Allocating commodity volumes in the citrus export cold chain: A case for the Port of Durban

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Declaration

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Abstract

In this study, the feasibility of using "forced" allocation as a mechanism to aide in alleviating capacity challenges at the Port of Durban is explored and insights on the impact of reallocation to the citrus export cold chain is provided. The use of the mechanism is explored by limiting the allowable citrus throughput that may be handled at the Port of Durban for varying throughput scenarios, and using allocation techniques to allocate the allowable citrus throughput amongst the competing production regions. An allocation model framework is formulated to optimally allocate the total citrus export volumes in a season to each of the South African ports that export citrus, taking into account the allowable port throughput constraint at the Port of Durban. The allocation model framework is modelled as a minimum cost transport problem and is solved using linear programming.

The results of the 2019 actual export season for citrus exports is compared to the results of the 2019 forecasted export season to determine if there is a single suitable allocation technique that can be used to allocate the allowable port throughput to the production regions in the allocation model framework for future export seasons. The results show that there is no single suitable allocation technique, and so allocations on forecasted citrus export volumes must be done on a case-by-case basis. A possible export plan for the 2021 forecasted export season is calculated using the allocation model framework for each scenario to provide a baseline export plan for the different allowable throughput scenario's at the Port of Durban. The forecasted citrus export volumes are forecasted using a four period double moving average forecasting model.

The feasibility of using "forced" allocation as mechanism to alleviate capacity challenges faced at the Port of Durban is assessed on two criteria, namely the availability of theoretical excess capacity at the alternate ports to handle the citrus volumes reallocated and the change in total transport cost to the citrus export cold chain. The assessment of the criteria, and the analysis of the results, indicate that the use of "forced" allocation is feasible in the majority of, but not in all of the port throughput scenarios. Even though it is feasible in terms of the available capacity, there is, however, an increased transport cost to the citrus export cold chain in the majority of the scenario's analysed. This additional transport cost must be weighed up against the cost of congestion and lost time, and will have to be absorbed by the citrus export cold chain. Even though there is an increase in transport cost, which can affect the total citrus export cold chain by as much as +35.2% (in the worst case scenario), the mechanism is deemed feasible as the impact of the increased transport cost is a relative measure that will have a varying impact amongst the different stakeholders of the citrus export cold chain and so each stakeholder will have to decide independently if it is feasible to them.

The study achieved its primary aim of alleviating capacity pressures at the Port of Durban by reallocating citrus volumes to all South African ports that can handle citrus under different levels of available capacity at the Port of Durban. Therefore, "forced" allocation is deemed a good alternative solution to the current congested situation.

Keywords: Allocation models; citrus exports; port capacity; Port of Durban

Opsomming

Hierdie studie ondersoek die lewensvatbaarheid van "geforseerde" toewysing as 'n meganisme om te help met die verligting van kapasiteitsuitdagings by Durban-hawe. Verder word insigte oor die impak van hertoewysing op die sitrusuitvoer-koue-ketting verskaf. Die gebruik van hierdie meganisme word ondersoek deur die toelaatbare sitrusdeurvoer wat by Durban-hawe hanteer kan word vir verskillende deurvoerscenario's te beperk, en gebruik te maak van toekenningstegnieke om die toelaatbare sitrusdeurvoer aan die mededingende produksiestreke toe te wys. 'n Toekenningsmodelraamwerk word geformuleer om die totale sitrusuitvoervolumes in 'n seisoen optimaal aan elk van die Suid-Afrikaanse sitrus hawens toe te wys, met inagneming van die toelaatbare hawedeurvoerbeperking by Durban-hawe. Die toekenningsmodelraamwerk is gemodelleer as 'n minimum koste vervoerprobleem en word deur die gebruik van liniêre programmering opgelos.

Die resultate van die 2019 werklike uitvoerseisoen vir sitrusuitvoere word vergelyk met die resultate van die 2019 voorspelde uitvoerseisoen om te bepaal of daar 'n enkele geskikte toekenningstegniek is wat gebruik kan word om die toelaatbare hawedeurvoer aan die produksiestreke in die toekenningsmodelraamwerk vir toekomstige uitvoerseisoene toe te wys. Die resultate toon dat daar geen enkele geskikte toekenningstegniek is nie, dus moet toekennings op vooruitgeskatte sitrusuitvoervolumes op 'n geval-tot-geval grondslag gedoen word. 'n Moontlike uitvoerplan vir die 2021 vooruitgeskatte uitvoerseisoen word bereken deur gebruik te maak van die toekenningsmodelraamwerk vir elke scenario om 'n basislyn-uitvoerplan vir die verskillende toelaatbare deurvoerscenario's by Durban-hawe te verskaf. Die sitrusuitvoervolumes word voorspel deur 'n vier-tydperk-dubbelbewegende-gemiddelde-vooruitskattingsmodel.

Die haalbaarheid van die gebruik van "geforseerde" toewysing as meganisme om kapasiteitsuitdagings wat Durban-hawe in die gesig staar te verlig, word op twee kriteria geassesseer, naamlik: die beskikbaarheid van teoretiese oortollige kapasiteit by die alternatiewe hawens om die sitrusvolumes te hanteer, en die verandering in totale vervoerkoste aan die sitrusuitvoer-koue-ketting. Die assessering van die kriteria, en die ontleding van die resultate, dui daarop dat die gebruik van "geforseerde" toekenning haalbaar is in die meerderheid, maar nie in al die hawe deurvoerscenario's nie. Alhoewel dit haalbaar is in terme van die beskikbare kapasiteit, is daar egter 'n verhoogde vervoerkoste vir die sitrusuitvoer-koue-ketting in die meerderheid van die scenario's wat ontleed is. Hierdie addisionele vervoerkoste moet opgeweeg word teen die koste van opeenhoping, asook verlore tyd, en sal deur die sitrusuitvoer-koue-ketting geabsorbeer moet word. Selfs al is daar 'n verhoging in vervoerkoste wat die totale sitrusuitvoer-koue-ketting met soveel as +35.2% (in die slegste geval scenario) kan verhoog, word die meganisme as haalbaar geag aangesien die impak van die verhoogde vervoerkoste 'n relatiewe maatstaf is wat 'n wisselende impak op die verskillende belanghebbendes van die sitrusuitvoer-koue-ketting sal hê, dus sal elke belanghebbende onafhanklik moet besluit of dit lewensvatbaar vir hulle sal wees.

