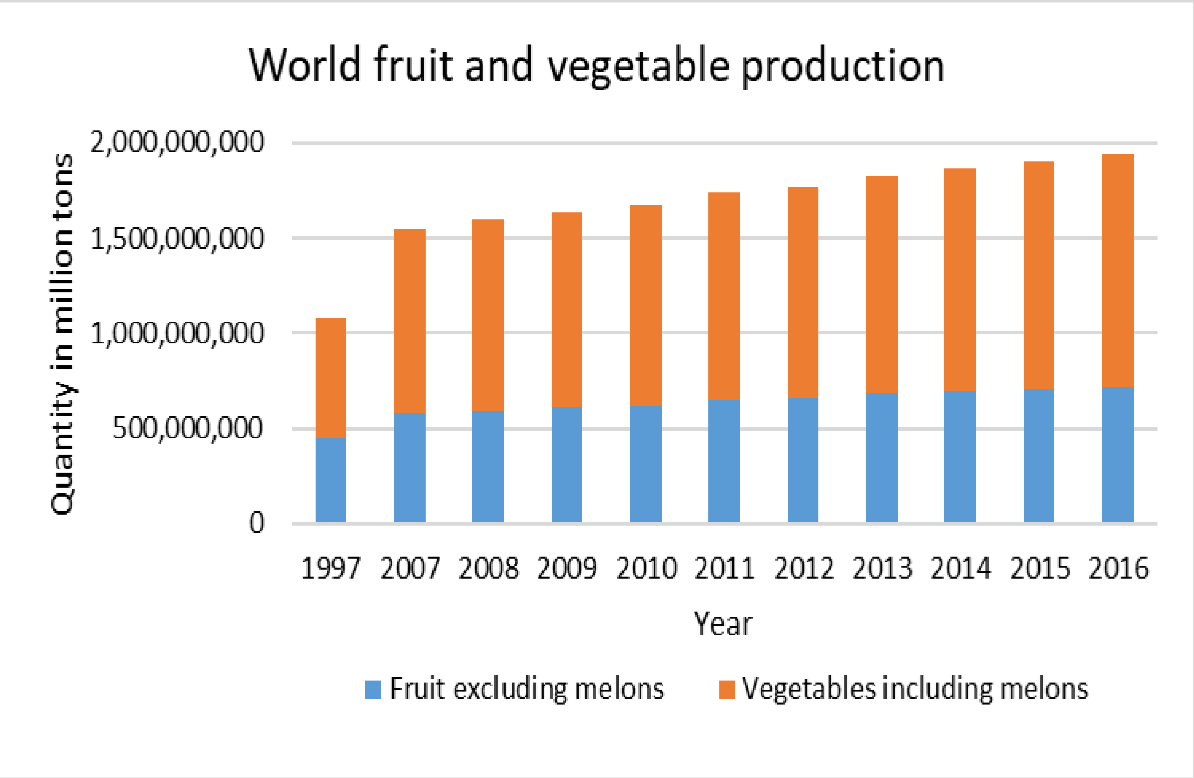


Figure 2: Total world fruit and vegetable production (FAOSTAT, 2018)

An expanding world population, globalisation and studies highlighting the importance and health benefits of consuming fresh fruit and vegetables are some of the drivers behind the increase in global trade in F and V (Diop & Jaffee, 2005; Regmi, 2001). This translates to an increase in the volumes of commodities traded and revenue generated which are beneficial to most agro-based economies.

2.2 Status of agriculture in Zimbabwe

Zimbabwe is an agrarian country with its economy largely reliant on agriculture. Nearly 80% (10.8 million) of Zimbabweans are rural, with agriculture forming a source of livelihood and income for 60-70% of the population (Euromonitor International, 2018). Literature shows that the agricultural sector is the largest employer, contributing significantly to the annual gross domestic product (GDP) in most developing countries (Aksoy & Beghin, 2004; Diop & Jaffee, 2005). 15-19% of the Zimbabwean GDP is from agriculture (Euromonitor International, 2018). Many industrial processes require raw materials from agricultural production demonstrating its significance on the world economy. 60% of the raw materials for the industrial sector come from the agricultural sector, accounting for 40% of total export earnings (Euromonitor International, 2018).

The Zimbabwean government extensively redistributed and reallocated many commercial farms during the Fast Track Land Reform Programme (FTLRP) that was launched in 2000, broadening the smallholder farmer base (Moyo, 2011). However, agricultural output declined by 60%, with the most significant decline observed between 2002 and 2006 (Moyo, 2011; SNV, 2014). The annual turnover stood at USD140 million in 1999 but declined to USD40 million by 2010. The FTLRP saw the categorisation of farmers and farms based on land size, forms of land tenure, landholder social status and the capacity to hire extra labour (Moyo, 2011). They were categorised as large-scale commercial (individual and agro-industrial estates), small-scale commercial and small-scale subsistence farms. Large-scale commercial farmers serviced mainly the export market, with the small-scale farmers supplying the domestic market.

Ornamental plants, fruits and vegetables fall under the horticulture sector in Zimbabwe. Fruit and vegetable cultivation in Zimbabwe have generally increased over the past 20 years (Figure 2). Before the implementation of the FTLRP, the Zimbabwean horticultural sector had been established over 10 years (SNV, 2014). A 32% rise in horticultural production has been observed since 2012 (SNV, 2014), suggesting the existence of a favourable enabling environment for horticulture in Zimbabwe. Despite this rise, PHL is a persistent problem along the fresh produce chain with up to 40% of food being lost (Kader, 2004). Studies on specific produce chains are scarce highlighting the need for research institutions, agricultural colleges and universities to cover this knowledge gap. Information gathered from research studies can be used to determine extent of PHL along specific fresh produce chains. This information can then be used in formulating policies and measures to curb PHL and ensure food and nutrition security. Zimbabwe faces the challenge of achieving global food security whilst reconciling demands on the environment and scarce resources like most countries in the world (Dogliotti, Giller, & Van Ittersum, 2014).

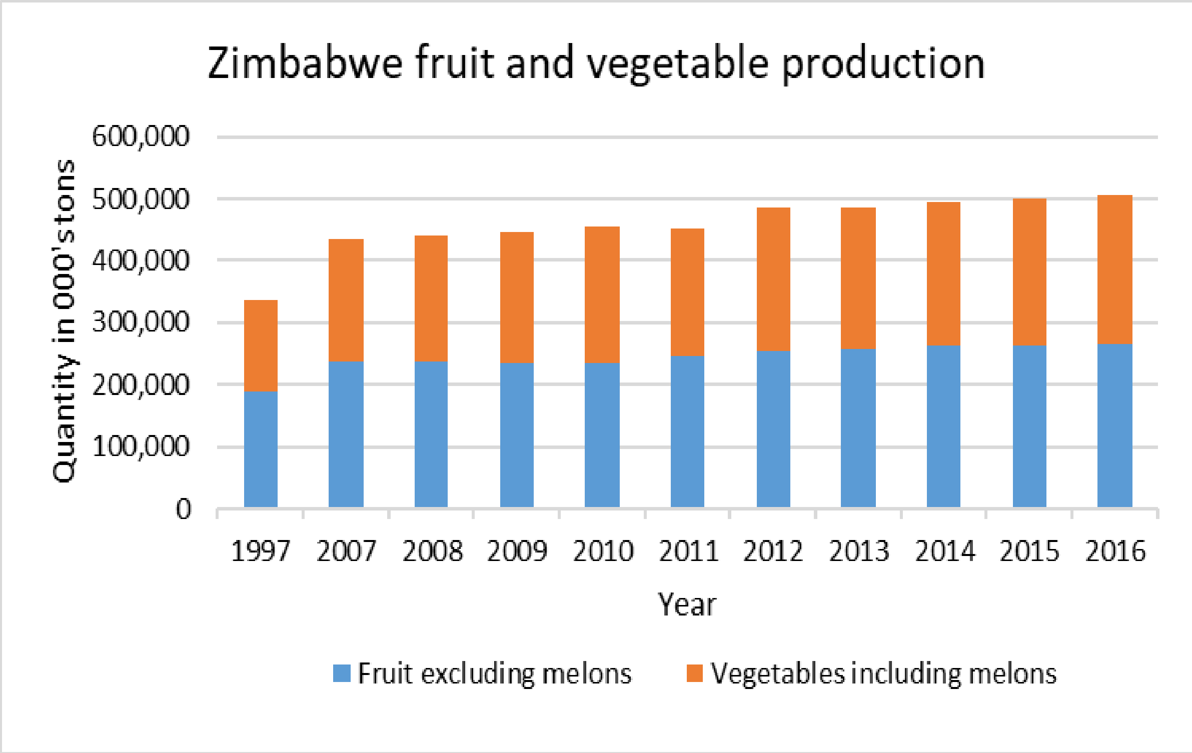


Figure 3: Total fruit and vegetable production in Zimbabwe (FAOSTAT, 2018)

2.3 Fruit and vegetable quality

Fruit and vegetable quality is characterised by intrinsic properties (e.g. flavour, texture, taste, appearance) and extrinsic ethical and sustainability standards which cannot be measured such as organic or fair trade production (Trienekens, 2011). Fruits and vegetables are living in nature, undergoing changes during their lifespan, from the moment of harvest to the point of consumption or waste. From a consumer perspective, the changes can be desirable as the degree of sweetness increases, the flavour intensifies, and colour development occurs. However, with extended storage the shelf life decreases as the produce shrivels and shrinks due to water loss and the cellular wall disintegrates, progressing to over-ripening and rotting among other undesirable developments (Brasil & Siddiqui, 2018). The major challenge with perishable produce is that these processes cannot be stopped, they can only be slowed down by technological interventions.

Kader & Rolle (2004) reported that quality attributes assigned to F and V differ according to specific market segments and individuals (grower, marketer, distributor, retailer, consumer) (Table 1). Farmers select cultivars exhibiting characteristics such as high yield potential, ease of harvest, ability to withstand long-distance shipping and resistance to pests and disease. Wholesalers and distributors on the other hand opt for firmness, appearance, and shelf-stability whilst consumers are more concerned with the appearance at the moment of purchase.

Table 1: F and V quality characteristic factors (Kader & Rolle, 2004; Brasil & Siddiqui, 2018)

Factor	Constituents
Appearance	Size: volume, weight, dimensions Shape: diameter ratio, uniform Colour: intense, homogeneous Defects: external and internal Surface wax coating
Texture	Succulent, firm, gritty, fibrous, hard, soft, fragile, lumpy, crisp, juicy, mealy, tough
Taste and aroma	Sweet, sour, astringent, off-flavour and odour, aroma
Nutritional quality	Dietary fibre, proteins, lipids, minerals, vitamins
Safety	Mycotoxins, microbial contaminants, chemical contaminants, natural contaminants

Reported quality components of F and V are important in this study because they reflect the standard of quality expected by various chain participants that should be maintained during all handling processes along the ASC.

2.4 Postharvest handling

Postharvest handling refers to all the activities carried out once produce has been harvested such as in-field processes, packinghouse operations, storage, transportation, and distribution (Affognon, Mutungi, Sanginga, & Borgemeister, 2015; Beharielal, Thamaga-Chitja, & Schmidt, 2018; Prussia & Shewfelt, 1993). Postharvest handling activities either negatively or positively affect F and V quality. Pre-harvest and harvesting methods should be carefully implemented to minimise the incidence of pest, disease, chemical and mechanical damage.

Pre-harvest factors of importance are:

- commercial cultivars with high yield potential,
- cultivation methods e.g. use of plant growth regulators,
- cultural practices to maximise yield and improve efficiency of farm operations,
- soil characteristics,
- water availability and quality, and
- physical damage (Prusky, 2011; Prussia & Shewfelt, 1993; Shewfelt, Prussia, & Sparks, 2014).

Pre-harvest	Harvest	Packinghouse operations	Packaging and storage	Transport	Distribution
Cultivar	Moment of harvest	Cleaning and washing	Handling	Mode	Retail display
Soil	Method of harvesting	Sorting and grading	Temperature	Temperature control	Time
Water	Pulp temperature	Pre-cooling	Time	Vibration	Handling
Climate	Season	De-greening	Relative humidity	Compression	
Cultural practices	Mechanisation	Waxing	Improper packaging	Airflow	
Growing conditions		Ripening	Improper storage		
Pest management		Handling			
		Automation			

Figure 4: Technical components of the fresh produce chain

2.4.1 In-field operations

In-field operations include harvesting and handling of produce. Harvesting, although not a postharvest activity, significantly influences fresh produce quality and marketability. Determination of moment of harvest is important. This should follow proper agronomic practises and procedures for individual fruits and vegetables because produce quality cannot be improved postharvest. It can only be maintained by employing methods that enhance shelf stability. Certain types of produce are harvested before they are fully ripened whilst some are more delicate if harvested earlier. Produce specifications imposed by the destination markets can influence the stage at which the produce is harvested.

The time of day of harvest is important as some fresh produce must be harvested during cooler daytime periods such as early morning because of sensitivity to dehydration if harvested when temperatures are high (Kader, 2010). Impaired flavour and shrivelling are characteristic of produce that has undergone accelerated transpiration due to the influence of exposure to high temperatures. When pre-cooling systems to remove field heat immediately after harvest are absent, it is more practical to harvest when temperatures are low.

Field workers handling produce during harvesting must exercise care to minimise mechanical damage and cross-contamination (Kader, 2010). Harvesting at appropriate stages of maturity, not mixing contaminated produce and using specially lined harvesting containers depending on the vulnerability of the produce to bruising reduce the occurrence of mechanical damage (Kader, 2010). Harvested produce may be sent to the packinghouse for further processing.

2.4.2 Packinghouse operations

2.4.2.1 Processing

Operations such as receiving, quality control checks, cleaning, washing, grading, sorting, cooling, and packing are carried out in the packinghouse. Variable portions of F and V are transformed into homogeneous lots which are packed together awaiting shipment. Sorting for defects is carried out manually although automated sorters may be used. Systems may be fully automated with conveyors for moving produce such as fruit from the cleaning tanks to packaging lines (Kitinoja & Kader, 2002). Studies by Bollen and Prussia (2014) showed that the use of automated systems yielded a high accuracy of between 60% to 95%.

All the processes that take place in the packinghouse are dependent on the specific requirements of the destination market for the F and V. Export quality produce must meet health and safety requirements for the destination market. Countries are imposing strict biosafety requirements to prevent the risk of importing pests and diseases which may ultimately affect their agricultural systems and natural flora and fauna ecosystems. Sorting and grading standards impose restrictions on supply chains and for stakeholders to remain competitive, they should conform to these standards.

One of the key features considered in packinghouse location is accessibility and proximity to the field, market, ease of entry and exit for vehicles and ergonomics (Kitinoja & Kader, 2002). Nearness to market and field shortens the amount of time spent transporting goods.

2.4.2.2 Packaging and storage

Perishable produce undergoes semi-permanent storage at various points along the supply chain. According to Shewfelt et al. (2014), storage aids in delaying selling of produce until market prices are favourable and extends seasonality of F and V ensuring a constant supply. Storage conditions and produce shelf-life determine length of storage which is dependent on initial quality and previous handling practices (Shewfelt et al., 2014). Points at which produce may be stored include: in-field in a harvesting shed awaiting bulk transportation to the packinghouse; at the packinghouse awaiting distribution to markets and wholesalers; retailers and traders temporarily store produce that would not have been sold to sell it on the next market day (Kitinoja & Kader, 2002).

Metabolic activities persist postharvest driven by energy generated from respiratory activities. Oxidation of organic compounds during respiration yields carbon dioxide, water and heat (energy). Kader and Rolle (2004) reported that accelerated use of water and internal energy by fresh produce resulted in loss of nutritional quality and appearance. In addition, transpiration (evaporative water loss from plants) was shown to cause wilting and shrivelling (Kitinoja & Kader, 2002).

The shelf life of stored produce is dependent on conditions of storage such as cold or ambient temperatures and management of these temperatures, relative humidity (RH), ventilation, and product mixes (Kitinoja & Kader, 2002). A study by Pathak et al. (2017) concluded that mixing fruit with different ethylene sensitivities should be avoided. In their study, apples (high ethylene producers) were stored together with green bananas and unripe kiwifruit (sensitive to ethylene) for 10 days at 15$_o$C. They observed increased respiration rates and ethylene production in the bananas and kiwifruit which indicated accelerated quality deterioration. This study showed that F and V should be stored separately based on sensitivity to ethylene. However, separation of fresh produce is not practical and is unavoidable during transportation, storage and retail display.

Ahmad and Siddiqui (2015a) stated that average cold storage conditions generally employed are 2 - 5$_o$C at 85 - 95% relative humidity. Properly designed and operated refrigerated storage facilities will extend the storage life of commodities by providing a low temperature, high humidity environment which reduces moisture loss and decreases respiratory activity (Table 2).

Table 2: Recommended storage parameters for various fruits and vegetables (adapted from Thompson et al. (1999) cited in Ahmad and Siddiqui (2015b))

Fruits and/or vegetables	Relative humidity (RH)	Temperature
Leafy vegetables, crucifers, temperate fruits, berries	90 – 98%	0 – 2°C
Citrus, subtropical fruits, fruit vegetables	85 – 95%	7 – 10°C
Tropical fruits, melons, pumpkins, root vegetables	85 – 95%	13 – 18°C

2.4.3 Transportation and Distribution

Depending on the intended market, multi-modal transportation may be used: road, sea, air and rail. Timeous transportation and distribution of produce is dependent on modern and efficient transport systems. Produce destined for local markets travels shorter distances compared to export produce. Transportation and distribution of fresh produce requires taking into consideration quality variability and storage time (Ghezavati, Hooshyar, & Tavakkoli-Moghaddam, 2017). In the fresh produce chain, transportation is a key factor determining final product quality on delivery to consumers. Temperature management, distance travelled, time to destination, airflow, and mechanical damage are areas of concern (Prussia & Shewfelt, 1993; Shewfelt et al., 2014). Prior research shows that most developed countries have adequate logistical frameworks with competent functional systems while developing countries are faced with the challenge of inadequate and inefficient systems and infrastructure which may be rudimentary if at all present (Gustavsson, Cederberg, Sonesson, Van Otterdijk, & Meybeck, 2011). Good quality produce may be mechanically damaged due to vibrations and rough handling during transportation on badly damaged roads (Caixeta-Filho, 1999; Idah, Ajisegiri, & Yisa, 2007). Transportation and distribution systems should therefore be developed to ensure they are compatible with produce to be handled accounting for time and temperature management (Caixeta-Filho, 1999; Idah et al., 2007).

2.4.4 Food safety and traceability

Food safety has become a major issue globally due to the emergence of pathogens regardless of the innovations and improvements in science and technology (Nguz, 2007). Ensuring fresh produce is free from physical, chemical and microbial contaminants such as extraneous matter, pesticide residues, mycotoxins and microbes is a key aspect of food safety. Private food safety and quality standards such as the British Retail Consortium (BRC), Global-GAP, Euro Retailer Produce Working Group – Good Agricultural Practices (EurepGAP) and Nature's Choice have been in use since the 1990s in the European retail market to safeguard end-products (Trienekens, 2011). Although adoption of these standards is voluntary, farmers intending to market their produce to supermarkets are required to satisfy these protocols (Berruto & Busato, 2009). These have since been adopted on a global scale by various supermarket chains and importers as important guidelines to ensure adequate control of food safety and quality and coordination of supply chain activities.