Die studie het geslaag in sy primêre doel, naamlik die verligting van kapasiteitsdruk by Durban-hawe, deur die hertoewysing van sitrus volumes aan al die sitrus hawens, onder verskillende vlakke van kapasiteit beskikbaarheid by Durban-hawe. Gevolglik word "geforseerde" toewysing as 'n goeie alternatiewe oplossing vir die huidige oorlaaide situasie beskou.

Sleutelwoorde: Durban-hawe; hawekapasiteit; sitrus uitvoere; toekenningsmodelle

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List of Acronyms

CBS Citrus Black Spot
CEO Chief Executive Officer
CGA Citrus Growers' Association of Southern Africa
CGA KIS Citrus Growers' Association of Southern Africa Key Industry Statistics
GDP Gross Domestic Product
LP Linear Programming
MSE Mean Square Error
NF1 Naive Forecast 1
TEU Twenty Foot Equivalent Unit
US$ United States Dollar
ZAR South African Rands

CHAPTER 1

Introduction

"Logistics efficiency and market access will determine the growth prospects of citrus exports going forward."
- Justin Chadwick 2018, *CEO of the Citrus Growers' Association of Southern Africa* [112]

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1.1 Introduction

The South African fresh fruit export cold chain is constructed out of multiple complex components that work in harmony to deliver a final product that meets all regulatory and quality requirements, and specifications in both the exporting and importing country. Currently, fresh fruit exports account for approximately 35% of all agricultural exports from South Africa [45], with approximately 90% of all fresh fruit production being destined for the export market [89], and has an estimated value of R26 billion [46]. The biggest contributors of these fruit volumes in the 2019 export season were citrus, pome fruit and table grapes, which accounted for approximately 95% of the fresh fruit exported [45].

The fresh fruit export industry is a significant role player and contributor to the wider agricultural industry. Although agriculture, and thus fresh fruit exports are relatively small in relation to the South African GDP, their indirect role and impact on the economy is more significant as it is a major generator of foreign-exchange and a significant employment provider, especially in rural South Africa [34]. In the current South African economic climate these two factors alone make it imperative that the fresh produce export industry, and its related components and processes, be continuously improved to optimise efficiencies and stay competitive in the global export market.

1.2 Background

The disproportionate growth in fresh produce commodity exports in relation to the growth in available capacity and infrastructure has placed tremendous strain on the operations and efficiency of the fresh produce export cold chain. This strain on the cold chain is present throughout the year. However, it has a greater presence during the winter months (May to August) as two of South Africa's major commodities, namely citrus and maize, are both exported during this period, with over 50% of the citrus export volumes being exported through the Port of Durban. The total citrus volumes exported from 2008-2019 are shown in Figure 1.1, which shows a general trend of growth over the years. Figure 1.2 shows the citrus export contribution over the years for each port. The graph shows that the Port of Durban handles over 50% of the citrus exports from South Africa. Figure 1.3 shows the distribution of total citrus exports through the Port of Durban and other South African ports across the shipping weeks for the 2019 export season starting in January. The peak periods in the graph correspond to the winter months in South Africa. As a result of these increased volumes, over the years and during the winter period, there has been a noticeable rise in congestion, especially around the Port of Durban, and bottlenecks in the export cold chain.

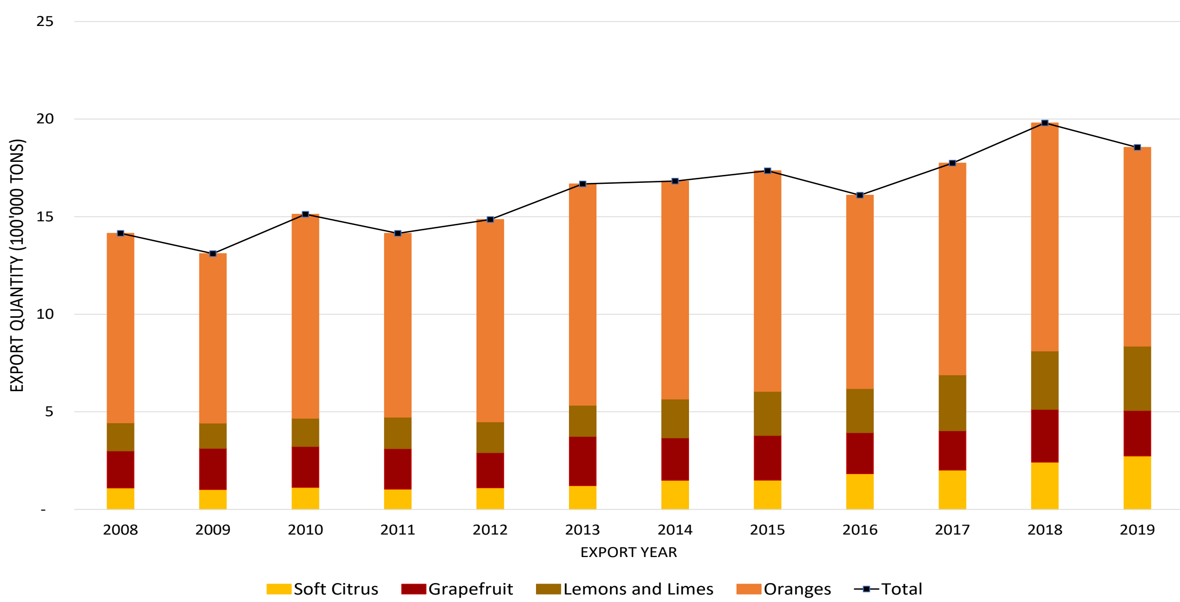

FIGURE 1.1: *Tons of citrus exported from South Africa per citrus type for the period 2008-2019. Adapted from [24, 26, 27]*

Citrus exports in South Africa are transported via two modes, namely reefer containers and break-bulk in specialised reefer vessels. Capacity analysis for all commodity imports and exports at the Eastern Ports (Port of Durban and Port of Richards Bay) show that there is a projected shortage of container capacity for the period 2018-2022 during the berth deepening project at the Durban Container Terminal [105], as seen in Figure 1.4. Even if the Port of Richards Bay utilises 100% of its container capacity of 0.5m TEU's (twenty foot equivalent unit) per annum, there will still be a shortage of container capacity at the Port of Durban during this period, as seen in Figure 1.5. Break-bulk, however, has a capacity surplus as seen in Figure 1.6. Historical

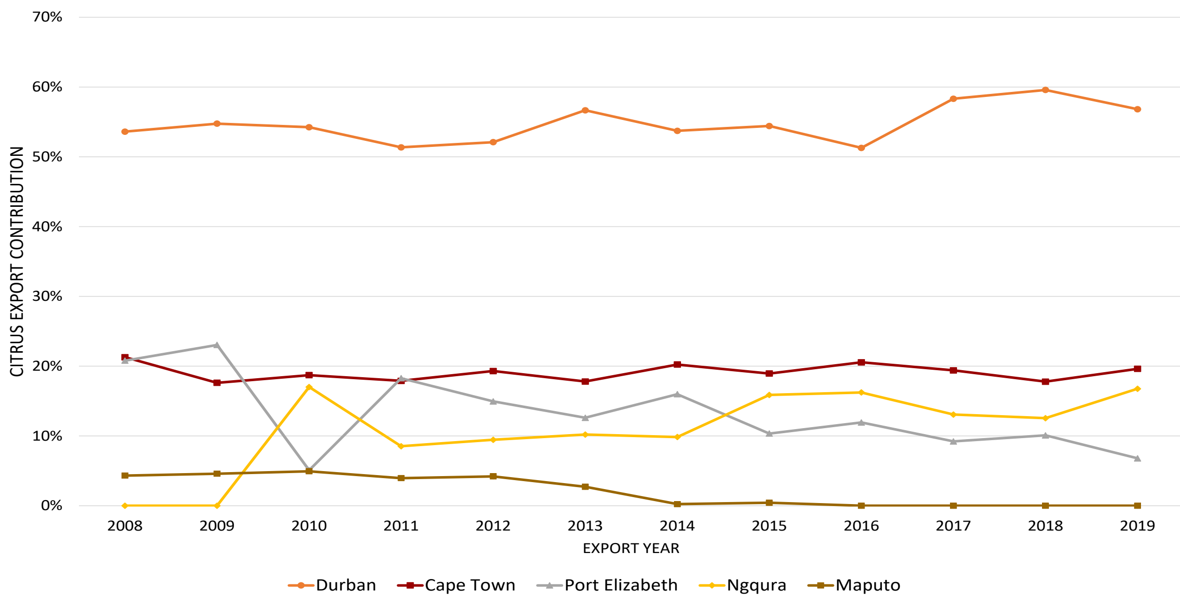

Figure 1.2: *Port contributions of citrus exports for the period 2008-2019. Adapted from [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27]*

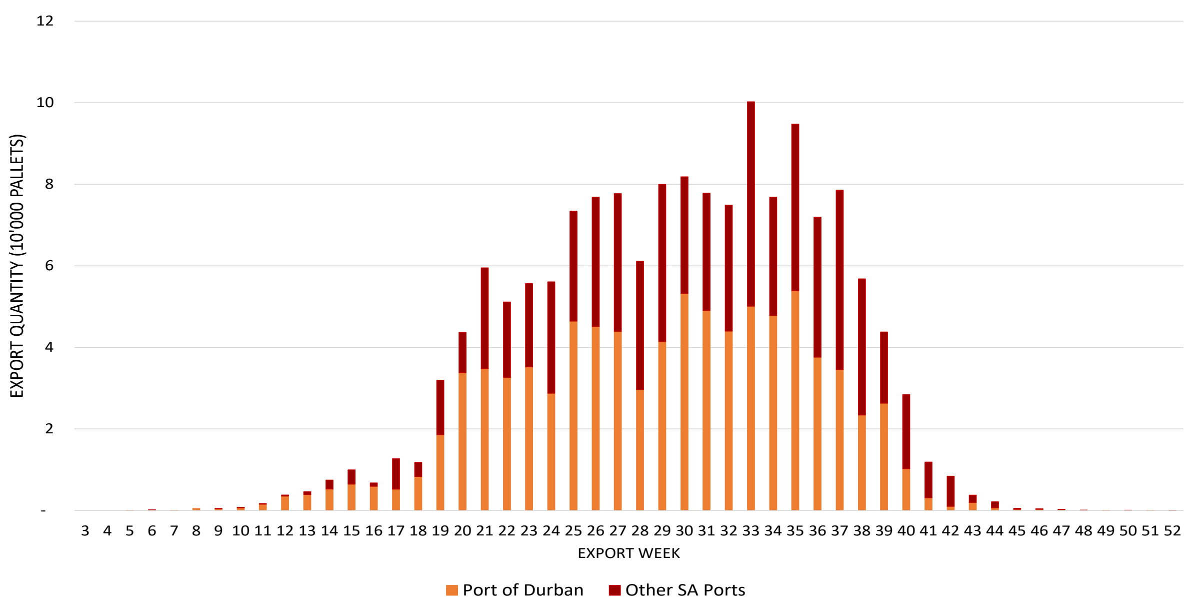

Figure 1.3: *Weekly pallets exported from the Port of Durban and other SA ports for all citrus types in the 2019 export season. Extracted from data supplied by Company X*

analysis of the citrus pallet volumes transported via break-bulk versus reefer containers shows that the use of break-bulk is reducing each year whilst the use of reefer containers is increasing as seen in Figure 1.7. This raises a concern as the demand for container capacity at the Port of Durban is expected to increase each year if the volume of citrus exported through the Port of Durban keeps increasing, unless importing countries adjust regulations and allow more citrus to be exported as break-bulk in specialised reefer vessels. This increase in container demand, however, cannot be absorbed by the break-bulk industry by forcing exporters to use this mode, as more shipping lines are starting to invest more in vessels that ship reefer containers, which is reducing the supply of specialised reefer vessel capacity in the market [49, 115]. These factors are placing pressure on a system that already has a shortage of available container capacity. This may potentially cause an unfavourable impact in the citrus export cold chain, such as additional congestion and missed shipments.