Tracking and tracing has become increasingly important in the ASC. Public health and safety issues related to fresh produce have increased the demand for traceability systems. A traceability system tracks the forward and backward movement of produce and information along the fresh produce chain. Products can be traced back to the raw materials, farmer and previous handlers in the fresh produce chain (Berruto & Busato, 2009). Bollen (2009) introduced the concept of identifiable units (IUs) (Figure 5) which apply to resources, products or activities. IUs may be used to facilitate tracing of F and V to country of origin, specific pallets, shipments or packs. An ideal scenario would be the ability to trace back to the individual fruit but Bollen (2009) concluded that tracing to that level was not practical.

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Figure 5: A postharvest system showing identifiable units (IUs) (Bollen, 2009)

Product recalls pose a huge threat to the ASC and require elaborate management strategies. Recalls may cause a decline in sales, loss of customer confidence and loyalty and high costs due to compensation of customers and other chain players, process improvements, lab analyses and disposal of defective goods. An improved traceability system can aid in preventing crises in the long run and can be cost effective, thereby avoiding losses in sales and profits by facilitating quick and accurate product recalls where food safety incidents occur.

2.5 Postharvest loss

Postharvest loss (PHL) in fruits and vegetables (F and V) is the reduction in quantity or quality (Table 3) at any point along the food supply chain (Lipinski et al., 2013; Parfitt, Barthel, & Macnaughton, 2010). Quantitative losses result from a decrease in weight of the produce whereas qualitative losses are a result of the F and V becoming inedible, undesirable to consumers and deteriorating in nutritive value (Parfitt et al., 2010). Severity of damage may be minor (small defects) or major (rot of fruit) leading to loss of a significant portion of the harvest. Furthermore, PHL results in loss of income for households and loss in revenue that could have been generated from export earnings for countries with agro-based economies. This makes it difficult for developing countries to achieve adequate food and nutrition security, having to rely on foreign aid and food imports to supplement strained food resources. PHL is significant in the earlier stages of the fresh produce chain for developing countries while for developed countries losses tend to be at the retail and in consumers' homes stages (Figure 6). Such losses are termed as waste because in most cases perfectly edible portions of food are deliberately discarded due to cosmetic reasons (Hodges, Buzby, & Bennett, 2010). F and V with minor blemishes or misshapen may be deemed unmarketable and discarded.

Table 3: Some examples of quantitative and qualitative PHL

Qualitative	Quantitative
Infestation by pests such as rodents	Infestation
Microbiological contamination	Harvesting at inappropriate stage e.g. immature or over-mature
Decrease in nutritional value	Inadequate storage
Changes in colour, texture, taste, smell	Poor handling

Extent and severity of postharvest losses incurred varies according to the region, season and commodity (Sibomana et al., 2016). Developing countries are the worst affected by PHL. Greater losses are realised during the hot summer periods as compared to the cold winter months. Seasonal variation in the availability of commodities affects prices because some products become more expensive when out of season. Non-perishable commodities such as cereals and grains incur fewer losses as compared to perishable commodities such as fruits and vegetables.

PHL is influenced by factors such as environmental conditions (Kotir, 2011; Ringler, Zhu, Cai, Koo, & Wang, 2010), technological innovations (Parfitt et al., 2010), logistics, economic environment (Macheka, Manditsera, Ngadze, Mubaiwa, & Nyanga, 2013; Pswarayi, Mutukumira, Chipurura, Gabi, & Jukes, 2014) and global trade. The individual or collective action of these factors has a direct or indirect influence on PHL.

Qualitative and quantitative PHL data is obtained by use of a combination of interviews, surveys or sampling. PHL has been reported in terms of physical and economic loss. Macheka, Spelt, Bakker, van der Vorst, & Luning (2018) used farmer operating conditions and quality-controlled logistics to assess sources of PHL in the tomato, banana and flower supply chain at farm level. Their studies identified determination of processing volumes, maturity indices, time of harvest and storage methods as significantly impacting PHL. Musasa et al. (2013) administered interviews and questionnaires in determining PHL loss and farmers perceptions on the orange supply chain. The results indicated a PHL of 40% per season per farmer. Mvumi, Matsikira, and Mutambara (2016) quantified the PHL of banana in terms of economic value. Farm-level operations such as handling and transport were identified as the leading factors contributing to PHL amounting to 27% of total bananas harvested in the 2011-2012 season. A 40% deficit to meet local demand was uncovered which implied that export of bananas under these circumstances was not possible.

According to Parfitt et al. (2010), food supply chains for subsistence producers are very short. Even if rudimentary harvesting methods are employed, e.g. use of sticks to harvest mangoes resulting in bruising, extent of PHL is minimal compared to longer supply chains. There is a readily available local market for all quality of fresh produce (Macheka, Spelt, van der Vorst, & Luning, 2017; Parfitt et al., 2010). Effective reduction of PHL in developing countries requires the study of a system to come up with measures ideally suited to the context of operation (Kader, 2004). The flow of each commodity along the supply chain would need to be studied to facilitate the identification and development of technologies that can be applied (Kader, 2004; Kader, 2005; Kitinoja & AlHassan, 2010). The technologies should be sustainable, applicable and inexpensive for developing countries to adopt and maintain. Crops of agricultural significance in Sub-Saharan Africa such as cereals, grains and pulses have been extensively studied with sustainable storage and distribution technologies having been developed.

Figure 6 is an infographic diagram showing the extent of PHL in various regions of the world. Developed countries experience the greatest losses as food waste in retail stores and consumers homes. For developing countries, greater PHL is realised at the processing and distribution phases of the chain.

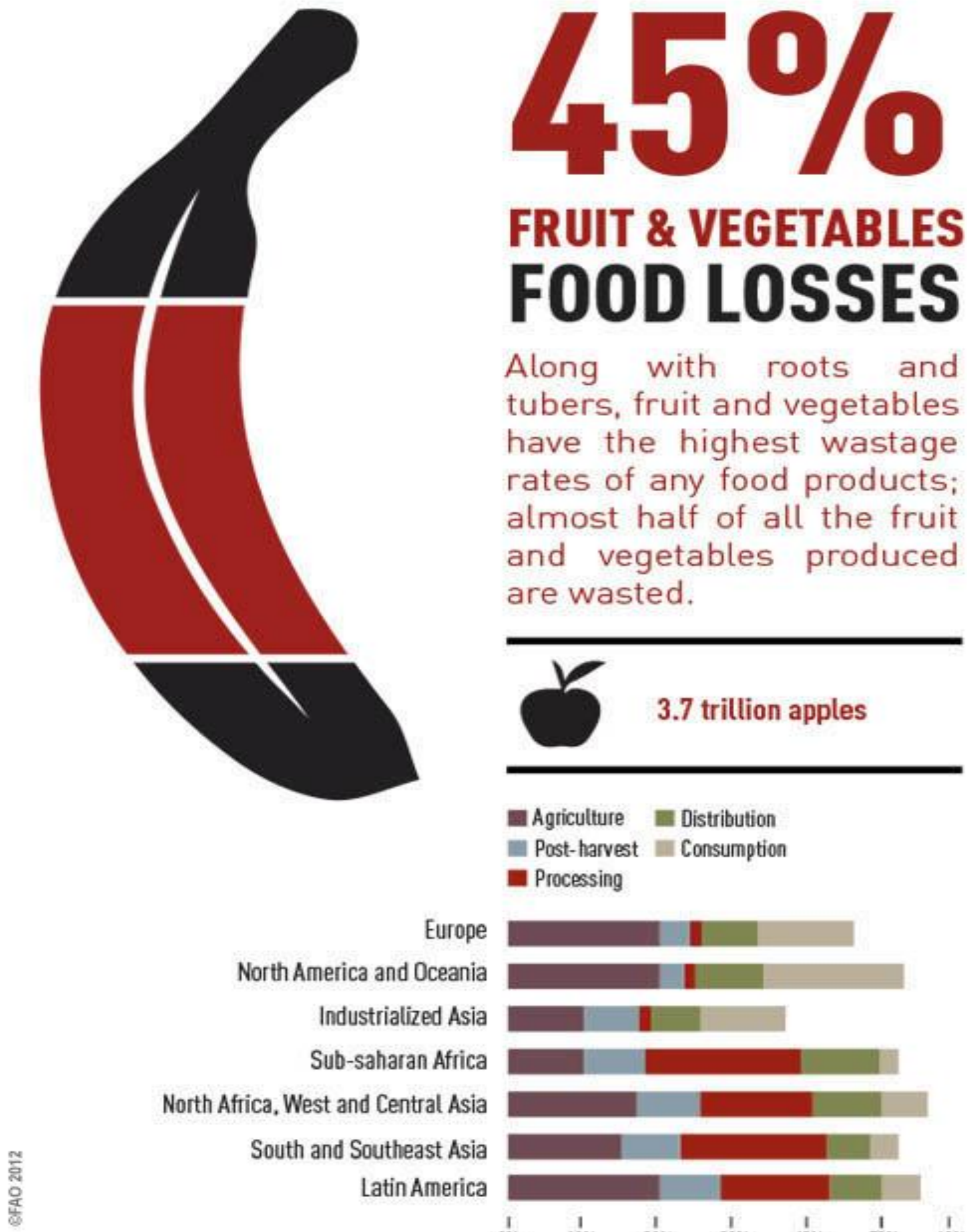

Figure 6: Infographic showing global F and V losses synthesised from various studies (Source: UN FAO SAVE FOOD Initiative 2012)

2.5.1 Quantifying postharvest loss

Existing methods for quantifying PHL are mainly initiatives by the Food and Agriculture Organisation (FAO). Studies undertaken to quantify PHL have measured losses at specific points of the chain excluding equally important stages (Ambler, Brauw, & Godlonton, 2018; Ghosh, Fawcett, Perera, Sharma, & Poinern, 2017). Some authors have quantified PHL of the entire supply chain system (Underhill & Kumar, 2015). Gustavsson, Cederberg, Sonesson, and Emanuelsson (2013) used the food balance sheets (FBS) provided by FAO to quantify food loss estimates in various regions of the world. Developing countries lacked sufficient data that could be used which resulted in the use of estimations. The authors highlighted the need for research focussed on case studies quantifying the losses and outlining the root causes throughout the supply chain.

2.6 Logistics in fruit and vegetable supply chains

To feed the world, logistics plays a vital role. The past two decades have seen an increase in the number of studies on F and V supply chains focussing on the logistics aspect either as food research or logistics research. Driving factors were identified as globalisation, changes in food supply chain network structures, increasing demands on food safety and quality and changing consumer consumption habits (Dani & Deep, 2010). Supply chain management (SCM) is about matching supply and demand (van der Vorst, van Kooten, & Luning, 2011). From a logistics perspective, SCM deals with choices regarding the design of distribution networks, transport and production infrastructures, inventory management, and management of the flow of goods and information (van der Vorst et al., 2011). Berruto and Busato (2009) state that, "the goal of logistics services is to ensure the availability of the right product, in the right quantity, at the right time, in the right conditions, right place, to the right customer and at the right cost."

Agri-food supply chains (ASC) refers to all steps and processes including participants involved in the movement of horticultural produce from farm-to-fork (Ahumada & Villalobos, 2009). Figure 7 gives an illustration of all the key stakeholders in ASC. The participants considered in this thesis are the farmers, traders, retailers, exporters, wholesalers and marketers. Farmers are the key participants that should be involved and consulted in decision making processes at every stage of the in the ASC.

Maintenance of optimum produce quality complicates supply chain design and management of ASC (van der Vorst et al., 2011). F and V impose certain demands on logistics because of the following factors:

- Highly perishable nature,
- sensitivity to external environmental factors,
- high uncertainty in demand and pricing,
- dependence on natural conditions for production,
- seasonal production and availability, and

- stringent health and safety requirements imposed due to customer expectations (Shukla & Jharkharia, 2013).

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Figure 7: Key stakeholders involved in the agri-food supply chain (La Gra, Kitinoja, & Alpizar, 2016)

Efficient logistics systems enhance supply chain efficiency. At the moment of harvest, freshness is at its optimum and deteriorates with prolonged storage. Therefore, decisions on chain design should not only be aimed at improving logistics but also at the preservation of food quality so that the right products are delivered with the right quality at the right place and time (van der Vorst et al., 2011), giving rise to the concept of quality-controlled logistics (QCL).

Quality Controlled Logistics (QCL) makes use of variations in product quality, developments in technology, heterogeneous needs of customers and the possibilities to manage product quality development in the distribution chain (van der Vorst et al., 2011). According to van der Vorst et al. (2011), “Quality Controlled Logistics is that part of supply chain management that plans, implements, and controls the efficient, effective flow and storage of food products, services and related information between the point of origin and the point of consumption in order to meet customers' requirements with respect to the availability of specific product qualities in time by using time-dependent product quality information in the logistics decision process.” Products with similar characteristics are batched together from farm-to-fork, integrating logistics activities with time-dependent quality control information as illustrated in Figure 8.

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Figure 8: Quality controlled logistics concept (van der Vorst, van Kooten, Marcelis, Luning, & Beulens, 2007)

Chapter 3 : Methodology

A combination of qualitative and quantitative data collection and analysis was administered. This chapter explains the choice of data collection instrumentation – semi-structured interviews; research participants; and data collection method. Data analysis incorporated both qualitative and quantitative approaches. Data was collected within a few weeks during the winter season (June – July) of 2018 in Zimbabwe. Both primary and secondary sources were made use of in the collection of data on postharvest handling practices at different stages of the chain (farmer, retailer, exporter, marketer, wholesaler, and trader).

3.1 Research Design

3.1.1 Case study

A case study is the preferred method of inquiry when "how" or "why" questions are being posed (Yin, 2014). The case study approach was selected for the following reasons: the researcher has no control over issues occurring in the agri-food supply chains (ASC); enabled studying a real system in its natural state to understand overarching phenomena, and; lack of enough studies analysing the systems to develop dedicated solutions ideally suited to their context of operation. Yin (2014) states that case studies are a useful research tool for exploring a phenomenon in its natural or real-life settings.

The issue of validity and reliability of gathered data is dealt with through triangulation (Table 4). Triangulation involves incorporating multiple data sources in empirical research (Verschuren & Doorewaard). An example of triangulation is having multiple interviewees (data) by several interviewers (observer), complemented with time series data (methodological). Multiple methods (interviews, questionnaires, observation) can be used when gathering data from either a single or several entities such as groups, people or organisations. Case studies have been used in studying fresh produce chains by other researchers (Ghosh, Fawcett, Perera, Sharma, & Poinern, 2017; Macheka, Spelt, van der Vorst, & Luning, 2017; Underhill & Kumar, 2015). Documents, interviews and observations were incorporated in the study.

Table 4: Types of triangulation

Triangulation type	Examples
Data	Using more than one data source; multiple interviews by more than one interviewer; collecting data at different occasions
Observer	More than one observer in the study; different evaluators
Methodological	Combination of different types of data collection methods, e.g., qualitative and quantitative
Theory	Perspectives of the same data

3.1.2 Document analysis

Initial document analysis involved a review of literature, secondary data and official statistical material on studies related to postharvest handling practises along fresh produce chains to gain an understanding of associated problems. It relied on scientific literature, market reports and books which were accessed from different search engines (Google Scholar, Scopus, Science Direct, Emerald Insight) using different combinations of key words (“postharvest loss”, “postharvest technology”, “postharvest handling”, “logistics”, “supply chain management”, “food safety and security”, “fruit and vegetable”, “agri-food”, “supply chains”, “simulation modelling”). Literature analysis from relevant studies led to the identification of themes and sub-themes which were used as a basis in the structuring of the interview questionnaire guide (Appendix C). Although the questionnaire guide themes and sub-themes were essentially the same across all the participants, the questions were formatted to suit the role and activities of each participant in the fresh produce chain. Some technical components from the commodity system assessment methodology (CSAM) (Appendix D) were used as a guideline in drafting the guide. La Gra (1990) developed the commodity systems assessment methodology (CSAM) which has since undergone editions and revisions over the years (La Gra, Kitinoja, & Alpizar, 2016). CSAM consists of 26 components related to production, postharvest handling and marketing of produce. It was conceptualised following identification of the need to develop methodology to resolve issues related to postharvest handling throughout the supply chain. It has since been used to assess PHL of fresh produce in South Asia and sub-Saharan Africa along the ASC (Osei-Kwarteng, Gweyi-Onyango, & Mahunu, 2017).

3.1.3 Sampling

Selection of informants for the interviews was an important step. Data and information was gathered from participants in the selected F and V ASC. The initial phase involved identifying the ASC participants for the selected commodities. Non-random purposive sampling was used to gather the required informants. Purposive (judgmental) sampling is a type of non-probability sampling in which the units to be observed are selected on the basis of the researcher’s judgment about which ones will be the most useful or representative (Babbie, 2016). Contact had been initiated with an agri-business organisation that facilitates the gathering of relevant agricultural data from all commodity markets in Zimbabwe months prior to data collection. An informal meeting was set up which led to the identification of agricultural regions relevant to the study and organisations that dealt with farmers. This led to an initial “snow balling” of participants suggesting potential informants which was key in recruiting additional participants (Food Loss Waste Standard, 2016). Snowball sampling is a non-probability sampling method, often employed in field research, whereby each person interviewed may be asked to suggest additional people for interviewing (Babbie, 2016). One key informant in the horticultural industry was formally identified, who gave an in-depth overview of the Zimbabwean horticultural sector.

3.1.4 Study location

The study was conducted in Zimbabwe, a land-locked country which is in Sub-Saharan Africa. Zimbabwe is subdivided into five agro-ecological zones or natural regions (NR I to NR V) (Figure 9) based on mean annual rainfall. NR II and III are the key food production areas which have since shrunk by 49 and 13.9% respectively since the 1960s (Mugandani, Wuta, Makarau, & Chipindu, 2012). Obvious implications of this shrinkage to food security have been attributed to climate change and variability. These regions supply fruit and vegetables to Harare where most of the fresh produce is marketed and distributed to other parts of the country, region and/or world. Farmers were purposively drawn from NR II in Marondera and Mazoe, located within the Mashonaland East and Mashonaland Central provinces of Zimbabwe. Traders were drawn from Domboshava and Mbare Musika commodity markets. Marketers, wholesalers and retailers were drawn from Harare.

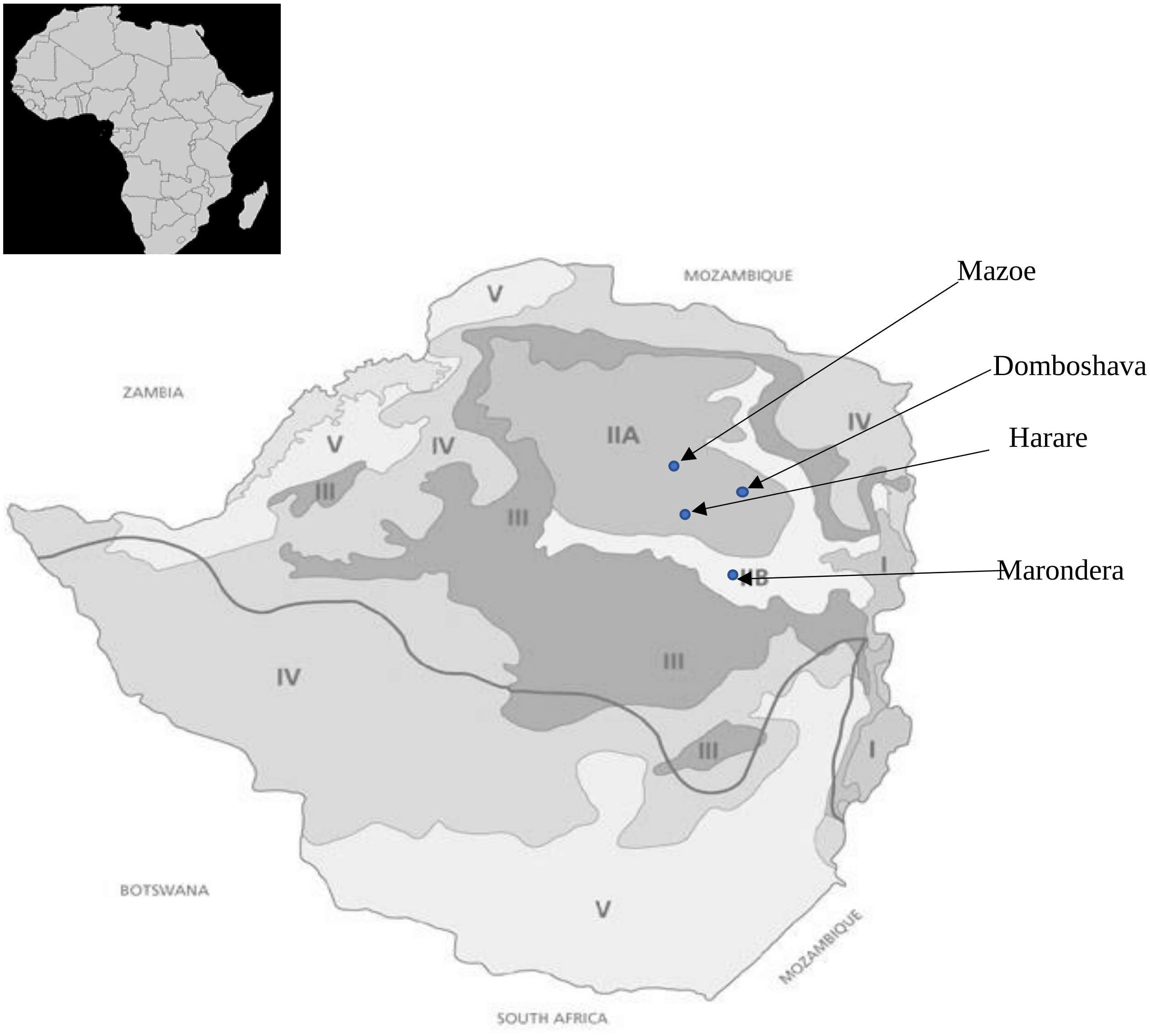

Figure 9: Map showing the agro-ecological zones of Zimbabwe and study areas (adapted from FAO, 2006)

3.1.5 Study commodities

Banana (Musa *spp*.), tomato (*Solatium lycopersicum*), green pea (*Pisum sativum*) and orange (*Citrus sinensis*) supply chains were selected for the study (Figure 10: ***Total* banana, orange, pea and tomato production in Zimbabwe (FAOSTAT, 2018)**

Banana (Musa *spp.)*, tomato (*Solatium lycopersicum*), green pea (*Pisum sativum*) and orange (*Citrus sinensis*) supplSelection was based on their availability (Figure 11) during the winter period when the data was collected (June - July 2018), their importance in the Zimbabwean local and export trade markets and lack of enough studies relating to food losses along these agri-food supply chains (ASC).

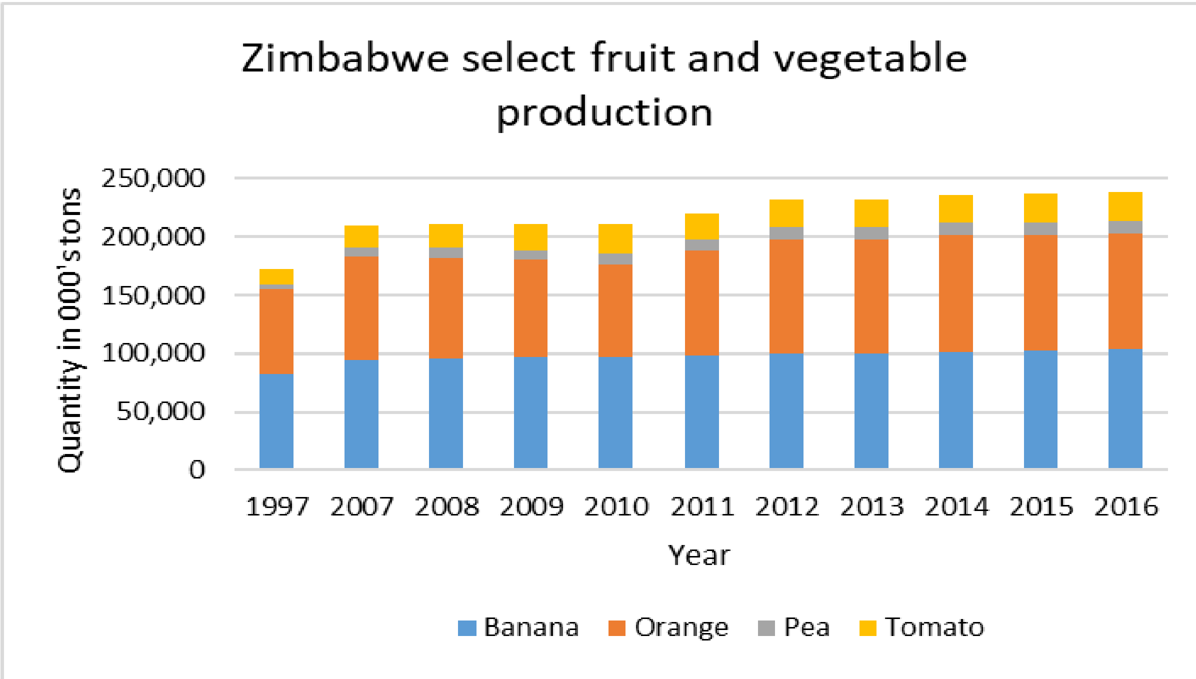

Figure 10: Total banana, orange, pea and tomato production in Zimbabwe (FAOSTAT, 2018)

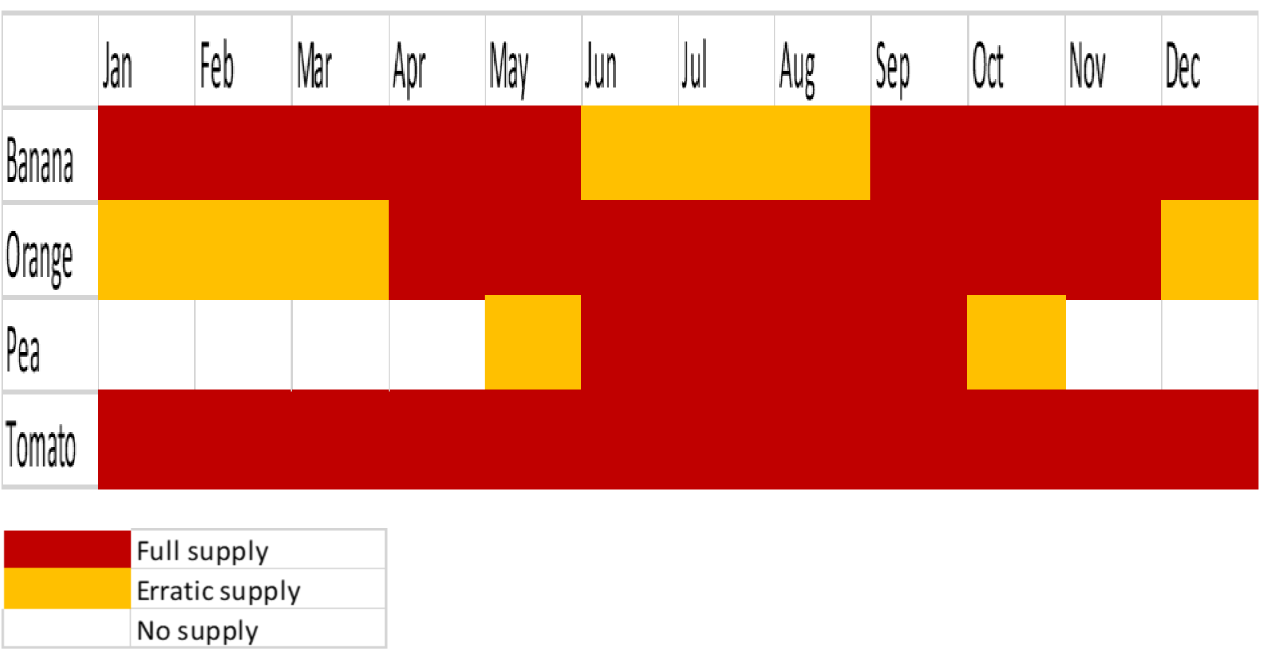

Figure 11: F and V supply seasons in Zimbabwe

Banana (Musa spp.): Banana production increased (by 186%) from 16 000 tonnes to 45 775 tonnes between 2015 and 2017 due to the introduction of out-growers programmes and increase in area under cultivation (Mvumi et al., 2016). However, only 2 000 (5%) tonnes were exported (to South Africa and Zambia) in 2017 compared to 5 000 tonnes in 2015 (Mvumi et al., 2016). Increased production without the expansion of export markets may lead to gluts in the local market.

Green pea (Pisum sativum): Green peas are exported to Europe (mainly Netherlands and the United Kingdom). There is a dearth of literature on green peas supply chains in Zimbabwe.

Orange (Citrus sinensis): Oranges are a significant commodity on the local and export market. Very few studies have been carried out on the orange supply chain (Musasa et al., 2013).

Tomato (Solatium lycopersicum): Tomato is key in livelihood sustainability on the local trade market (Macheka et al., 2017). Zimbabwe does not export tomatoes.

3.1.6 Interviews

A research information sheet detailing the nature and intent of the study was also distributed through various institutions, farmers' and support organisations. This helped ensure that potential respondents were made aware of the study aims and objectives. Participants who were interested in the study contacted the researcher and scheduled for either telephone or face-to-face interviews. A walk-in and hand-out approach was also used for other participants, mostly traders at their market stalls. Interviews were conducted using a list of semi-structured questions targeted at farmers (large-scale commercial farmers, small-scale commercial farmers and small-scale subsistence/smallholder farmers), traders, marketers, exporters, wholesalers and retailers of fresh fruits and vegetables, covering various aspects of the ASC. The questions were translated into the local language before administration. Each interview lasted approximately 15 minutes to 1 hour. Certain interviews were followed up by subsequent telephone conversations to clarify on remarks made by the participants during interviews. The key informant was also one of the commercial farmers. Some of the interviews were recorded and transcribed and other responses were recorded on the questionnaire as not all informants were keen on having their responses recorded. The interview guides are presented in Appendix C. Discussions with participants in the chain provided insight into postharvest handling systems from the perspective of the chain participants.

Twenty-seven (27) semi-structured interviews were conducted. 27 participants who took part in the study were: 4 Large-scale commercial farmers (LS-CF), 3 small-scale commercial farmers (SS-CF), 3 small-scale subsistence farmers (SS-SF), 3 marketers, 2 wholesalers, 3 retailers and 9 traders. The 27 interviews included one interview with a key informant in the Zimbabwean horticultural industry who was also one of the SS-CF and one telephone interview with a marketer as illustrated in Table 5 below. Studies have been carried out to assess PHL along ASC in both developed and developing countries in Australia (McKenzie, Singh-Peterson, & Underhill, 2017), Fiji (Underhill & Kumar, 2015) and Samoa (Underhill, Zhou, Sherzad, Singh-Peterson, & Tagoai, 2017). Another similar qualitative study focussing on PHL and waste during primary production was conducted in Scotland (Beausang, Hall & Toma, 2017).

Each respondent was assigned a unique identifying code and number. These codes enabled the identification of respondent type, commodity traded and transcription notes. The lists identifying the respondents were kept separate from their data.

Table 5: Semi-structured interviews list of participants interviewed

Participant	Commodity	Location of interviews	Number of interviewees
LS-CF_1	Orange	Packingshed	1
LS-CF_2	Pea	Packingshed	1
LS-CF_3	Pea	Factory	1
LS-CF_4	Pea	Packingshed	1
SS-CF_1	Banana, Tomato	Field, Harvesting shed	1
SS-CF_2 + Key informant	Tomato	Mbare produce market	1
SS-CF_3	Tomato	Field, harvesting shed	1
SS-SF_1	Tomato	Field, kitchen	1
SS-SF_2	Tomato	Field, kitchen	1
SS-SF_3	Tomato	Field	1
R1 – R3	Mixed	Retail store	3
W1 – W2	Banana, Orange	Wholesale depot/warehouse	2
Td1 – Td 4	Mixed	Mbare produce market	4
Td5 – Td9	Mixed	Domboshava produce market	5
Mk1	Orange	Telephone	1
Mk2	Pea	Office, Storage	1
Mk3	Pea	Office, Shed	1

LS-CF – Large-scale commercial farmer, R – Retailer, W - Wholesaler, Td - Trader, Mk - Marketer

3.1.7 Direct observation

Visits to the participants' premises also followed, observing activities and examining their information systems where possible validating responses obtained from the interviews. Direct observations provide additional information and new dimensions of understanding the phenomenon under study such as the condition of buildings, equipment and location of the organisation (Yin, 2014). Observations and interviews were carried out simultaneously in some cases. Photographic images were obtained where appropriate.

3.1.8 Data analysis

Data was manually coded and analysed. Recorded data was transcribed daily for each interview that took place, including notes from the field. Some participants opted for manual recording of their responses instead of voice recordings. No statistical analyses were undertaken for the case studies. The lack of standardised numerical data in qualitative studies nullifies the use of statistical analysis methods. Interview guides were adapted to the individual participant group types and consisted of essential categories relating to the participant, business of the participant, F and V of interest, and postharvest activities. Review of literature and pre-existing knowledge led to the identification of key themes in postharvest handling and logistics a priori. These were broadly identified as in-field operations, packhouse operations, distribution and transportation.

3.2 Human ethics statement

Informed consent from all participating subjects was sought and given prior to their participation in the study. The research was conducted in accordance with the Lincoln University Human Ethics Regulations (Application Number 2018 – 18).

3.3 Limitations of the qualitative aspects of study

- Unavailability of documented data on F and V production and marketing with the official government departments and farmers' associations. The researcher had to use data from Non-Governmental Organisations sites and FAO of which in some cases data was also unavailable.
- Unavailability of key informants, even if interviews were planned and times agreed in advance, some of the informants were not available.
- The CSAM developed by La Gra (1990) is more robust encompassing various aspects (technical, social, infrastructure, economic) of postharvest handling. The present study however was limited to the technical aspects of postharvest handling systems due to limited resources.
- Efforts to collect exact volumes of F and V traded from all participants were not successful as it was deemed as confidential information. They however gave estimated values, where possible.

Chapter 4 : Simulation modelling

4.1 Simulation modelling

Simulation technology usage as a decision support tool in supply chains has gained popularity. Researchers can study systems and related interconnected networks. Assessment of system performance for the whole network allows for the making of informed decisions on the impact of changes to the chain. Simulation modelling involves experimenting with digital prototypes of actual models to forecast their projected performance in real-world scenarios. Its rapid adoption and growth in use has been facilitated by development of software packages. Sensitivity analyses can be easily, quickly and safely performed with no risk to the real system.

Computerised discrete event simulation has evolved into an integral tool in the analysis of complex socio-economic systems. Simulation tools are not only popular for modelling biological and environmental systems, but also find use in manufacturing and supply chain systems (Suraj, Sharma, & Routroy, 2016). Documentation and analysis of planned operations can be modelled using software. Flowchart modules allow for complex decisions to be made, facilitating process timing characteristics to be obtained such as cycle time. Model validation can be done by comparing key operating parameters against real-world values. Key statistics can be collected when the simulation is run over an extended period. Running the model helps identify work in progress bottlenecks, resource and operator utilisation. The goal of any organisation is to operate efficiently, sustainably and profitably with minimal losses along the supply chain.

4.2 Modelling F and V supply chains

An extensive literature review by Soto-Silva, Nadal-Roig, González-Araya, and Pla-Aragones (2016) of 28 papers on operational research models applied in ASC showed that most models addressed transport, allocation, planning and routing problems at the production and distribution phases of ASC. 16 of the 28 reviewed papers applied linear programming, with the rest using non-linear programming, heuristic algorithms and metaheuristics. The authors highlighted that future research should focus on the integration of different methods.

Van Der Vorst, Tromp, and Zee (2009) introduced the concept of supply chain redesign in a discrete event simulation model (Agro-Logistics Analysis and Design Instrument, ALADINTM) that incorporated food quality changes and environmental load. The model integrated food quality analysis, sustainability issues and logistics. Another study by Leithner and Fikar (2018) integrated generic food quality decay models in a strawberry supply chain using AnyLogicTM. Expansion of these generic keeping quality models to simulate other F and V supply chains was suggested. Alternative distribution systems (such as warehousing, crossdocking and alternative transport), ordering policies, stock rotation schemes were evaluated for tomatoes, peppers, strawberries and tomatoes (Leithner and Fikar, 2018; Van der Vorst et al., 2009). Research in this area is currently ongoing in industrialised countries. Simulation software has been applied in modelling multi-compartment distribution in a catering supply chain (Jansen, Van Weert, Beulens, & Huirne, 2001) and simulating ASC (Beshara, El-Kilany, & Galal, 2012).

This thesis considers the discrete event simulation software ARENA®, developed by Rockwell Automation (Kelton, 2015), in the generic simulation of a F and V supply chain from farm to dispatch to destination market. Use of simple spreadsheet calculations is limiting in that it does not allow imitation of real-world operations like ARENA® does.

4.3 Steps in a simulation study

Outlined below are the series of steps (Figure 12) used in a simulation study.

- **Problem formulation and model objectives**: A clearly defined and understood problem statement outlining what the project is set out to accomplish. Boundaries of the system are defined.
- **Conceptualisation:** Characteristics of the system to be modelled identifying essential features and selection and modification of model assumptions. The construction of flow charts and conceptual framework diagrams aids in visualisation of the system under study.
- **Data collection**: Collection of needed input data and design of the conceptual model are analogous processes. Data collection is through direct observations, interviews and/or obtaining historical data from relevant databases and documentation.
- **Model translation**: Appropriate software is used to construct a simulation model incorporating data obtained.
- **Model verification and validation:** Verification is determining that the chosen program is performing as expected. Validation is determining that the model is accurately representing the actual system and identifying any dissimilarities between the actual system and the model. Model validation can be performed by comparing the output result of the model with historical data and performing sensitivity analyses.
- **Run model:** Running the model involves deciding on the number of replications and run length of the simulation.
- **Analyse data:** Interpretation of output data using statistical methods of analysis due to the stochastic nature of discrete event simulation model elements.
- **Implementation:** Written reports are generated. Results obtained from the simulation runs support decision-making processes.