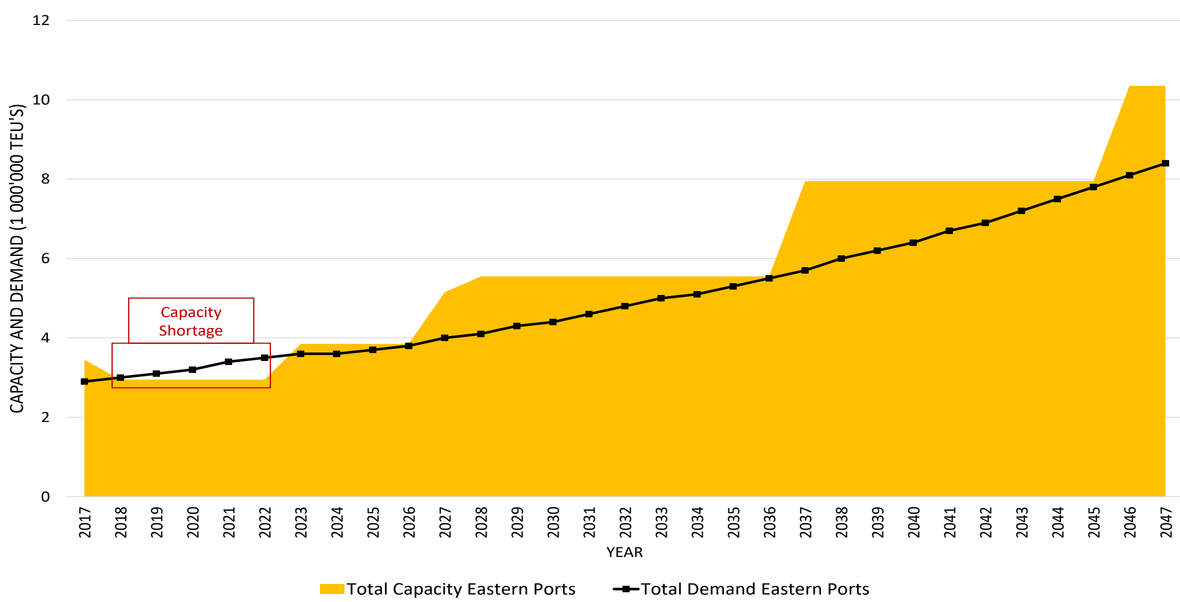

FIGURE 1.4: *Eastern Ports container demand and capacity analysis for imports and exports of all commodities. Adapted from [105]*

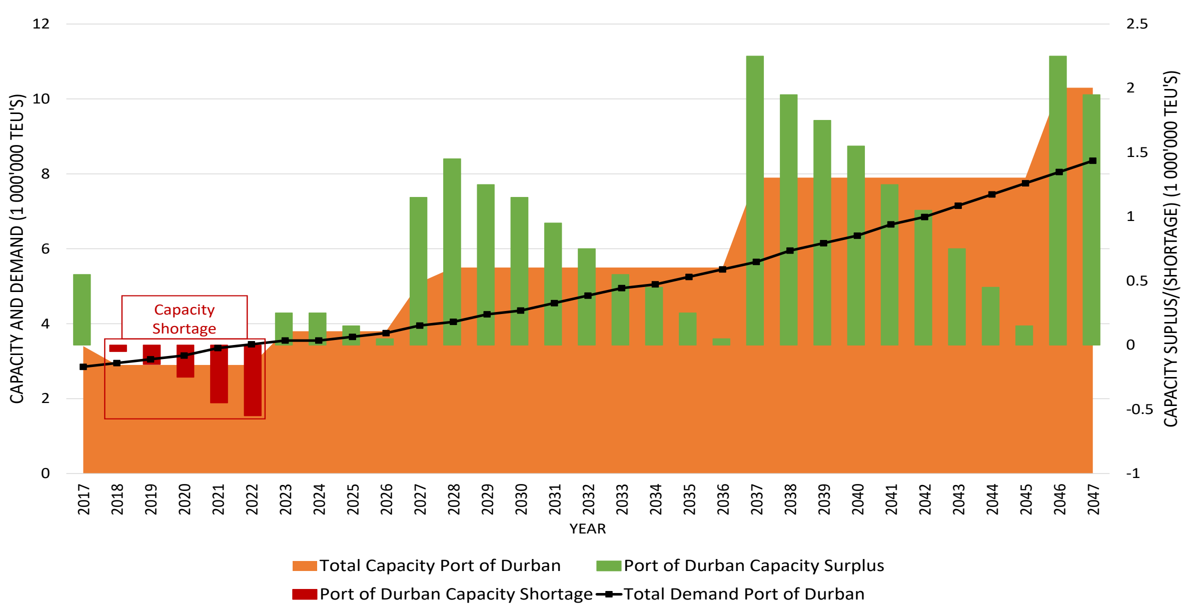

FIGURE 1.5: *Port of Durban container demand and capacity analysis for imports and exports for all commodities. Adapted from [105]*

Coupling this expected capacity shortage for containers at the Port of Durban, which is the mode that the majority of citrus is exported by (90% in 2018 and a projected 92% in 2019), the increasing demand for reefer containers for citrus exports and the increase in congestion, which causes longer waiting and turn-around times, results in a noticeable challenge for the citrus