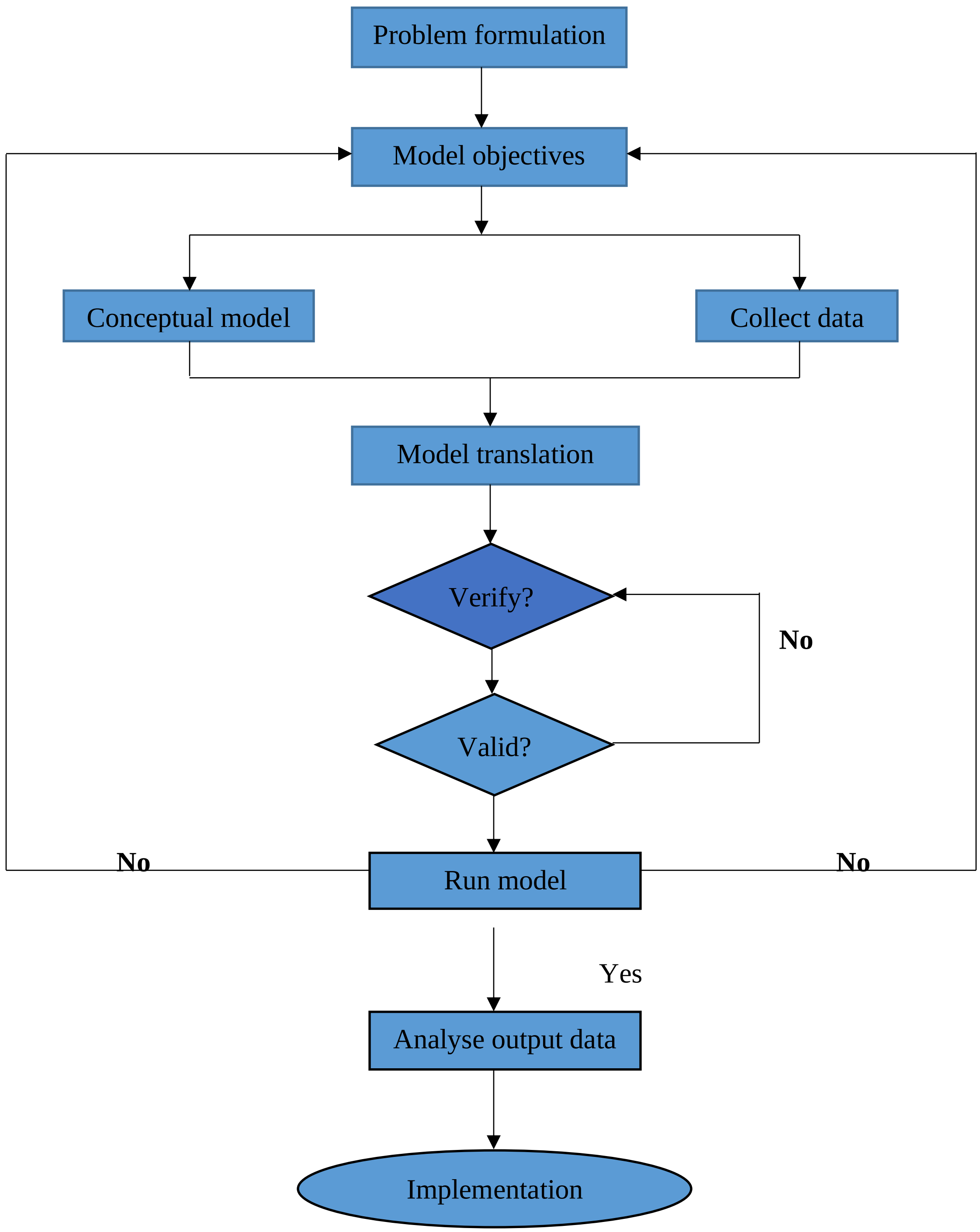

Figure 12: Steps in a simulation modelling project (Kelton2015)

4.4 Simulation software

A system is a group of objects that are joined together in some regular interaction toward the accomplishment of a purpose (Kelton, 2015). Objects that flow within the system are referred to as entities and the relationships amongst the entities can be logically or mathematically expressed. The entities within the system are characterised by attributes. Entities can be grouped into sets, chains, files or lists. The dynamic behaviour of a system is studied by observing the activities that are portrayed by the entities. Entities move from one block to the next through interconnected lines. These activities are defined for the system. The beginning and ending of each activity is called an event. The state of the model remains constant between consecutive event times, and a complete dynamic portrayal of the state of the model is obtained by advancing simulated time from one event to the next (Banks, 1999). This timing mechanism, referred to as the next-event approach, is used in many discrete simulation languages (Banks, 1999).

For the model implementation, ARENA® simulation software (Rockwell) was used. ARENA® is a general-purpose package suitable for modelling discrete, continuous, and mixed systems and uses blocks to build the models. The graphical interface allows the user to follow and understand the flow of entities and their attributes through the model. ARENA® is similar to other simulation software such as ExtendSim™ and ALADIN that have been used in simulating ASC (Amer, Galal, & El-Kilany; Beshara et al., 2012; Jansen et al., 2001; Van Der Vorst, Tromp, & Zee, 2009).

Table 6: Some components of ARENA® adapted from Kelton (2015)

Component	**Description**
Entities	Dynamic objects within the system that are created, move around and are disposed of as they exit the system
Resources	Facilities or persons in a system that provide services to the system entities
Queues	Entities compete with each other for resources. When the resource is not available, entities wait in a queue until it is available. Queues generally follow the LIFO or FIFO rule

4.5 Model development

This section aims at describing the main elements used for developing the simulation model imitating the real-life study. Two supply chains are chosen for the case study design, orange and pea. The models were built in ARENA® v15.0 simulation environment from Rockwell Automation. Flow charts and conceptual diagrams are used as logical representations of the studied chains to aid in understanding the systems under study.

4.5.1 Structural data

A generic model to represent the F and V packhouse operations is developed. The general product flow for the studied ASC is described to show the different parts of the chain under study. Product flow starts at the farms that send the fresh produce to the packinghouse, distribution centre, retailers and then the consumers. A schematic diagram of the supply chains is shown in Figure 13. Participants in the chain do not keep large inventories of produce because of perishability.

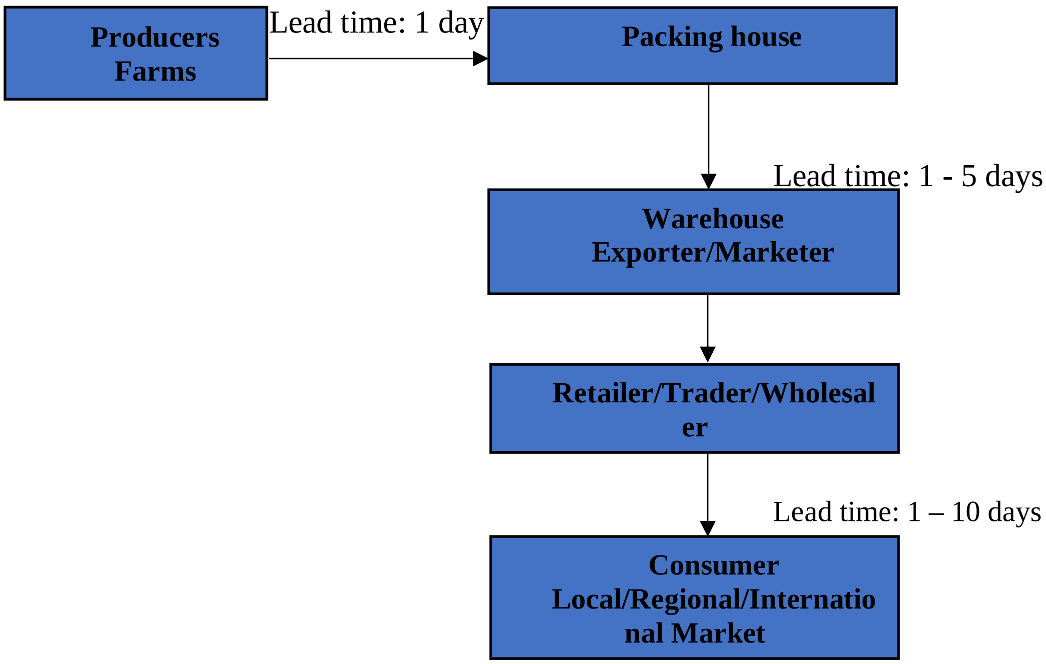

Figure 13: Schematic diagram of the studied supply chains

4.5.2 Input parameters

4.5.2.1 Input Analyzer

Where applicable, actual data that was recorded during field observations on interarrival time, processing time and waiting time was fed into the in-built Input Analyzer application of ARENA® for analysis. The data sample was fit to all distributions and ARENA® automatically selected the best fitting statistical distribution parameters for the raw data. Input Analyzer uses the chi-square and Kolmogorov-Smirnov (K-S) goodness-of-fit hypothesis tests to test the data for reliability. Additionally, ARENA® reports the corresponding *p*-value, which falls between 0 and 1. A large *p*-value suggests that the theoretical distribution is a good fit for the data (Kelton, 2015).

4.5.2.2 No data distributions

Ad hoc data was used in instances where actual data could not be recorded for activity times. The triangular distribution was selected. The basis of the distribution parameters and times was decided following interviews with the packhouse operator who provided the processing times. The triangular distribution allows non-symmetric distribution of values around the *mode (most likely)* value (Kelton, 2015). This distribution has bounded values all falling within the defined minimum and maximum value range.

4.5.3 Model assumptions

Simplifying assumptions were made to construct a simulation model for the studied ASC as follows:

- Raw materials and workers are always available
- F and V arrival is continuous during simulation
- Operational costs are neglected (they are beyond the scope of this study)
- No machine breakdowns
- 1 shift of 10 (8am – 6pm) hours per day with scheduled breaks (15min, 30min and 15min)
- Products are processed at each node according to a First-in-First-Out allocation policy
- Products are assumed to arrive in batches rather than in kilograms
- The products are perishable, they must be transported from the farm within 1 – 10 days of harvesting and storage.
- No losses during transportation.
- Outputs such as by-products are beyond the scope of the model
- Oranges: 70% for export market, 25% local market and 5% for juicing factory

In order to build the model, data that needed to be collected included: Number of workers, scheduled operation times in minutes, number of boxes of oranges exported, probabilities of oranges falling within classes 1,2 and 3 and those destined for the juicing factory, and scheduling of breaks.

4.5.4 Validation and verification

Process maps were reviewed and cross-referenced with the process flow that was observed during data collection. The modeller walked through the process with the packhouse operator. The modeller sought further clarification on any processes that were unclear. Initial model verification involved the observation of animation of the simulated entities (i.e. the F and V) to ensure that they were following the logic of the model. A screen shot of the model is provided in Appendix G. Prior to running the simulation model, logical errors were identified and corrected using the ARENA® debugger. Model validation involved comparing the model output value number of entities for each of the specified markets to the actual values of the real system.

4.5.5 Sensitivity analysis

Sensitivity analysis was performed to validate model structure. It tests how sensitive a model is to changes in model parameters or structure (Breierova, Choudhari, & Forrester, 1996). The analysis served to assess the impact of changes to some parts of the system. The logic is that any variations to the values of key input parameters should result in a change in the output parameters of the model. Performing a sensitivity analysis may result in the development of alternative scenarios that may aid in resolving the issues they face. According to Breierova, Choudhari, & Forrester

(1996), observations of the behaviour of a model to changes in parametric values are useful in model building and evaluation.

Most model parameters are difficult to measure accurately in real world scenarios. Therefore, estimated values are used to account for this uncertainty by modellers. To develop an accurate and valid model, sensitivity analysis is performed to determine the level of accuracy for the parameters (Breierova, Choudhari, & Forrester, 1996).

From the studied model, the parameters that can be changed are the number of loads of incoming oranges and staggering the scheduled breaks of the packhouse workers. The packhouse workers all currently go on scheduled breaks at the same time. The number of incoming oranges is dependent on conditions such as weather and yield. One tractor is used to move oranges from the field to the packhouse, this can be increased. During the field observations, the packhouse operator highlighted that they were operating below the desired capacity. He reported that oranges are supposed to be harvested 24 hours prior to processing, undergo conditioning and then be processed the following day. However, due to reasons beyond their control (state of the economy and staffing), they were harvesting and processing on the same day.

Key performance indicators (KPI)s for the simulation model include throughput (amount of fruit handled in the system), usage, utilisation and amount of time the entities spend in the system (Kanchanasuwan, 2018). KPIs such as total operating cost, shelf life, wastage and lead time were not studied in this system. This would have required additional input data which was beyond the scope of the thesis. This can however be pursued in further research.

4.6 Oranges

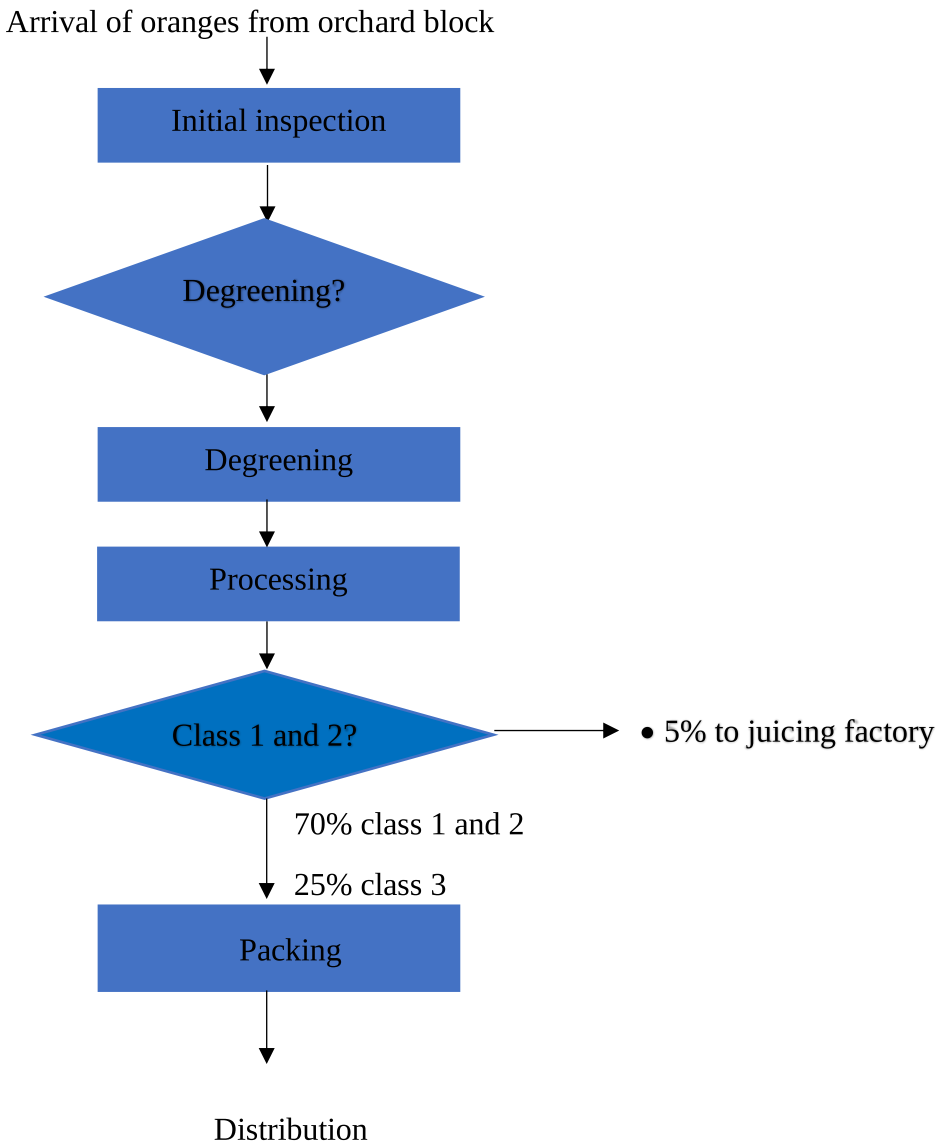

Figure 14: Process flowchart of farm operations for oranges

Table 7: Explanation of orange supply chain activities

Activity	Resources
Arrival of oranges from orchard block – time taken for harvested oranges to reach the packingshed	Tractor pulling 3 trailers of 2 tonnes each
Initial inspection – inspection to check whether oranges are ripened but still green and other quality checks	1 Packinghouse inspector
Degreening – Oranges that are ripened but still green are sent to the degreening rooms where ethylene gas is applied	3 degreening rooms available
Processing - all processes involved prior to sorting represented in the model by the route and station modules	-
Class 1 and 2? – Sorting of the different sized oranges into 1 of 3 pre-determined categories by mechanical sorters	-
Packing – packing of the oranges for the domestic or export markets	16 workers for class 1 and 2 16 workers for class 3
Distribution - sending the fruit to the various markets	Various modes of transportation

Setup parameters

Setup parameters for the model include the model run length, number of replications and common random numbers used in all experiments.

The model was run for 100 replications with a simulation runtime of 600 minutes (duration of a 10-hour shift.

4.7 Output data from the orange model

Key KPIs for this model were the throughput of the system, time the entity spent in the system, waiting time and human resource utilisation (See Appendix G).

Results indicated that an average of 13 (orange loads) entities exited the system (9 Class 1 and 2, 3 Class 3 and 1 destined for the juicing factory). According to the packhouse inspector, their daily target is 100 tonnes, approximately 16 loads. He however reported that they failed to reach even the 16T target due to various factors.

Usage of human resources was high for the packhouse workers (seized an average of 200 times) compared to the inspector who was seized an average of 15 times. The packhouse inspector is responsible for ensuring that the quality of oranges received adheres to stated specifications. He inspects the incoming oranges from the orchard. The sets of degreening rooms are used for storage of other commodities when not in use. Usage is relatively low (sized an average 2 times) during the run.

Instantaneous utilisation of the degreening room, packhouse inspector and packhouse workers was 55.44%, 19.13% and 11.87% respectively. The packhouse operator stated that at any given time there are 100 employees in the packinghouse carrying out various functions. Although they have fixed numbers of workers for packing (16 each for Class 1 and 2 and Class 3), more employees may be added according to the amount of work that has to be done.

The average waiting times for the degreening and inspection queues were recorded as 0.00 minutes. This means that no queues formed at these phases of the system. The average waiting times for the packing queues was 1.6 minutes for the class 1 and 2 queue and 1.3 minutes for the class 3 queue. This can be due to the high numbers of persons packing.

Entities spent an average of 59 minutes in the system, with a maximum value of 66 minutes. This can be attributed to the scheduled breaks. All 100 employees go on breaks at the same time. There is no staggering of breaks. The researcher observed that the roller conveyor is stopped during breaktimes.

Sensitivity analyses was carried out to see if changes to the system input parameters resulted in a change n the system.

Scenario 1 – Increasing the number of entity arrivals to 2, that is 2 orange loads per arrival resulted in a doubling of the throughput to 25 entities (18 class 1 and 2, 6 class 3 and 1 to the juicing factory). This resulted in a doubling of resource usage (average number seized being 3 degreening room, 30 packhouse inspector and 398 packhouse workers) and an increase in utilisation of resources 74.21%, 38.19% and 16.93% for degreening room, packhouse inspector and packhouse workers respectively. Waiting times for degreening and packing queues were 0.00 minutes. However, the inspection queue average waiting time was 3.71 minutes. The average time spent by an entity in the system was 59 minutes with maximum average reducing from 66 to 62 minutes.

Scenario 2 – Increasing the numbers of entity arrivals to 2 and staggering the breaks of the employees did not result in significant changes in the system. The figures were the same.

Scenario 3 – Staggering the employee breaks with entity arrival 1 yielded similar results to the original model.

Pea – The green pea postharvest chain was observed from the farm to the distribution centre. The pea chain was excluded from the simulation modelling process because more time was needed to collect operational data due to the numerous processes the peas were subjected to. Another constraint was that the information needed was also deemed as sensitive by the farms visited and it was difficult to make estimates based on little to no data available.

Banana – The banana postharvest chain was not observed from the farm due to time constraints. Most of the information gathered was obtained from two main depots in Harare. However, since the information they provided for the on-farm activities could not be validated or verified by observation, it was not used in the simulation study.

Tomato – The tomato chain was excluded from simulation modelling because the operational data and numerical data for the model could not be collected. The interviewed farmers did not have written records for verification and validation.

4.8 Limitations of simulation modelling

It is not possible to guarantee that a simulation model will provide the right solutions to address a particular problem. Runs carried out are based on randomly generated numbers which do not assure reliability. To ensure that the data generated from the model is as accurate as possible, input data must be accurate. This means that a system must be carefully and closely studied in order to gather accurate data that can be used in the model. Complex systems also present unique problems in that they may be impossible to simulate and if simulated, the data generated may be impossible to interpret.

Chapter 5 : Results and discussion

The findings of the study from semi-structured interviews and participant observations on postharvest handling are presented and discussed.

5.1 General information

The first part of the questionnaire collected general background information from the participants on educational background, farm size and source of seed (where applicable), workforce size, and commodities. All the farmers in the study obtained their seed from accredited seedhouses. Work force sizes ranged from 1 to about 200 for larger organisations, which was a reflection of the complexity and size of operations. Participants (farmers) hired extra labourers during peak periods of harvesting. One trader mentioned that their highest level of education was primary level, one SS-SF attended college and the rest of the traders and SS-SF had gone up to secondary school. This led the researcher to conclude that perhaps level of education influenced activities related to decision making and handling of produce in the chain. However, concrete conclusive results can be obtained by carrying out an analysis to find out if there is a correlation between level of education and decision-making processes by participants in the studied ASC. LS-CF and SS-CF had higher levels of education with additional agricultural training. LS-CF and SS-CF trained their employees and had periodic refresher sessions. SS-SF were mostly untrained but learnt from experience. Due to limiting costs of hiring labour, SS-SF were helped by community or family members. Although information on age and gender was collected, it was not analysed in the study because the sample was not representative of the whole population.

5.2 Zimbabwean F and V supply chain mapping and characterisation

The supply chain channels for fresh produce vary according to produce type and target market. They can be classified into three general categories as domestic (within Zimbabwe), regional (within the African continent) and international (overseas markets). The chain starts from the farmers who have a number of alternative buyers from within the broad categories. Further down the ASC consists of networks of various actors (traders, wholesalers, retailers, marketers, middlemen) who play key collaborative roles in the movement of produce from farm-to-fork as shown in Figure 15. Chain length can either be short (from farm-gate to consumer) or long (from farm to export market). Longer chain lengths correspond to a greater PHL.

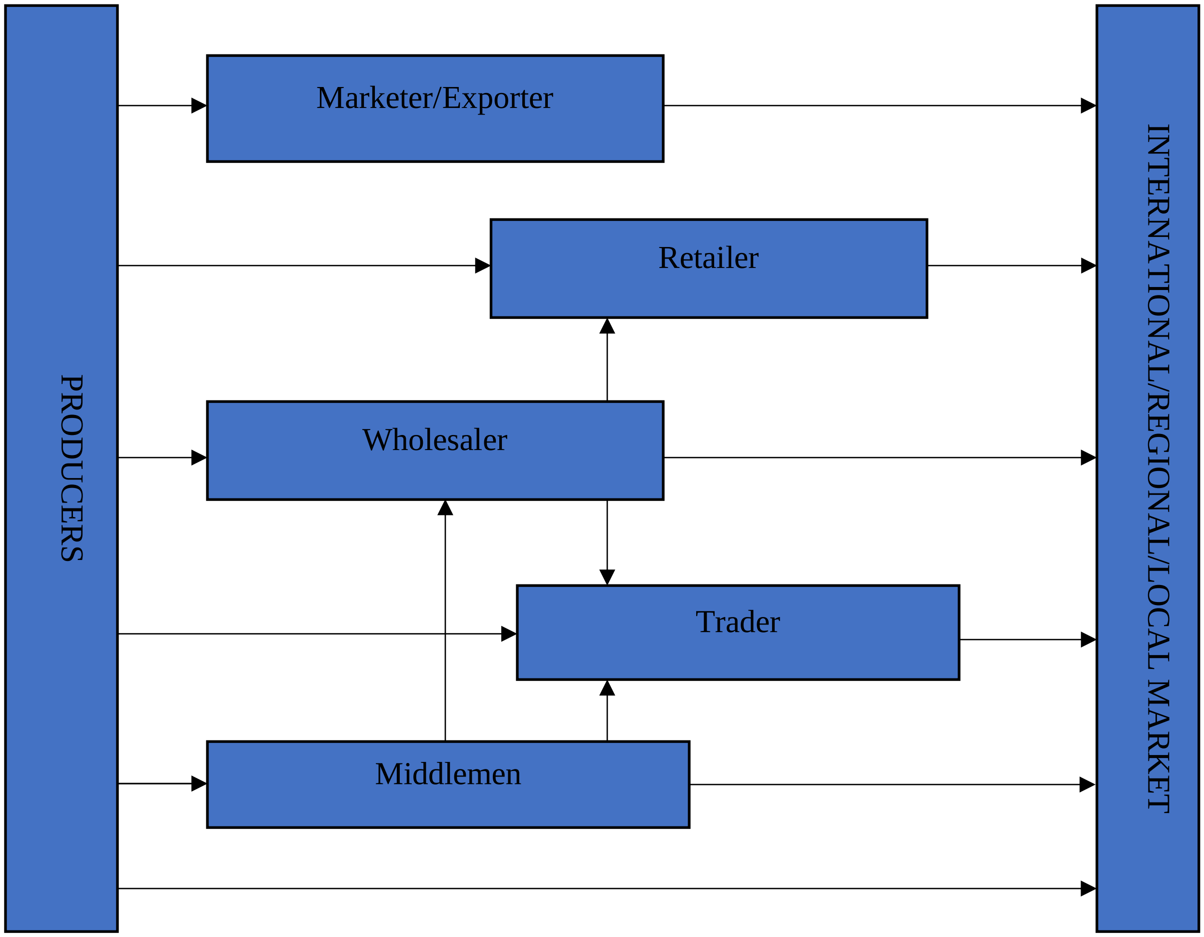

Figure 15: Simplified flow chart of the studied fruit and vegetable supply chains

5.3 Overview of the studied chains

5.3.1 Green pea (*Pisum sativum*)

5.3.1.1 Process description

Two LS-CF selected in the study grow the snow pea or mangetout (*Pisum sativum* var. s*accharatum)* and sugar snap (*Pisum sativum* var. *macrocarpon*) varieties for the export market and one LS-CF the garden or shelling pea for the domestic market. Although export markets were identified, distribution beyond Zimbabwe was not considered as it is beyond the scope of the thesis. Pea exports are carried out by individual farmers, mostly LS-CF and by marketers following consolidation of peas from several contracted farmers. The main export markets for peas are in Europe (Netherlands, Germany, Sweden and the United Kingdom). Peas are picked by multiple teams of workers who move through the field carrying plastic trays lined with bubble wrap. Filled trays are stacked on a trailer pulled by a truck and the workers pick up empty trays repeating the process until the trailer is full. Alternatively, the workers take the filled trays to the harvesting shed located within the field where a truck collects the harvest and transports to the packinghouse.

Transfer of peas from the field to the packinghouse/shed takes 5 to 20 minutes depending on the location of the field. The received peas undergo an initial quality inspection to determine if they meet the specifications for the intended market in terms of pod filling (essentially for shelling or garden peas) maturity, pest and disease. Non-conforming peas are rejected and discarded (composting or disposed), down-graded (diverted to a lower market) or used as animal feed. Green peas require immediate cooling following harvest to remove field heat. Conforming peas are weighed and cooled to reduce the temperatures from about 15 - 18oC to 2 - 5oC for a period of 18 - 24 hours. Cooled peas are trimmed, graded, sorted, packed and stored in cold rooms.

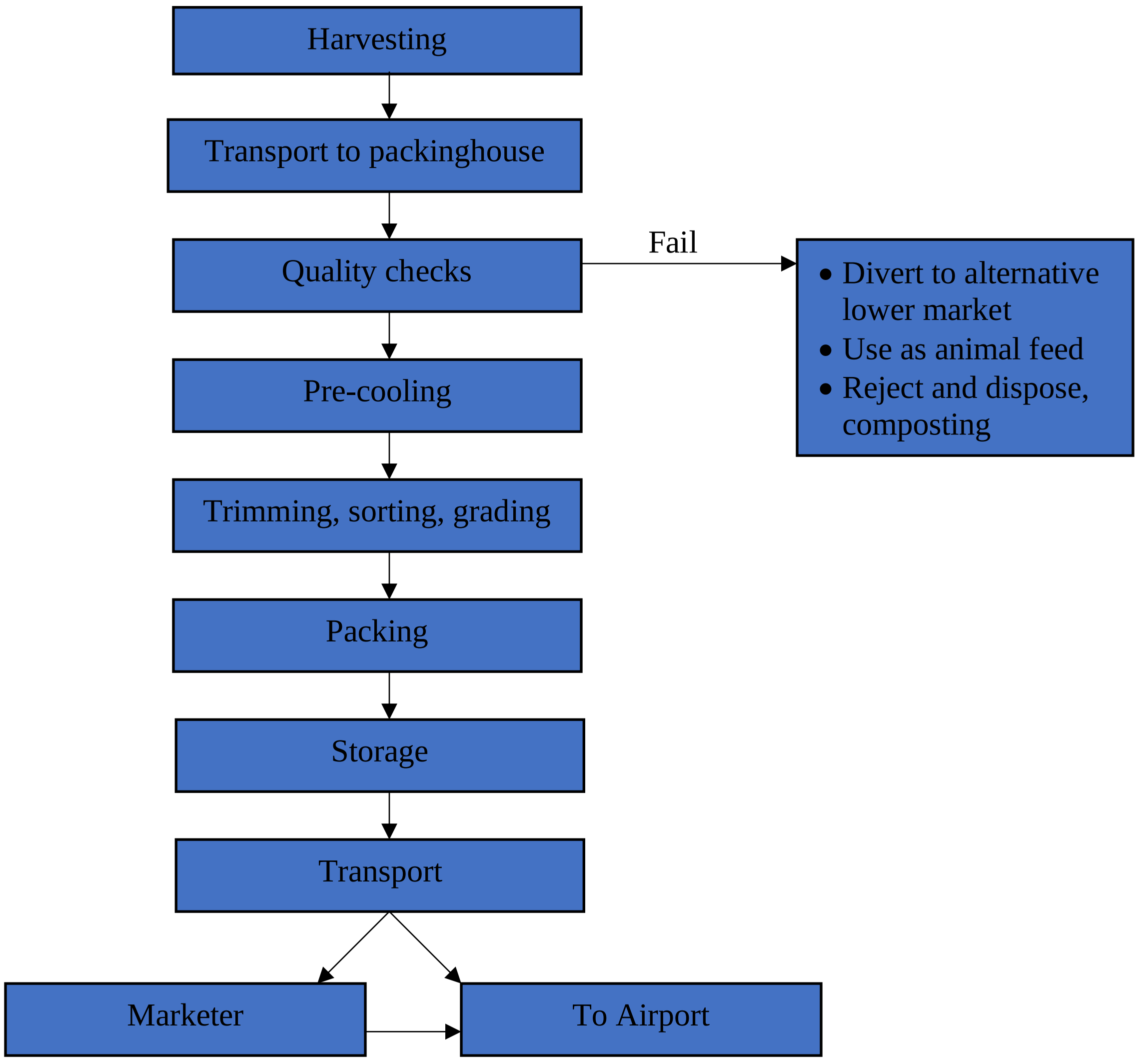

Figure 16: Postharvest process map for peas

5.3.1.2 Process analysis and observations

- Green peas are harvested in bubble wrap lined plastic crates to minimise bruising. Bruising due to poor reaping techniques was cited. When bruised, the marks appeared white at later stages of processing and are deemed unfit for exporting.
- Adherence to standards such as GlobalGAP, EurepGAP and BRC implies that LS-CF have health and safety policies and procedures in place displayed clearly on walls for all employees to adhere to.
- Peas are dumped on the table surfaces during grading, sorting and trimming. Work stations and trays are sanitised pre- and post-processing to prevent cross-contamination. Severely diseased produce is rejected and condemned and either composted or disposed of to prevent cross contamination.
- The cold chain for peas is maintained from farm-to-fork. LS-CF own refrigerated trucks which are used during transportation. LS-CF_2 mentioned that they deflated vehicle tyres to prevent the drivers from speeding because the roads are in bad shape.
- Losses although said to be very minimal sometimes occurred when product was in transit at international airports. Mk1 and LS-CF mentioned that shipments transported on passenger flights could be left on the hot tarmac for hours when flights were delayed leading to produce being rejected at the destination market.
- Powdery mildew, thrips, rots, blood from accidental cuts and worms resulted in a 100% rejection of peas.
- Marketer warehouse has plenty of capacity for storage. Pallets of different F and V awaiting dispatch to various destination markets were observed.

5.3.2 Orange (Citrus sinensis)

5.3.2.1 Process description

Traders, marketers and wholesalers buy their fruit direct from the grower. Navel (April – June) and Valencia (June – April) oranges are the two major types of oranges marketed locally and internationally. Brix ratio and juice percentage determine whether fruit has ripened and is ready for picking. A cull/blemish factor analysis is performed on every production day to determine the quality of harvest from a selected orchard. This is done prior to processing to ascertain produce quality from selected orchards and to get an estimate of production quantities for the various markets. The analysis evaluates pest and natural enemy management programmes implemented during the season and aids with decisions on integrated pest management regimes to follow in the next season. Teams of 80 workers carrying picking bags move through the orchards manually picking ripe oranges. Once filled, the bags are emptied into three trailers that are pulled by a tractor. Trailers are filled every 10 - 15 minutes. The workers are paid based on the number of bags they fill up which could explain the rate at which the trailers were filled up, the more bags one filled translated to more income. Trailers hold 2 tonnes each of oranges which are transferred to the packinghouse.

At the packinghouse, ripened oranges are received and wet dumped into chlorinated water where the oranges are sterilised and washed. Some fully ripened oranges are harvested with the skins green. These are are sent for degreening to specialised degreening rooms. Ethylene gas is applied which results in the change of skin colour from green to orange. Following degreening, the oranges are dumped in chlorinated water. Roller conveyors move the oranges through the processes of drying, application of wax and fungicides to the sorting tables. Grading and packing are performed manually. Fruit diameter is used to classify oranges into specific categories or counts. Count refers to the number of oranges of a specific diameter that can fit into a carton. For example, most export quality oranges fall under classes 1 and 2 and are of count size 125. Oranges are packed into 15-kilogram boxes (125 oranges per box, for export) or net bags and palletised awaiting dispatch to specified markets. Export boxes were stacked on standard pallets measuring 1000mm x 1200mm. Each pallet contained 70 – 80 boxes of fruit.

Table 8: Sizing of oranges

Count	Diameter (mm)	Minimum fruit diameter (mm)
125	62 - 70	62
105	64 - 73	66
88	67 - 76	69
72	70 - 80	74
64	73 - 84	77
56	77 - 88	81
48	81 - 92	86
40	84 - 96	95

5.3.2.2 Process analysis and observation

- Fruit on the ground in the field could have been dropped by pickers. Dropped fruit is left on the ground to prevent cross contamination of sound fruit with soil microbes.
- LS-CF_1 in this study remarked that PHL was minimal. Automation of the system minimises accidental dropping of fruit on the floor in the packinghouse. Fruit lying on the ground and tables was observed in the packinghouse.
- Farmer is expected to adhere to certification standards of the different export markets.
- Losses were observed at trader phase due to inefficient storage systems. Fruit packed in netbags was stored in large wooden bulk bins. One trader highlighted that they disposed of the fruit if not sold for 14 days.