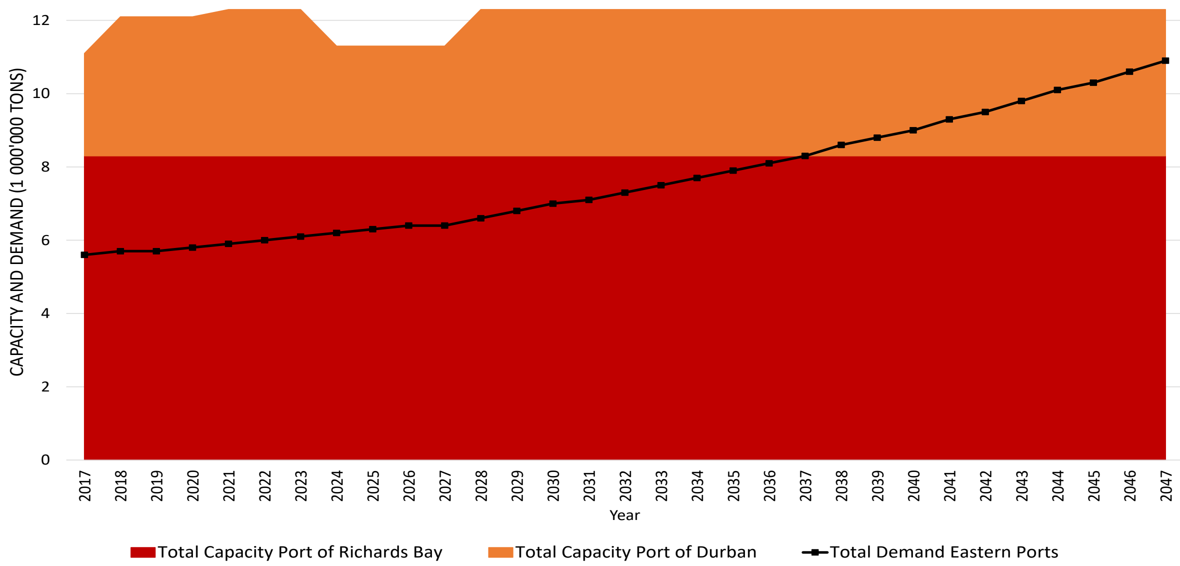

FIGURE 1.6: *Eastern Ports break-bulk demand and capacity analysis for imports and exports of all commodities. Adapted from [105]*

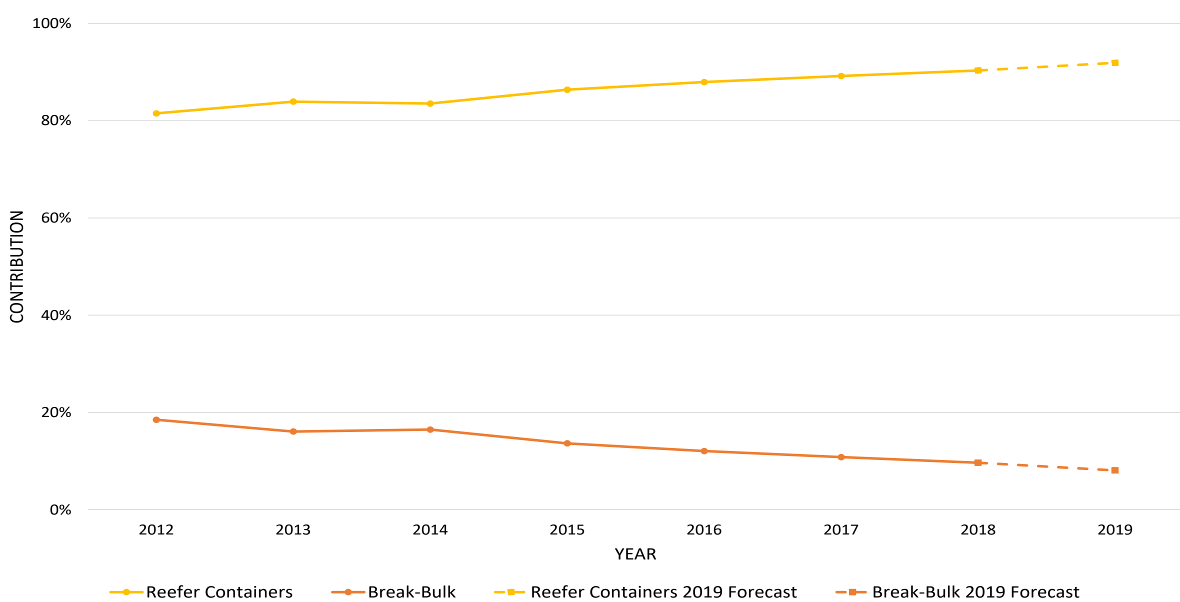

FIGURE 1.7: *Historical pallet contribution of citrus break-bulk and reefer container volumes. Adapted from [4, 5]*

export cold chain, especially during periods of high demand for capacity. Failure to intervene in finding a solution(s) to these challenges may lead to excessive strain being placed on the entire system, especially on critical export cold chain nodes, of which the Port of Durban is one. This will have major repercussions and an unfavourable impact on both the upstream and downstream stakeholders of not only the citrus export cold chain, but the fresh produce export cold chain as a whole.

Thus, there is an imminent need for solutions to be explored, which would ease the strain exerted on the citrus export cold chain system. Possible solutions may be explored on two of the key factors that are at play in the export cold chain process. The first, is infrastructure development, which includes available truck supply and port facilities. This factor is directly related to the supply of capacity. The second factor at play, is the actual commodity and its volume throughput. This is directly related to the demand for capacity. The demand in this instance refers to the capacity required to accommodate the citrus export volumes at each port at a specific point in time. Thus, there is potential for solutions to be explored in dealing with the supply of capacity and/or the demand for capacity.

The option of infrastructure development is not favourable due to the fact that the challenges previously mentioned are already placing strain on the existing system. Unfavourable economic conditions in South Africa and the long time frames associated with infrastructure development projects may result in a costly investment that may take years before both the increased capacity is made available to accommodate the demand, and a return on the investment is realised. Secondly, a variety of infrastructure development projects are already in the pipeline, however, their commission dates are not in the near term and so there is a need for a solution to be explored that has a significantly shorter time frame to address the capacity issues. Lastly, infrastructure development is not only unique to the citrus export cold chain, but rather impacts the fresh produce cold chain and greater export supply chain.

1.3 Motivation

Citrus exports represented approximately 60% of total fresh fruit exported in 2019 and fresh fruits account for 35% of agricultural exports, which equates to nearly 21% of total agricultural exports being citrus exports, with the Port of Durban handling more than half of the total annual citrus exports each season. These two elements, thus play an important role in the agricultural industry and economy as a whole. Therefore, citrus exports, and more specifically those through the Port of Durban, have a significant role to play in improving and maintaining the competitiveness and growth of the South African fresh fruit export market.

According to Justin Chadwick, the Chief Executive Officer of the Citrus Growers' Association, the efficiency of the logistics infrastructure in the citrus export cold chain will be a determining factor for citrus export growth and remaining competitive in the global citrus export market [112]. Citrus export volumes over the years have shown a continued trend of growth, with the volume handled at the Port of Durban showing the same trend, thus stressing the importance of ensuring that the export process for citrus is relieved of any inefficiencies, especially at the Port of Durban.