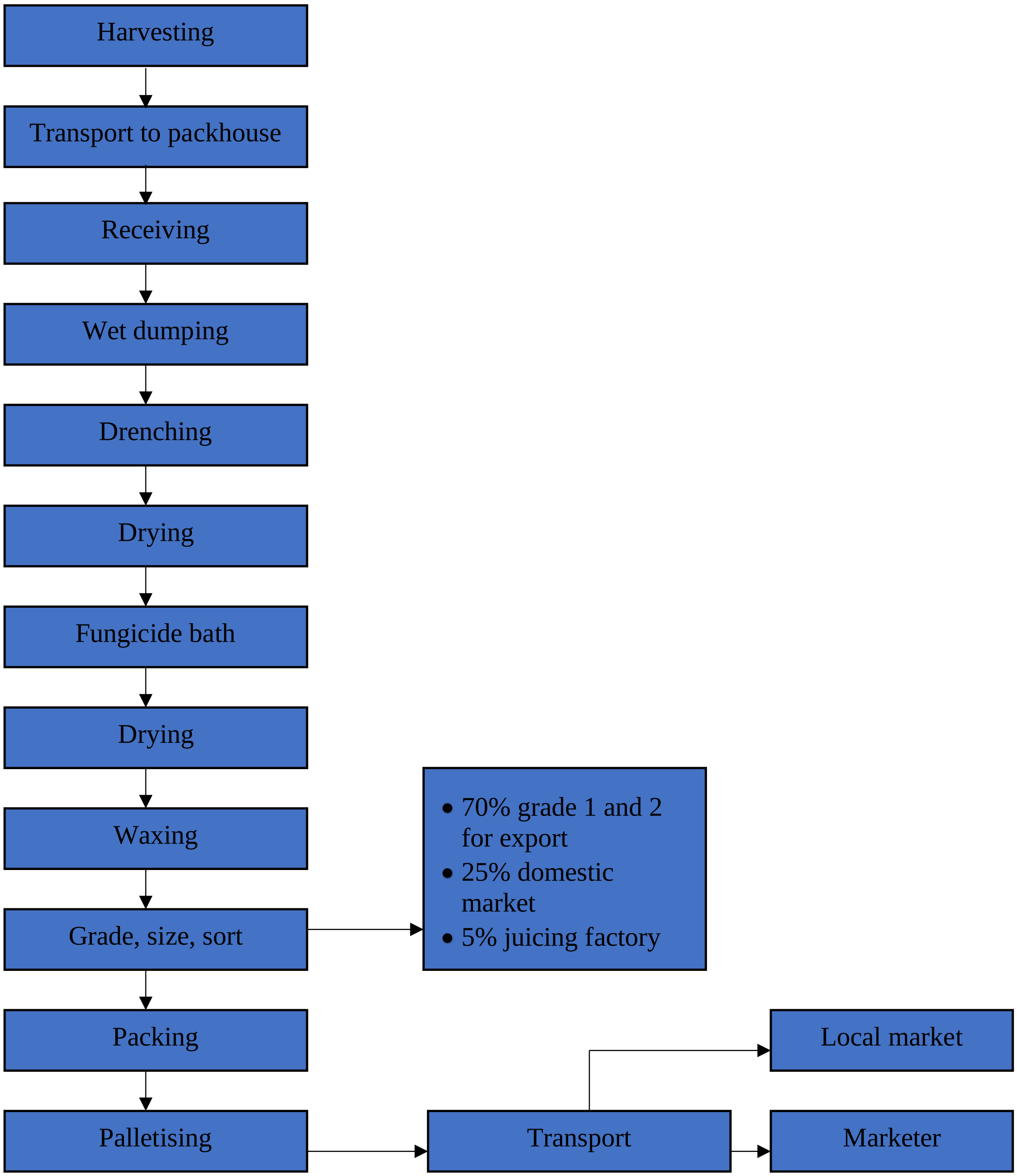

Figure 17: Postharvest process map for oranges

5.3.3 Tomato (Solarium lycopersicum)

5.3.3.1 Process description

SS-CF and SS-SF in the study primarily grow tomatoes for trade at the local markets whereas LS-CF grow for domestic consumption. Farmers may supply their produce direct to traders, fruit and vegetable markets and consumers. Middlemen were found in this supply chain, linking farmers to markets. SS-CF supplied both formal and informal markets (supermarkets, wet markets, farmers markets, vegetable shops, schools, hotels, fast food outlets) whereas SS-SF mostly supplied to informal markets. Tomatoes are handpicked from the vine by teams of workers carrying 20 – 25 L plastic buckets. Sizes of the teams vary (1-10) depending on farmer type and size of farm. Market specifications dictate the stage of ripening desired. Because fully ripened tomatoes (red) are easily bruised, they are harvested slightly under-ripe.

5.3.3.2 Process analysis and observations

- Mechanical damage at the harvesting stage due to rough handling.
- Markets dictated stage of harvest, with retailers, wholesalers and traders preferring yellow (slightly underripe) tomatoes instead of red ones because they have a longer shelf-life. The farmers mentioned that farm-gate customers opted for fully ripened (red) tomatoes.
- Bags of packed produce were placed directly on the floor, exposed to microbial contamination. One of the SS-SF stored their unripened tomatoes on a sack on the kitchen floor.
- The absence of storage facilities at the farmers' markets meant that any unsold produce was left covered at the traders' open stall. Traders mentioned that they had problems with rodents gnawing produce which they would throw away. Produce of traders with stalls at the far ends was exposed to all weather elements.
- Although the use of smooth plastic buckets prevented abrasion, fruit at the bottom of the buckets cracked due to compression.
- SS-SF harvested their produce early in some instances due to lack of transportation. For example, one farmer stated that they had to have their produce packed and ready for pick up at 2am to get to the market. However, this also meant that in instances when said truck would not show up the produce would undergo heat damage whilst waiting for alternative transport.
- Both SS-CF and SS-SF highlighted the problems brought about by pests, particularly the leaf miner *Tuta absoluta*. One farmer mentioned that they lost an entire harvest of tomatoes to the pest. However, another farmer was able to salvage part of the harvest by use of "cocktails" of pesticides not meant for the control of pests in agricultural produce. The farmer went on to state that they sold the produce at the farmer's markets.
- SS-CF and SS-SF mentioned that getting assistance from the government extension officers was difficult because transport was unavailable for the officers to travel to the villages. The key informant in the study stated that due to the shortage of vehicles for use by the extension officers, one had to use their own transport to collect the officers to get assistance.

5.3.4 Banana (Musa *spp*.)

5.3.4.1 Process description

Bananas produced in Zimbabwe are marketed locally and are regionally exported to South Africa, Zambia and Mozambique. Bananas are harvested, sorted, graded and packed into 340 – 360 kg bulk plastic or wooden bins which are loaded onto flat-deck 30-tonne haulage trucks and transported to depots overnight. The stacked banana bins are covered with tarpaulin. Bananas arrived at the depot daily in the morning, were unloaded (around 5am) and inspected to check pulp temperature and to ensure they had been correctly graded. Re-grading was performed if the variances in sizes were extreme. Off-loaded bananas were stored in ripening rooms and then transferred to cold rooms. Bananas were either sold in bulk to traders at the depot or dispatched from the depot to retailers.

5.3.4.2 Process analysis and observations

- Crates with spoiled and rotten bananas at one of the depots were observed placed next to crates with bananas that were fit for consumption.
- All bulk bins and crates contained fruit with visible brown spots on the skin. These signified possible mishandling at points that were not observed in the ASC.
- At the farmers' markets, bananas were stored in 18 kg stackable plastic crates. Bananas sold exhibited various levels of decay. The traders threw away over-ripened fruit when they had severely blackened but in most cases even the decaying ones were sold at very low prices (e.g. USD1 for 20 or 30 fingers of bananas).

5.4 Food safety and traceability

The European Union Regulation (EC) 178/2002 defines traceability as "the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution" (Commission, 2002). LS-CF have robust food safety and traceability systems because their systems are periodically audited by representatives of the certification programmes they are subscribed to. The farmers revealed that getting access to European and Asian retail markets without ascribing to their certification standards was difficult. SS-CF and SS-SF did not have any certification standards they adhered to and had no traceability systems in place. Food safety and hygiene is not enforced in Zimbabwe.

5.5 Food loss estimates

Data on food loss estimates was available from LS-CF who performed direct measurement on all the goods they received, and all produce that was put in rubbish bags in the packinghouse. The farmers pointed out that yield losses in primary production were difficult to quantify. SS-CF and

SS-SF in the study did not keep records of the amount of product they lost. One SS-CF farmer had a small scale that was used for weighing produce destined for sale. Marketers in the study reported that there was no loss on their part because they received packed produce and only facilitated in its movement to the next point of the ASC. Wholesalers, retailers and marketers reported that they re-weighed all received consignments to ensure that they adhered to the specified order quantities. Traders did not keep records of any produce lost, they did not measure losses at all.

Table 11 summarises findings from the qualitative aspect of the study characteristic to all the studied ASC.

Table 9: Handling stages and characteristics of postharvest loss in the studied chains

Stage	Loss characteristics
In-field	Impact and abrasion injury
	Poor handling techniques
	F and V damaged during harvesting (bruising)
	Dropping F and V
	Edible F and V left in the field
	Knife cuts
Packinghouse operations	Dropping produce on floor
	Cross-contamination
	Contamination during cutting and trimming
Packaging	Inappropriate packaging resulting in damage to produce e.g. wooden crates and bins bruising fruit
	Under- and over-filling
Storage	Pests (insects and rodents), disease,
	Spoilage due to cross-contamination
	Mixing of produce
	Inappropriate storage conditions (e.g. ambient instead of cold storage)
	Absence of storage facilities
	Lack of cold storage facilities
Transport	Transport infrastructure
	Bruising, abrasion
	Non-refrigerated trucks
	Open trucks and lorries
	Inappropriately packaged mixed loads
	Delays (roadblocks, bad roads, weather)
Distribution	Retail display (mixing F and V)
	Lack of cooling
	Lack of cold storage facilities

5.6 Key logistics aspects

5.6.1 Supply and demand

Changing consumer demands influence supply and demand. Demand forecasting by export markets on expected order quantities for an entire season assists farmers in making decisions on the amount of land to cultivate to meet this demand and inventory management.

Mk2 reported that they exported on average 15 tonnes of fresh F and V per day, which could not be met by a single farmer. Therefore, they consolidated peas from several farmers to meet this demand. LS-CF_1 stated that daily production quantities of oranges were set at 100 to 120 tonnes per day. They experienced a slump in production post FTLRP and only resumed exports in 2012 even though they were still not operating at maximum capacity. The farmer highlighted that currently they could only fill one truckload per day of 24 pallets for export instead of 3 to 4 truckloads.

Although there is a constant supply of tomatoes throughout the entire year, prices increase in winter corresponding to a decrease in supply. Tomatoes do not grow well in winter and need to be grown in greenhouses. SS-SF in the study cited costs associated with purchasing and setting up greenhouses as being prohibitive. However, during the hot summer months, the market experiences an oversupply of the commodity which pushes the prices down. SS-CF_3 mentioned that middlemen/brokers/marketers at farmers' markets formed an important network which assists farmers with information on market trends, demand and supply. They have studied the markets and had key information networks amongst themselves.

5.6.2 Poor infrastructure

Marketers, retailers, wholesalers and LS-CF generally had cold storage facilities at their farms or premises. Table 10 illustrates the maximum age of use of different F and V displayed on cold room doors at a visited farm packinghouse.

Table 10: Maximum age of use for different fruits and vegetables

Product	Maximum age of use
Mange tout (peas)	Day 5
Sugar snap (peas)	Day 5
Stone fruit	12 hours
French tarragon	24 hours
Blueberries	Day 3
Courgettes	Day 4
Chillies	Day 7

If kept for longer periods, the shelf life further along the ASC decreases. SS-CF and SS-SF without access to cold storage had to ensure that their produce was sold as quickly as possible. Mbare farmers' market is overcrowded with no storage facilities. Traders kept all unsold produce at their market stalls in stacked crates, boxes, netbags or covered on display. Two different farmers' markets were visited in Domboshava: one was purposely built for marketing produce and the other one was a large fenced open area where traders covered the bare ground with sacks and laid out their produce. Although a large open shed where traders stored unsold produce for the next market day. All traders highlighted that the produce was exposed to pests (mostly rodents). Infrastructural development can aid in improving conditions of storage and marketing of produce thereby minimising food loss.

The concept of value addition was observed among traders who made mixed vegetable packs to prevent extensive loss of whole batches of produce. They however made fresh cut produce at the market under unsanitary conditions. For example, one trader was chopping up unwashed vegetables in a large bowl using a multipurpose knife. The implications of this activity to human health are immense.

5.6.3 Transport

The case studies showed that transport logistics is a challenge experienced by SS-SF and traders and not the other participants. It only became a challenge for LS-CF and marketers when their produce was in transit beyond the borders of Zimbabwe. Open trucks and lorries are a common mode of transportation. Transport issues are coupled with poor roads, making transportation of horticultural crops difficult. Not much can be done by the chain participants in terms of improving road infrastructure as it is the duty of the governing ministerial bodies and authorities. Kader (2005) highlighted the same issue.

Table 11: Summarised responses from the semi-structured interview based questionnaires							
	LS-CF	**SS-CF**	**SS-SF**	**Marketers**	**Traders**	**Retailers**	**Wholesalers**
Harvesting	• Maturity indices used to determine moment of harvest (days to harvest, total soluble solids, size, appearance, acid content, juice percentage) • May depend on market specifications • Manual (handpicking) • Highly trained supervised staff • Bubble-wrap lined plastic crates • Smooth plastic buckets • Picking bags • Performed at any time of day 6am-5pm, 9am-5pm, 8am-4pm • Ideal conditions should be cool and dry	• Maturity indices used to determine moment of harvest (days to harvest, colour, size) • May depend on market specifications • Manual (handpicking) • Trained staff • Smooth plastic buckets • Performed early morning (6am) or late afternoon (from 3pm) • Ideal conditions should be cool and dry	• Maturity indices used to determine moment of harvest (days to harvest, colour, appearance, number of leaves on plant) • May depend on market specifications • Manual (handpicking) • Family members, local community • Smooth plastic buckets • Performed early morning or in the afternoon (6am, 9am, 2pm, 3pm) • Ideal conditions should be cool and dry	• N/A	• N/A	• N/A	• N/A
Postharvest operations	• Carried out in packinghouse • Inspecting, grading, sorting, washing, waxing, cleaning, weighing, accelerated ripening, degreening • Mechanical or manual • Removal of mechanically damaged, diseased • Highly trained supervised staff	• Carried out in harvesting shed in field or in buildings used as office spaces • Inspecting, grading, sorting, cleaning, weighing • Manual • Removal of mechanically damaged, diseased • Trained staff	• May be performed in the open field or in the homes • Grading, sorting, cleaning • Removal of mechanically damaged, diseased • Manual • Labour is usually family members, local community	• N/A	• N/A	• N/A	• N/A
Packaging	• Market specifications (some markets supply packaging material which is paid for by the farmer)	• Reusable plastic crates and wooden boxes, plastic trays	• Reusable wooden crates, plastic trays, single-use plastic bags	• Supplies packaging material to farmer at the expense of the farmer	• Single-use plastics, plastic trays, net bags • Large cardboard	• Products on display may be packaged or unpackaged in large open reusable wooden or plastic	• Products in large bulk wooden or plastic crates, bins and net bags

	• Recyclable cardboard, recyclable plastic trays, net bags which the end user may reuse, single-use plastics				boxes for storing produce	crates, bins and net bags	
Storage	• Blast chillers for removing field heat immediately after harvesting • Maintenance of cool chain practised • Temporary storage in cold rooms due to perishable nature of produce • LIFO or FIFO inventory allocation policy • Pests and insects management	• No cooling facilities • Storage facilities range from open sheds in field to small multi-functional closed rooms • Ambient conditions • Pest and insects management	• No cooling facilities • No specialised storage facilities • Produce may be temporarily stored in the kitchen on the floor or if available, an empty room in the house • Ambient conditions • Pest and insects management	• Blast chillers for cooling of produce that arrives at the warehouse below expected optimum temperature • Cold rooms available • FIFO inventory allocation policy • Pests and insects management	• No cooling facilities • No cold storage facilities • Pests and insects • Open market shed	• Cold rooms available • Cold storage available • FIFO inventory allocation policy • Pests and insects management	• Cold rooms available • Cold storage facilities available • Controlled atmosphere • FIFO inventory allocation policy • Pests and insects management
Transportation	• Own refrigerated trucks • Tractors fixed with trailers for moving produce from field to packinghouse • Refrigerated trucks from packinghouse to distribution centre • Delays due to weather conditions during the rainy season, roadblocks • Bad road conditions i.e. potholes	• Own small trucks and lorries • Delays during the rainy season due to weather conditions, roadblocks • Bad road conditions i.e. potholes	• Hire transport in groups when sending produce to market • Use of wheelbarrows, animal-drawn carts for transporting produce from field to homesteads • Delays during the rainy season due to weather conditions, roadblocks • Bad road conditions i.e. potholes	• May provide transport to collect produce from farmers • Own refrigerated trucks • Delays due to weather conditions; flight delays, roadblocks • Bad road conditions i.e. potholes	• Hire transport to collect produce from farms or wholesalers • Delays during the rainy season due to weather conditions, roadblocks • Bad road conditions i.e. potholes	• May use own trucks to collect produce from farms • Delays during the rainy season due to weather conditions, roadblocks • Bad road conditions i.e. potholes	• Produce is delivered to the wholesaler in 30 tonne flat-bed trucks • Delays during the rainy season due to weather conditions, roadblocks • Bad road conditions i.e. potholes
Food safety and traceability	• Systems in place compliant to requirements of different market standards e.g. GlobalGAP, BRC	• General standards of cleanliness and hygiene observed	• General standards of cleanliness and hygiene observed	• Systems in place according to requirements of different markets e.g. GlobalGAP, BRC	• General standards of cleanliness and hygiene observed	• General standards of cleanliness and hygiene observed	• General standards of cleanliness and hygiene observed • Traceability systems in place

Fresh produce quality deterioration is a result of several factors, resulting in qualitative and quantitative losses as was shown in the study. The results are consistent with the report by Kitinoja & Kader (2002) that the problems associated with PHL in developing countries are mostly related to handling and temperature control. Furthermore, ongoing biochemical reactions accelerate deterioration. This makes it difficult to prolong the shelf-life under ambient conditions. Shelf-life extension is only possible under cold storage conditions coupled with humidity control (Kitinoja & Kader, 2002).

Fruit and vegetables are classified as either climacteric or non-climacteric. Non-climacteric fruit can only be harvested when fully ripened. Harvesting of unripe oranges will result in PHL and quality deterioration. The farmer in the study tested the orange fruit to determine total soluble solids and brix ratio before picking to prevent PHL as unripened oranges would have to be discarded.

Thow & Priyardarshi (2013) highlighted that the growth of farmers from developing countries is hindered by weak economies and lack of support mechanisms to develop their infrastructure. For them to compete on the global market whilst struggling to survive under harsh economic climates seems an insurmountable task (Kasso & Bekele, 2016).

Chapter 6 : Conclusion and recommendations

6.1 Conclusions

In this thesis, agri-supply chains of four commodities were studied: banana, orange, pea and tomato in Zimbabwe. The first research objective was to map the studied agri-supply chains (ASC) from farm-to-fork using semi-structured interview-based questionnaires. An interview protocol based on the literature review of similar previous studies was developed. Data gathered mapped the different ASC from the farms to three distinct markets (domestic, regional and international) with various actors serving each marketing channel. The results showed that the main chain participants were the producers (farmers), marketers, traders, retailers and wholesalers. LS-CF dominate the pea and orange export chain because they have established infrastructure to support pea production and are able to meet the required standards imposed by global retailers. SS-CF and SS-SF in the study marketed their produce locally.

The second research objective used a combination of interviews and observation techniques to identify the source and nature of postharvest losses in the mapped ASC. It emerged from the study that consumers are becoming increasingly conscious of their dietary intake and are demanding high quality fresh produce. Therefore, regional and international markets imposed specific product quality requirements which had to be adhered to by producers. PHL was both quantitative and qualitative in nature with sources identified as in-field activities (harvesting and handling), packaging (material and type), storage conditions (time and temperature), distribution and transportation (infrastructure). While the sample of participants in the study provided vital information on the relationship between PHL and handling of F and V, quantification of these findings was not possible. The qualitative approach has limitations in the number of participants that could be studied. However, the findings from the study highlighted issues that should be addressed in terms of educating participants on the importance of fresh produce safety and proper handling, provision of cold storage facilities at fresh produce markets, and road infrastructure development for PHL reduction in developing countries.

The third objective was to develop a simulation model of the mapped pathways. The study also highlighted the lack of studies on simulation modelling in agri-fresh supply chains in Zimbabwe. More studies are required make data on fresh produce chains readily available. Due to unavailability of sufficient data to model the tomato, pea and banana ASC, the orange pathway was modelled. The modelling process led to significant discoveries in lack of record keeping by most farmers and traders. They only recorded what they were selling and not the amount of total crop harvested. Poor record keeping means that they are not keeping track of the losses and gains realised from the harvest. This issue was found mainly at the traders and SS-SF.