The research provides insights into how reallocations of citrus volumes impact the citrus cold chain, which would allow exporters an opportunity to take this information into consideration when drawing up export plans should a shortage of capacity be anticipated at the Port of Durban before the export season commences. This would allow the exporters to make the necessary provision and plans before exporting, thus allowing them to remain competitive in the global market as they pro-actively manage the constraints. The research will also provide insights into whether "forced" allocation is a feasible mechanism to address the capacity challenges at the Port of Durban.

1.4 Problem Statement

It is proposed that an alternate solution to infrastructure development be explored that will aide in alleviating congestion and pressure on the citrus export cold chain at the Port of Durban. One potential mechanism is the use of "forced" allocation to optimally assign citrus export volume to South African ports that export citrus, especially during peak periods. With "forced" allocation, citrus producing regions will be forced to export citrus volumes through an alternative port instead of the Port of Durban as their allowable citrus export throughput at the Port of Durban will be limited. This mechanism, will however, change the dynamics of the commodity flows through the South African citrus export cold chain and the costs incurred by the relevant stakeholders. These changes require investigation to understand what the changes will be, if the use of "forced" allocation is a feasible alternative and how it should be implemented.

The research addresses the gap in the citrus industry of how citrus volumes should be reallocated to non-preferred ports should their preferred export port (Port of Durban) have a capacity shortage. The research also identifies what the incremental transport cost would be to the citrus export cold chain at the various citrus throughput reallocation levels and if the volumes reallocated can be handled at the alternative ports.

1.5 Research Aim, Objectives and Questions

The prominence of citrus exports in the winter months, when heavy congestion is experienced and there is the greatest demand for capacity at the Port of Durban, led to this study. The study utilises a case study approach and focuses on the citrus volumes moving through the Port of Durban.

The research investigates scenarios in the citrus export cold chain whereby throughput at the Port of Durban is limited to a certain percentage of total citrus export volumes from all production regions. The surplus throughput is then moved from the Port of Durban to an alternative port for export. The aim of the study is to explore a mechanism to optimally allocate the citrus export volumes in the citrus export cold chain to the respective ports taking into account the limit on the allowable citrus throughput that the Port of Durban may handle, as well as understand the impact on the citrus export cold chain as a result of allocating the volume to alternative ports.

Apart from the land transport cost implications, the following indirect benefits may also be realised, which are not investigated in the study:

1. Potential congestion cost reductions.
2. Potential reduction in commodity wastage/lost income resulting from missed shipping.
3. Improved port utilisation and efficiencies.
4. Risk mitigation as the citrus throughput handled is spread more across the ports, instead of being concentrated at the Port of Durban.

The following set of objectives assisted in achieving the aim of the study:

1. Understand the situation of the citrus export cold chain in South Africa, both currently and the projected future. This includes analysing, amongst others, the:

- Seasonal citrus export volumes.
- Port citrus throughput and capacity.
- Contribution of citrus relative to other exports.

2. Develop a model that executes the allocations of citrus, taking into account the various variables and constraints, and calculates the cost of the "to-be" situation.

3. Analyse the results of the allocations to understand the impact on throughput at other ports and in the export cold chain as a result of using "forced" allocation, the change in the citrus export distribution profile, and what the incremental cost is to the system.

The following set of research questions are answered to achieve the aim of the study:

1. What is the contribution of each South African port in terms of citrus exports?
2. What is the breakdown of citrus exports from the CGA production regions?
3. What flow network is currently being used for the citrus exports?
4. Does additional capacity exist at the other South African ports? What is the size of this available capacity?
5. What allocation techniques are available for executing allocations?
6. What constraints and parameters need to be considered in the model developed to execute the allocations?
7. Does transport cost increase as a result of the allocations and by how much?
8. Does the flow network change to what is currently being used as a result of using the allocation model?

Table 1.1 provides a breakdown of where each of the objectives are addressed in the study.

Objective Number	Objective	Research Questions	Addressed in Chapter
1	Understand the situation of the citrus export cold chain in South Africa.	One, Two, Three and Four	Two, Four and Five
2	Develop a model that executes the allocations of citrus.	Five and Six	Four
3	Analyse the results of the allocations to understand the impact.	Seven and Eight	Five and Six

TABLE 1.1: *Breakdown of where each research objective is addressed and where each research question is answered in the study*

1.6 Research Scope and Assumptions

The study only focuses on the citrus export cold chain and places specific emphasis on reducing the citrus throughput assigned to the Port of Durban. The study only analyses that portion of the citrus export cold chain between the farm gate and the port gate. The 2019 citrus export season was used as the base year in the study to develop and refine the models, and a forecast was executed to provide possible allocation plans for the 2021 export year based on the different scenario's of allowable port throughput at the Port of Durban, which represent instances of projected capacity shortages.

The following set of assumptions were used during the research:

- Break-bulk (conventional) and reefer (container) volumes were aggregated and seen as reefer volumes.
- There are no holding points between the farm gate and the port gate.
- Only South African ports equipped to handle citrus are considered.
- It is assumed that a ship is available at the port to accommodate the volumes required for export.
- Citrus moving through South Africa is split into three corridors, namely the Northern Corridor, the Central Corridor and the Southern Corridor. Table 1.2 shows the production regions included in each corridor and its preferred export port. The numbering of the regions corresponds to the numbering used in this study to model the problem. Figure 1.8 shows a map of the production regions and is categorised based on their respective corridor. Those highlighted in orange are in the Northern Corridor, those in grey are in the Central Corridor and those in maroon are part of the Southern Corridor.
- Export volumes used are the volumes that were passed for export, no rejections are taken into account.
- The supply of vehicles to transport citrus to the port is assumed to be sufficient and available.
- The Port of Port Elizabeth and the Port of Coega are combined and seen as one entity for the purpose of the study.
- Network costing used only includes the land road transport cost between a production region and the port.
- All Citrus Growers' Association of Southern Africa production regions are considered.

Corridor	Map Label (Figure 1.8)	Production Region	Preferred Port
Northern	1	Senwes	Durban
Northern	2	Letsitele	Durban
Northern	3	Hoedspruit	Durban
Northern	4	Nelspruit	Durban
Northern	5	Limpopo River	Durban
Northern	6	Onderberg	Durban
Northern	7	Nkwaleni	Durban
Northern	8	Southern KZN	Durban
Northern	9	Pongola	Durban
Northern	10	Burgersfort Ohrigstad	Durban
Northern	20	Swaziland	Durban
Northern	21	Zimbabwe	Durban
Central	11	Eastern Cape Midlands	Port Elizabeth and Coega
Central	12	Patensie	Port Elizabeth and Coega
Central	13	Sundays River Valley	Port Elizabeth and Coega
Southern	14	Western Cape	Cape Town
Southern	15	Boland	Cape Town
Southern	16	Orange River	Cape Town
Southern	17	Vaalharts	Cape Town

TABLE 1.2: *Production regions included in each citrus export corridor and the preferred export port [5]*

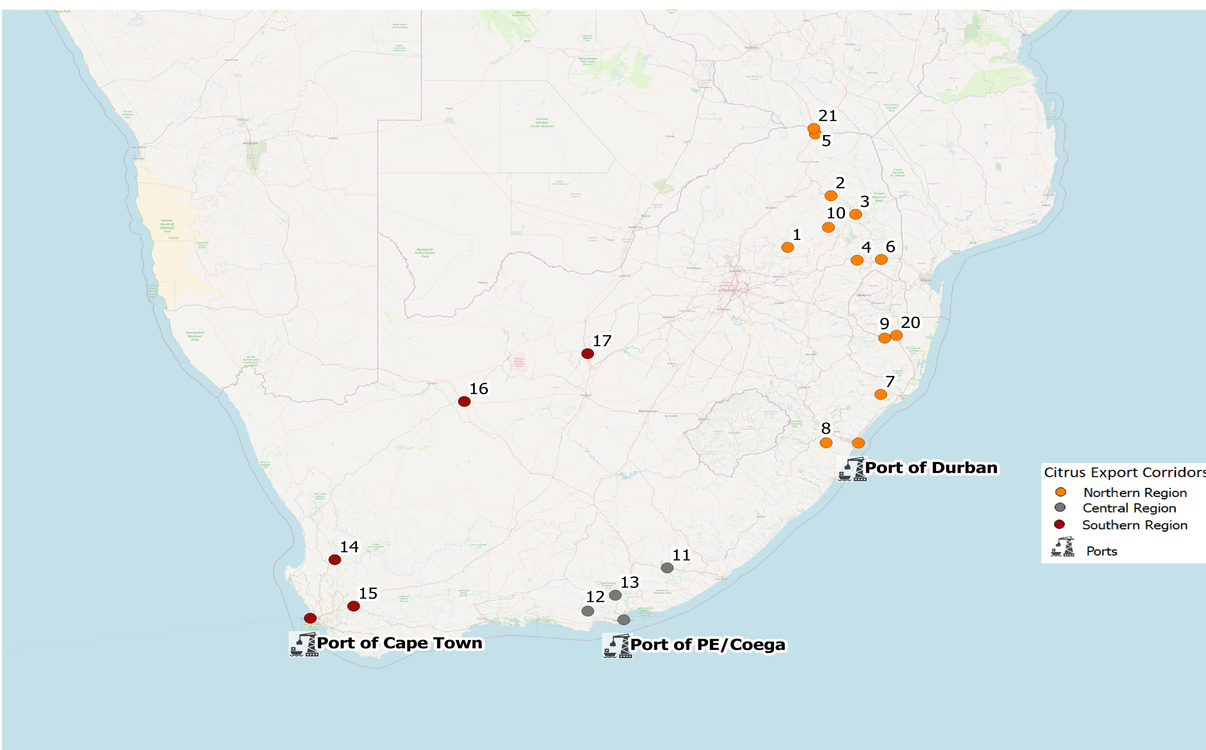

FIGURE 1.8: *Map of the CGA production regions categorised based on their respective corridor*

1.7 Project Outline

The remainder of the study is structured as follows:

- **Chapter 2: Literature Review: Citrus Export Industry**
  Chapter 2 provides an introduction and background to the citrus export industry in South Africa. It gives an overview of South African fruit exports, citrus pests and diseases, and discusses the South African citrus export market in a global context.

- **Chapter 3: Literature Review: Mathematical Models**
  Potential mathematical models and techniques that may be used in the research are reviewed along with previous applications of such techniques and models.

- **Chapter 4: Methodology**
  This chapter discusses the methodology followed in the research and flow of the research. An analysis of the data requirements for the model is provided.

- **Chapter 5: Results**
  Chapter 5 shows how the allocation framework model is applied and how the results are analysed and interpreted.

- **Chapter 6: Conclusion**
  Chapter 6 wraps up the study and brings all the components together. A final synopsis of the findings is given along with recommendations on future research.

CHAPTER 2

Literature Review: Citrus Export Industry

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2.1 Introduction

The following chapter reflects on the literature supporting the study from a supply chain and fruit industry perspective. Various different studies and techniques are covered from which arguments, assumptions and conclusions are drawn to be used in the study. This component of the literature review focuses on supply chain management, different types of supply chains and the fresh produce industry, with a specific focus on the citrus export industry. In addition, the chapter provides a brief overview of the role of industry organisations, international best practices and previous fruit export studies.

2.2 Supply Chain Management

A supply chain can be described as an integrated and connected network of organisations, processes and business functions that encompasses both upstream and downstream stakeholders from source to sink [13, 75, 82]. Supply chain management can be described as planning, coordinating and controlling the flow of resources, products, information, finances and services through the supply chain to deliver a final product to the end user [30, 31, 91].

2.2.1 Ambient and Cold Supply Chains

Ambient and cold supply chains exist as a result of product shelf-life and their sensitivity to temperature. Cold supply chains (cold chains) are temperature controlled supply chains and are commonly used to transport chilled and frozen products [82, 83]. Ambient can be defined as "of the surrounding area or environment" [108]. Thus, ambient supply chains are not necessarily temperature controlled and products are usually transported at the temperature of their surrounding environment.

2.2.2 Export and Import Supply chains

Exports and imports are both functions of international trade between countries and work in tandem with each other. Exporting is the shipping of goods out of the country for sale or use in another country and importing is the shipping of goods into a country [97]. Exporting is usually done to increase the global footprint and market-share of a company or when there is surplus in the domestic market. Importing is usually done to meet the demand for products when there is a shortage in the domestic market [101]. Therefore, the export supply chain deals with the processes of exporting a product out of a country and the import supply chain encompasses those processes involved in bringing a product into a country from another country.