Sensitivity analyses of the original orange model by changing input parameters resulted in a doubling of throughput in Scenario 1 but scenario 2 and 3 yielded no significant results. This showed that simulation models can indeed be used to test system performance without affecting the system.

6.2 Recommendations

This study sought to explore the postharvest handling practices of participants in agri-food supply chains and attempted to use a discrete event simulation model to study supply chains. Agent-based modelling (ABM) can be used in future research to simulate studied ASC networks. This requires an intensive information system design study which can incorporate a comprehensive cost-benefit analysis.

Future work could be directed towards employing larger samples to derive additional evidence as well as quantifying the produce lost due to specific causes because the study did not quantify the losses. This can be explored further in subsequent research, exclusively focusing on each commodity separately. Studies on quantification of PHL in Zimbabwe will aid in identifying points where handling may be improved to minimise loss and enhance food security. Another critical issue related to the absence of information is the unavailability of statistical information on fruit and vegetable which can be easily accessed. Such studies aid in gathering data which can be used in creating a useful database which can be accessed by future researchers.

Further studies are necessary to find out the extent of use of chemicals not meant for agricultural production by SS-SF. Such a study should take samples of produce from different farmers and test on residue levels of insecticides and pesticides. There are no regulatory bodies monitoring pesticide residues in agricultural produce that is sold at the local farmers' markets. Safeguarding public health should be of paramount importance because some farmers are using pesticides that endanger human health.

It would be interesting to note how increasing the speed of the roller conveyors in the orange system would affect the operating times and human resources. That could be taken up for further research. Another important aspect would be incorporating roller speeds, length and determine processing times for each orange in the system. This would require an in-depth analysis into the operations of the orange chain incorporating engineering design of the system which was beyond the scope of this thesis.

The last objective sought to identify possible mitigation strategies that could be employed based on the context within which the PHL were occurring. The following measures can be employed to address activities contributing to PHL in the studied chains:

- Educating all handlers of fresh produce on the importance and benefits of carefully handling fresh F and V to prevent or minimise damage.

- Construction of raised pedestals at farmers' markets to prevent farmers from selling produce off of barely covered ground surfaces. This will minimise microbial contamination.

- The government should set in place systems for small-scale farmers to market their produce to international markets. Without government intervention, it is difficult for them to actively compete on the global market. They lack the capacity in terms of infrastructure such as cold storage and reliable transportation systems. They also lack access to market information as the large-scale farmers.

- Demand forecasting is critical in food production systems. The interviewed famers (SS-SF and SS-CF) in the study did not have adequate knowledge on demand forecasting. This resulted in overproduction of other commodities and oversupply. The farmers then imposed their produce to the consumers at the farmers' markets, resulting in gluts and high incidences of PHL. Gluts in commodities result in lowering of prices which is unfavourable to some farmers.

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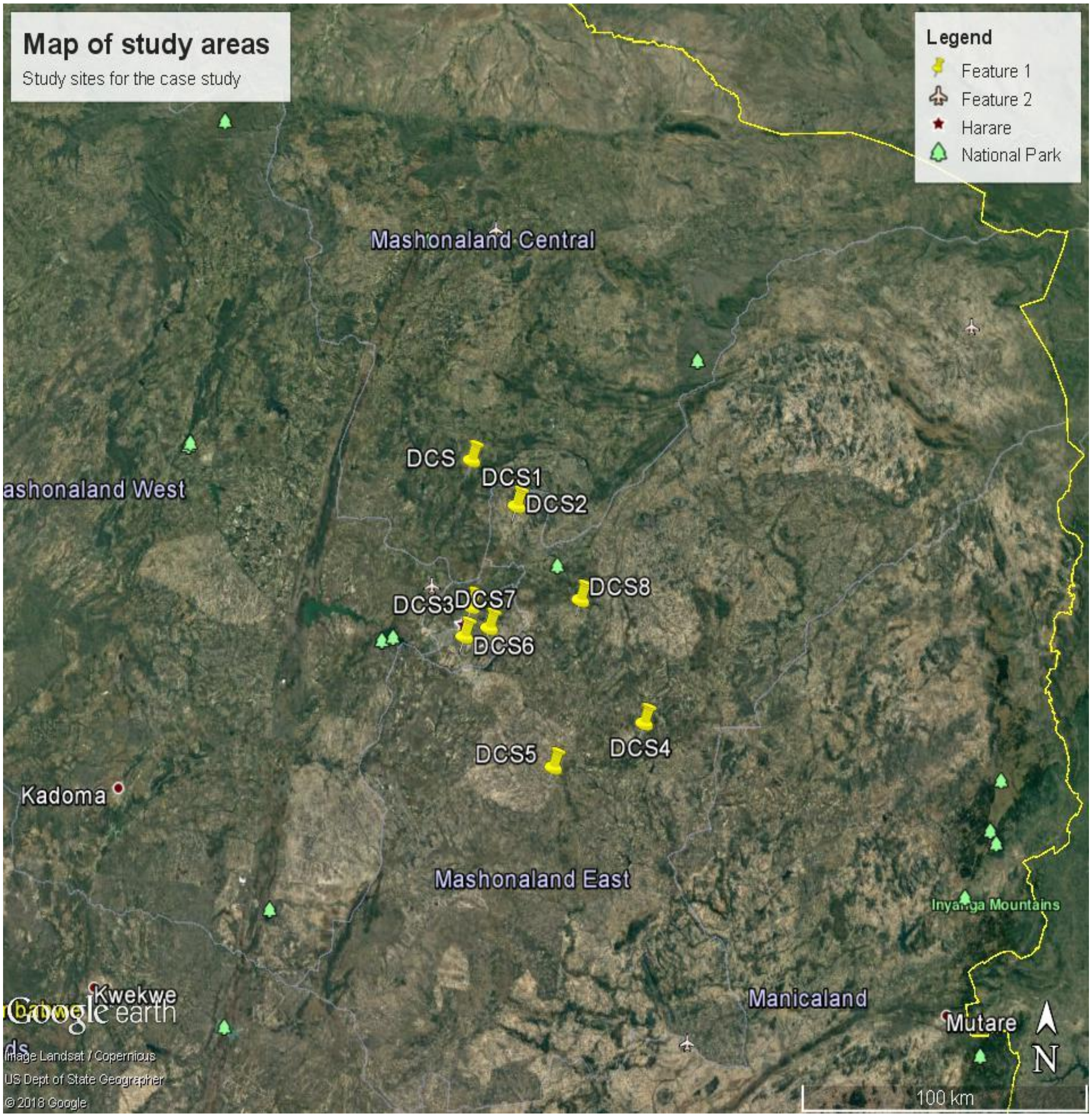
Appendix A: Image of map showing study sites



DCS – DCS 8 (data collection sites) areas of study (Source: Google Earth)

Appendix B: ARENA® Input Analyser probability distributions

Beta distribution	**Lognormal distribution**
Empirical distribution	Normal distribution
Erlang distribution	Poisson distribution
Exponential distribution	Triangular distribution
Gamma distribution	Uniform distribution
Johnson distribution	Weibull distribution

Appendix C: Questionnaire

A generic questionnaire was used in interviewing all participants with some questions modified to suit context of operation.

Section A: General Information

Gender				
Age	0-20	21-30	31-50	>50
Highest level of Education	None	Primary	Secondary	Tertiary
Farmer type	SS-SF	SS-CF	LS-CF	
Intermediary type	Trader	Retailer	Wholesaler	Marketer
Farm Size				
Size of workforce	1-5	6-10	11-20	>20
Years in field	1-5	6-10	11-20	>20
Fruit/Vegetable				
Source of seed				

Section B: In-field handling

Theme	**Questions**
Harvesting	• How do you determine the moment of harvest? – e.g maturity index, moisture content, colour, appearance, tenderness, texture • At what time of day is harvesting performed? • What equipment do you use, if any? • Explain the process

Section C: Postharvest activities

Theme	**Questions**
Selection, sizing, grading, inspection	• When and where is this this carried out? • What criteria do you use? – Shape, size, colour, weight, damage, maturity • Who is responsible? • Why is this done? • What equipment do you use, if any? • Explain the process
Postharvest treatments (chemical), if any	• When, where and how are the chemicals applied? • Reasons for the application of chemicals
Packaging	• Where in the system is packaging done? • What are the characteristics of the packaging material? – plastic, cardboard, wood • Where do you source it from?

	• Is it reusable and/or recyclable? • How do you package the product?
Cooling	• Do you cool the produce? • If yes, how? – cooling method and equipment • Is the cool chain maintained up to the final market?
Storage	• Where in the chain does the produce undergo storage? • Why is the product stored? • What are the characteristics of the storage facility? • What are the conditions of the storage facility? – temperature controlled, controlled atmosphere, humidity controlled • What types of produce are stored in the facility? • What is the distance from the storage facility to the farms or market? • What is the duration of storage for produce?
Transportation	• Where in the chain does transportation occur? • Who is responsible for transportation at the stages highlighted in the previous question? • What mode of transportation do is used? • Who owns the product during transportation? • Describe the transportation process (NB: time of day, stacking, nearness to engine) • Distance and duration of transport • Do you encounter delays during transportation? • What are the characteristics of the delays? – cause, length of delay • How is produce protected at the point of delay? • What effects of delays on produce have you experienced? • What alternative solutions do you use to reduce or avoid these delays?
Food safety and traceability	• Do you adhere to any food standards? – e.g. GlobalGAP, EurepGAP • What are your reasons for doing so? • Is there a food traceability system?
Intermediaries	• Do you deal with any intermediaries? • What functions do they carry out?

Section D: Quantities

	Minimum	Maximum	Average
Amount of produce handled weekly			
Amount of produce discarded weekly			

Appendix D: Components of the Commodity Systems Assessment Methodology (CSAM) (La Gra, 1990; La Gra et al., 2016)

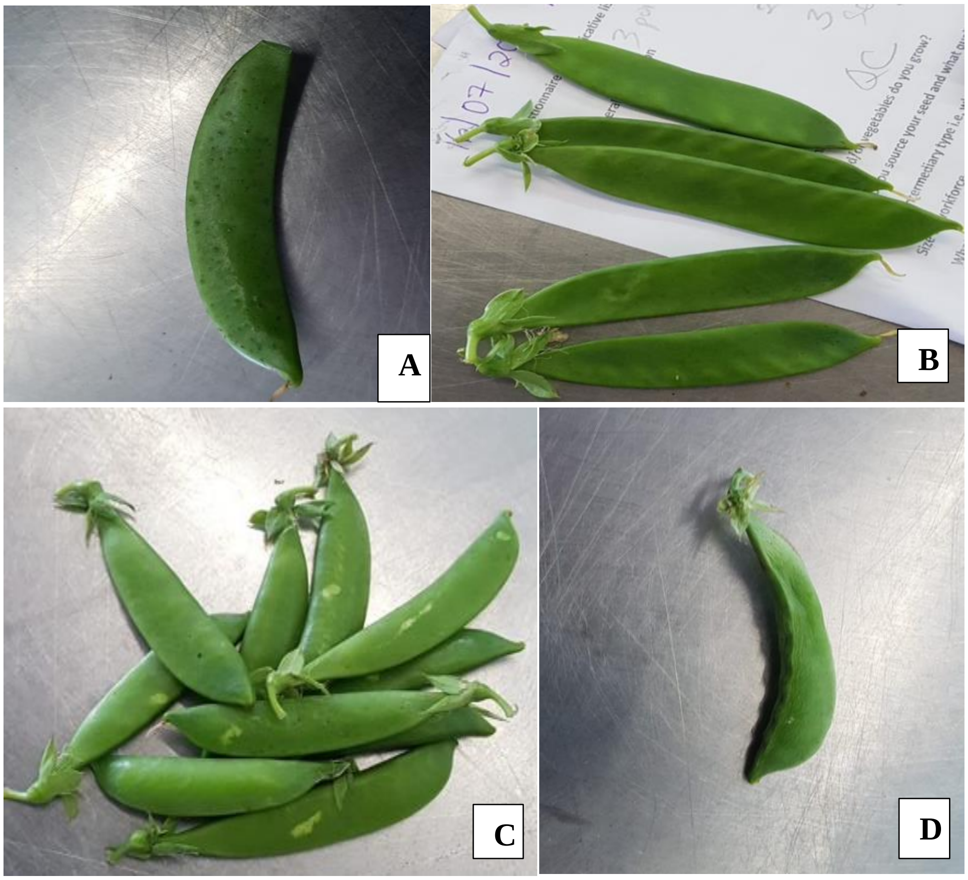
Material removed due to copyright compliance

CSAM covers the preharvest (pre-production and production) and postharvest (handling and marketing) aspects of the ASC. The food system is divided into 26 components spanning the entirety of the ASC. Questionnaires targeted at each of the components are used to assess weaknesses in the system leading to PHL, identify solutions and develop protocols to improve system efficiency.

Appendix E: Images taken during field observations

Right: Image showing tractor with attached trailers in front of the packinghouse. The tractor was used to transport oranges from the field to the packinghouse. **Left:** Image of signage above the grading station for oranges where fruits are sorted for defects. (Source: Author's own)

Left: Export quality oranges packed in a cardboard box with the top layer oranges individually wrapped in paper to minimize bruising. **Middle:** Packed oranges destined for the export market stacked on a pallet in the temporary storage area for oranges awaiting dispatch. **Right:** Image displayed on cold room doors at a packhouse showing maximum age for use for the various fruit and vegetables that are exported.
(Source: Author's own)



Images of peas showing various defects:

A: Blackspot due to fungal infection in the field.

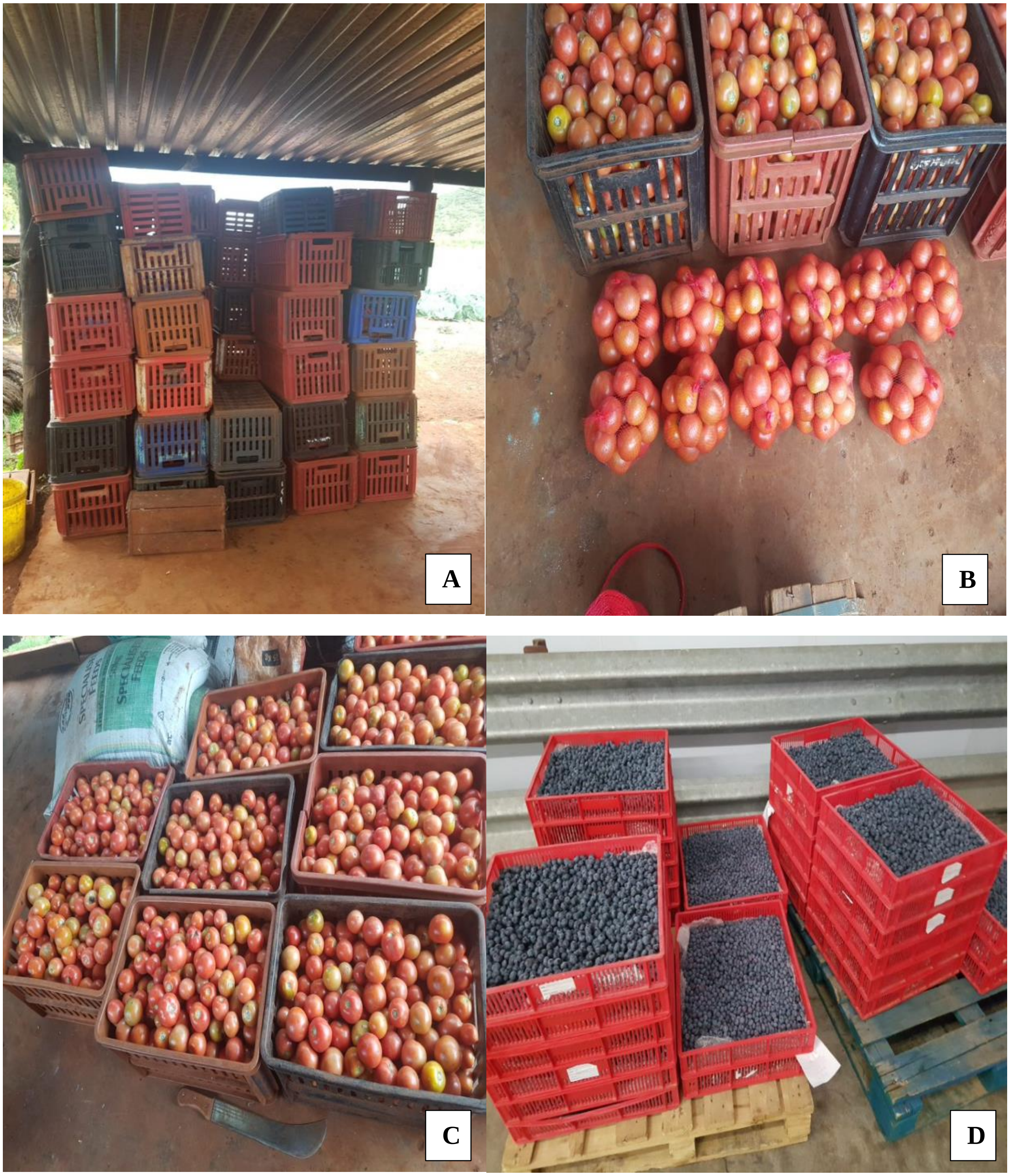
B: Immature peas reaped at inappropriate stage of maturity

C: Bruised peas due to poor handling

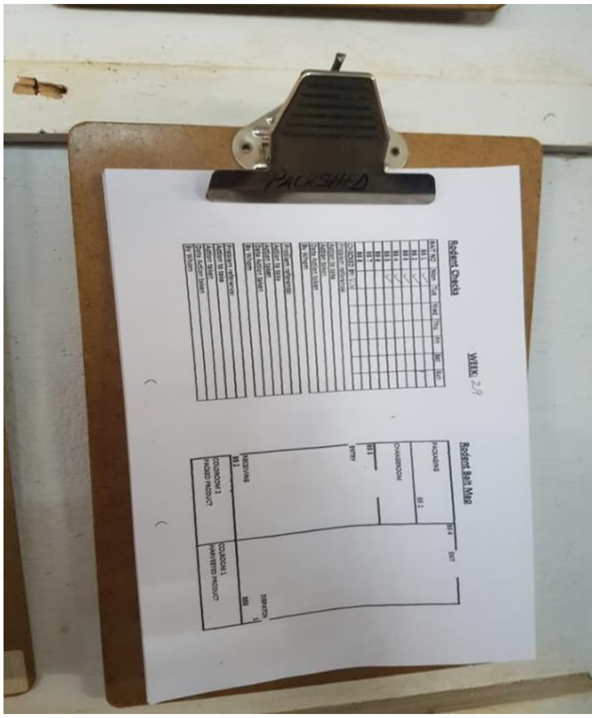
D: Dehydrated due to poor packaging or reaped when immature. (Source: Author's own)

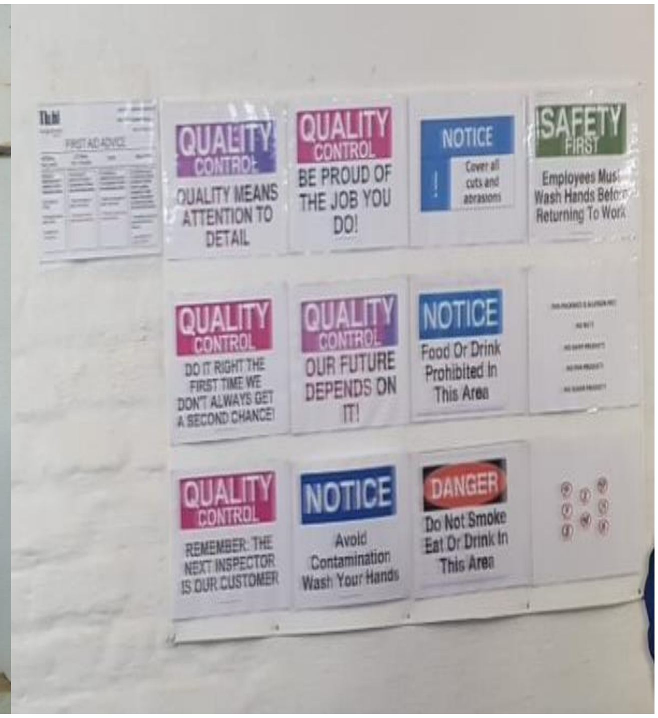
Left: Bubble wrap lined plastic crates for harvesting peas. **Right:** Peas packed and arranged in plastic trays according to the specifications of the destination market. (Source: Author's own)

Left image: Workers (in groups of four per table) in a packhouse sorting and packing peas into boxes destined for various markets**. Right image:** Boxes of fresh produce in a cold room at a distribution centre awaiting dispatch to different export markets. (Source: Author’s own)



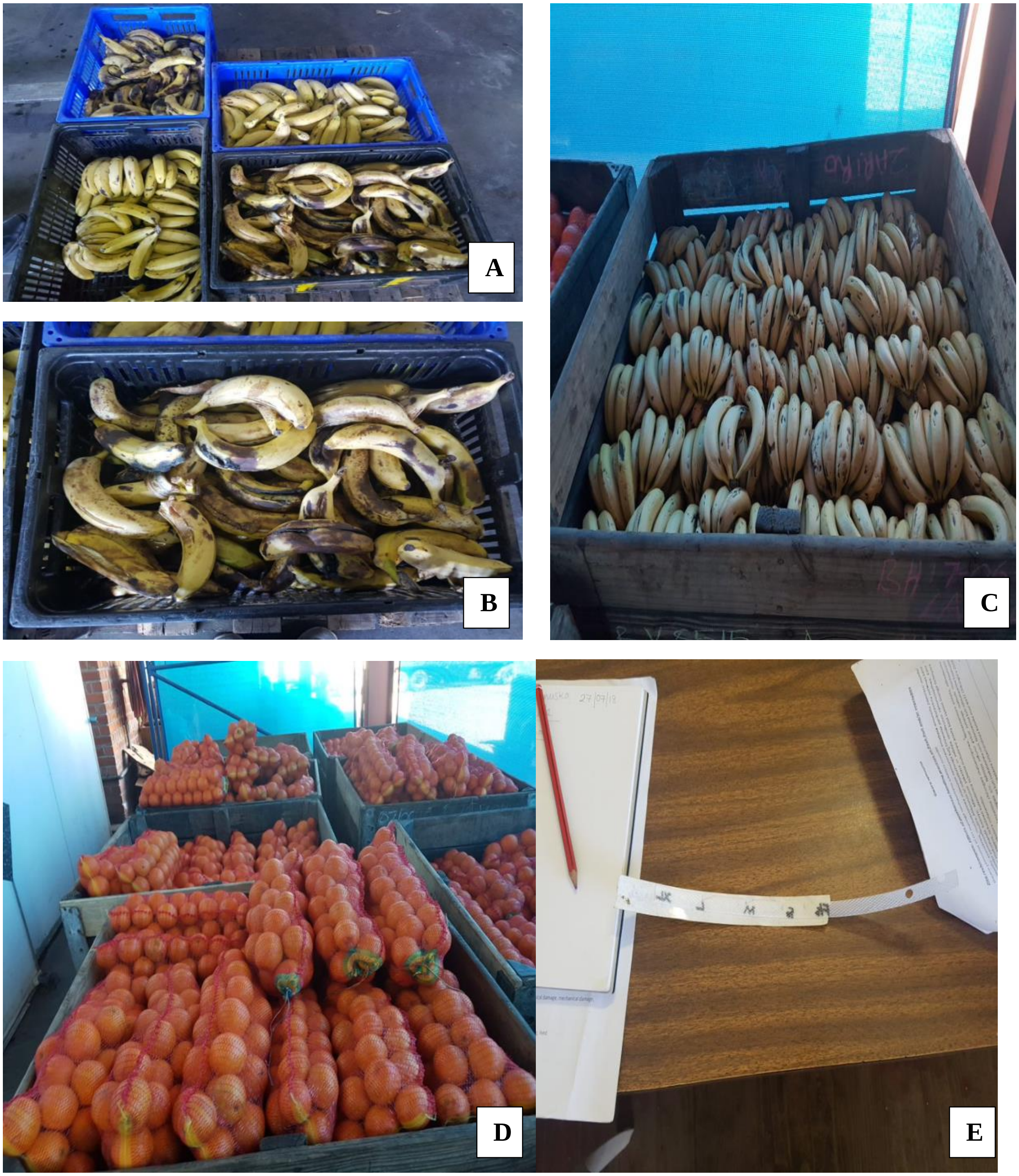
Various images showing: **(A)** reusable plastic crates used for storing F and V during transportation; **(B)** packed tomatoes placed on the floor in a harvesting shed awaiting transport to the farm-gate to sell; **(C)** tomatoes in crates stored in shed containing animal feed and **(D)** blueberries under cold storage awaiting packing. (Source: Author's own)





Left image: Pest control and management. **Right image**: Signs and notices observed on the walls highlighting the importance of safety and quality in the packinghouse.

Left image: Forced air cooling of fresh produce. **Right image**: Bananas in cold storage



Images showing: A: Crates with bananas at various stages of ripening; **B:** A crate with over-ripened (rotting) bananas; **C:** Bulk wooden crate with ripened bananas awaiting collection from depot; **D:** Bulk wooden crates with 15kg net bags of oranges awaiting transportation to markets and collection from depot by traders; and **E:** Instrument used to measure thickness of bananas when re-grading at the depot. (Source: Author's own)

A collection of images showing fruit and vegetables on display at Mbare Musika commodity market. (Source: Author's own)

A collection of images showing fruit and vegetables on display in a retail outlet. (Source: Author's own)

Appendix F: Tables showing distribution and input parameters for the orange model

Activity	Distribution	Action
Orange arrival from orchard	TRIA (35, 40, 45) minutes	1 entity per arrival

Oranges arrive from the orchard in a lorry pulling 3 trailers. 1 entity per arrival refers to 1 lorry pulling 3 trailers of 2 tonnes each. Each truck arrival therefore means 6 tonnes of oranges. 1 entity per arrival means 6 tonnes of oranges.

Activity	Distribution	Action
Inspection	TRIA (5, 7.5, 10) minutes	SDR
Degreening	CONST (4320) minutes	SDR
Packing Class 1 & 2	TRIA (20, 25, 30) minutes	SDR
Packing Class 3	TRIA (20, 25, 30) minutes	SDR

Inspection is carried out by the packhouse inspector.

Degreening takes place in the degreening rooms.

Packing is carried out by the packhouse workers based on a schedule.

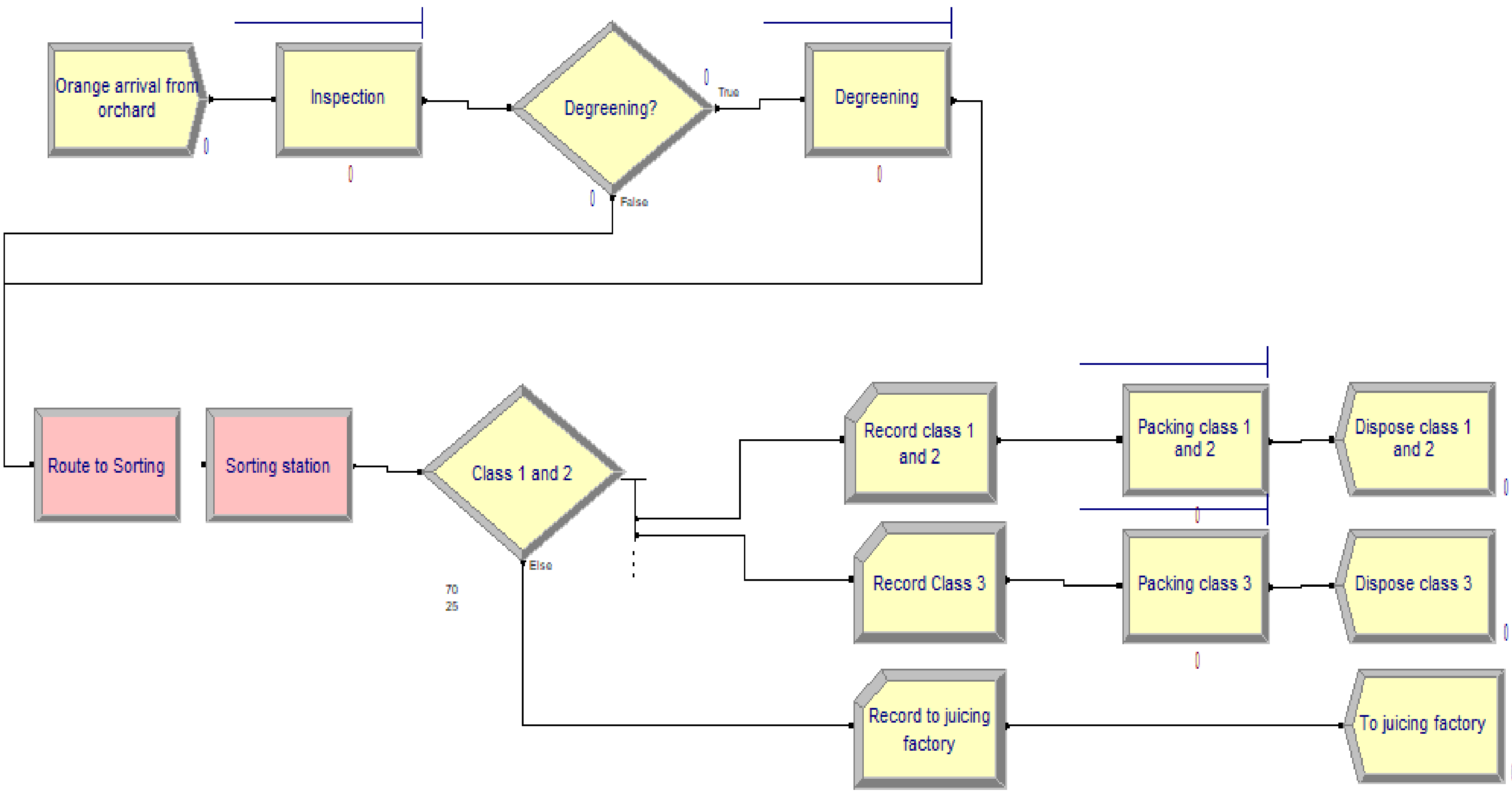
Activity	Distribution
Route to sorting station	TRIA (20, 25, 30) minutes

There are processes occurring between degreening and sorting. These include waxing, drying, fungicide application and grading. Because high volumes of oranges undergo this process on a roller conveyor, the packhouse inspector gave the amount of time it takes for the entire batch of 6 tonnes of oranges to be processed. One batch was also observed and took an almost similar amount of time to that reported by the packhouse inspector.

Resources	Capacity	Number of resources
Packhouse inspector	Fixed capacity	1
Degreening room	Fixed capacity	3
Packhouse workers	Based on schedule	100

Appendix G: Simulation model

Screenshots of the orange model and output data



Replications: 100 Time Units: Minutes

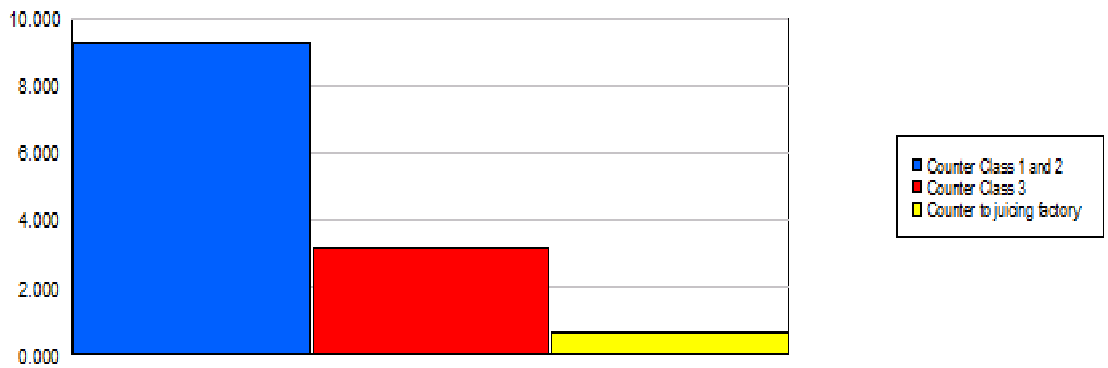
Key Performance Indicators

System

	Average
Number Out	13

Counter

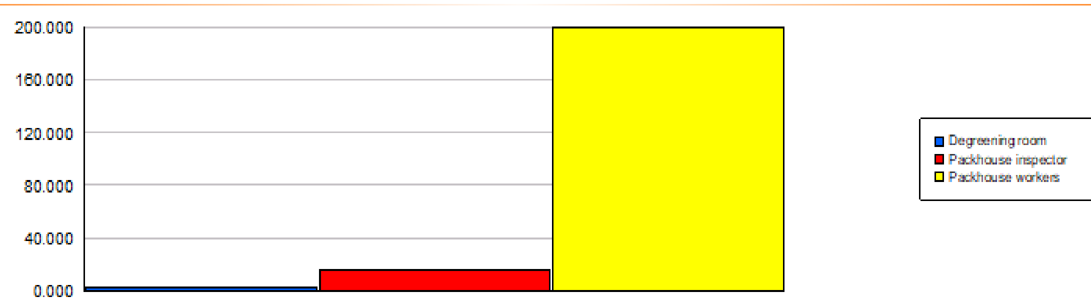
Count	Average	Half Width	Minimum Average	Maximum Average
Counter Class 1 and 2	9.2900	0.37	4.0000	13.0000
Counter Class 3	3.2100	0.30	0.00	8.0000
Counter to juicing factory	0.7100	0.16	0.00	3.0000



Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Degreening room	2.5500	0.22	0.00	3.0000
Packhouse inspector	15.4900	0.10	15.0000	16.0000
Packhouse workers	200.00	4.49	112.00	240.00



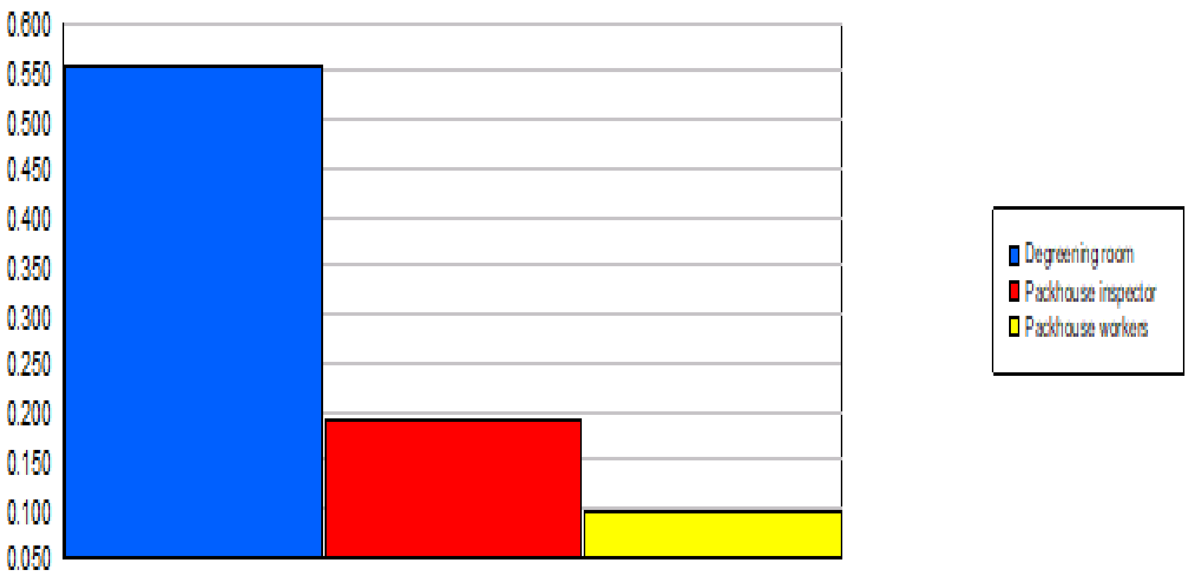
Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Degreening room	0.5544	0.07	0.00	0.9905	0.00	1.0000
Packhouse inspector	0.1913	0.00	0.1757	0.2105	0.00	1.0000
Packhouse workers	0.1187	0.01	0.05895390	0.1942	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Degreening room	1.6631	0.21	0.00	2.9714	0.00	3.0000
Packhouse inspector	0.1913	0.00	0.1757	0.2105	0.00	1.0000
Packhouse workers	8.6373	0.22	5.8383	11.0540	0.00	32.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Degreening room	3.0000	0.00	3.0000	3.0000	3.0000	3.0000
Packhouse inspector	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
Packhouse workers	90.0000	0.00	90.0000	90.0000	0.00	100.00

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Degreening room	0.5544	0.07	0.00	0.9905
Packhouse inspector	0.1913	0.00	0.1757	0.2105
Packhouse workers	0.0960	0.00	0.06487025	0.1228



Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Degreening.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Inspection.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Packing class 1 and 2.Queue	1.6054	0.23	0.00	4.5445	0.00	27.2669
Packing class 3.Queue	1.3110	0.69	0.00	27.2065	0.00	27.2065

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Degreening.Queue	0.3009	0.10	0.00	2.9260	0.00	7.0000
Inspection.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Packing class 1 and 2.Queue	0.02441645	0.00	0.00	0.05855938	0.00	1.0000
Packing class 3.Queue	0.00658249	0.00	0.00	0.05840035	0.00	1.0000

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Orange	31.1075	0.34	26.1701	34.0848	5.4030	38.8119

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Orange	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Orange	3.3082	0.27	0.2268	8.7820	0.00	30.0000

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Orange	25.0483	0.12	23.7106	26.6735	20.4175	29.9475

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Orange	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Orange	59.4641	0.50	52.8655	66.1945	27.5353	94.5351

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Orange	15.4900	0.10	15.0000	16.0000

Number Out	Average	Half Width	Minimum Average	Maximum Average
Orange	12.5600	0.23	7.0000	14.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Orange	2.1800	0.13	1.3164	4.7091	0.00	9.0000