The above terms are important as they help define the citrus export cold chain. During the movement of citrus around South Africa, the commodity must be handled by multiple stakeholders and is influenced by a variety of factors and so a supply chain is formed. Citrus is a perishable product and so must be transported in a controlled temperature environment to prolong the shelf life of the product. Hence, the supply chain for citrus is reclassified as a cold chain. Because the product is leaving South Africa it is considered an export, and so the cold chain is classified as an export cold chain. This definition is used as a basis to analyse more focused literature relevant to the citrus export cold chain.

2.3 Fruit Exports in South Africa

Citrus exports are one of many components of the fruit export cold chain in South Africa. As such, to understand the role of the citrus export cold chain in South Africa, a general overview of the South African fruit export cold chain must be known. Thus, literature is studied on both the general fruit export cold chain, and the citrus export cold chain to understand the roles of each, and their relationship with each other.

2.3.1 Overview of the South African Fruit Export Industry

Due to its climate and topography, South Africa has the ability to produce a wide variety of fruits [90] with production levels that exceed what can be consumed in the domestic market [53]. This surplus fruit is produced specifically for the export market because of the demand for it in the Northern Hemisphere in the "opposite season" when the Northern Hemisphere is unable to produce the fruit, and because of the high quality of the fruit produced in South Africa [53, 123]. Thus, the ability to compete in the export market is critical to the sustainability of the South African fresh fruit industry [123]. South African fresh fruit exports are a major contributor to the South African agricultural sector when one considers that fresh fruit exports are approximately 35% of all agricultural exports in South Africa [45]. Citrus fruit was the biggest driver of total fruit exported from South Africa in the 2019 export season with a contribution of 60% of fruit exports or 21% of agricultural exports, followed by pome fruit (21%) and table grapes (14%), with stone, subtropical and exotic fruit bringing up the rear with a 5% contribution in totality [45]. In terms of global trade, South Africa is the biggest exporter of fresh fruit by volume in the Southern Hemisphere [44].

The fruit produced in South Africa, for the export market, is divided into four categories; namely, citrus, deciduous, subtropical and exotic fruit [44, 90]. Deciduous fruit encompasses pome and stone fruit, as well as table grapes [53]. Pome fruit includes apples and pears [35], and stone fruit or drupes include peaches, plums, apricots, and nectarines [53]. The citrus fruit category is made up of oranges, lemons and limes, grapefruit and easy-peelers or soft citrus [46]. Litchi's, avocados, mangoes, pineapples and passion fruit make up the sub-tropical category [44]. Exotic fruit comprises of strawberries, blueberries, raspberries, melons, figs and pomegranates [44]. Fruit destined for the export market is produced throughout South Africa as seen in Figure 2.1, which shows the distribution of fruit regions in South Africa [46].

Fruit production for the export market is a continuous cycle with the entire production calendar encompassing a full year across all fruits, with certain fruit types being more prominent than others during specific periods [46, 123]. Figure 2.2 shows the export calendar for the different fruits exported from South Africa.

2.3.2 South African Citrus Industry

Citrus production in South Africa dates back to the early 1600's when the first trees were planted in the Cape region, with the first successful export of citrus happening in 1890 [109]. In 1940, the citrus industry was controlled and regulated by the government at the time, and was overseen by the Minister of Agriculture until 1997 when the industry was deregulated [109]. This deregulation resulted in increased competition as stakeholders did not have to market their product through the single statutory body 'Outspan'.

South Africa has 17 citrus growing regions located in seven provinces (Gauteng and the Free

FIGURE 2.1: *Fresh fruit production regions in South Africa [44]*

FIGURE 2.2: *South African fresh fruit export calendar [46]*

State do not produce citrus), which is expanded to 19 citrus producing regions under the representation of the Citrus Growers' Association of Southern Africa when Swaziland and Zimbabwe are included [26, 38, 41]. The list of CGA producing regions is found in Table 1.2. The production of citrus types across South Africa differs due to a variety of factors, with climate being the main driver. Citrus cannot tolerate severe frost and so production is confined to areas where temperatures rarely drop below 2°C and there is mild to frost-free winters. Sufficient water is also required for desirable growth and so suitable water sources are required to supplement the poorly distributed rainfall in South Africa [37]. The cooler climates of the Eastern and Western Cape allow for the production of Navel oranges, lemons and easy peelers such as satsuma's and clementines, with the remaining citrus producing provinces focusing mainly on the production of Valencia oranges, grapefruit and some soft citrus [38, 81].

Citrus exported from South Africa is comprised of oranges (Valencia and Navels [25]), lemons and limes, easy-peelers or soft citrus, and grapefruit [46]. The citrus season for exports runs predominantly from March to October [46], with the majority of the exports taking place during the winter months [44]. Citrus is produced throughout South Africa with the greatest production hectares for citrus in 2019 being found in Limpopo (41%), followed by the Eastern Cape (26%), Western Cape (18%) and Mpumulanga (8%), with the rest of the provinces making up the tail [27]. Valencia and navel oranges are the biggest volume contributors to total citrus exports with 35% of citrus exports being Valencia oranges and 20% Navel oranges in 2019. Lemons and limes (18%), soft citrus (15%) and grapefruit (12%) make up the remaining citrus volumes being exported in 2019 [27]. The year 2018 also saw record citrus export volumes out of South Africa, with approximately 137 million boxes exported out of South Africa, representing a growth figure of 0.7% on the previous year's exports [10].

Citrus is exported from South Africa through four South African ports, with Mozambique's Maputo port potentially being an additional port utilised from 2019 onwards for exporting citrus. The four South African ports are located in Durban, Cape Town, Ngqura and Port Elizabeth. The contribution of the volumes handled per port for the 2019 export season is shown in Table 2.1. These ports play an essential role in the cold chain as they are the link that allows the citrus growers in South Africa to access the international market and trade citrus, thus bringing in foreign-exchange, which is another important commodity to the South African economy.

Loading Port	**Contribution**
Durban	56.8%
Cape Town	19.6%
Ngqura (Coega)	16.8%
Port Elizabeth	6.8%

TABLE 2.1: *Citrus pallet throughput contribution for each Port in the 2019 export season. Adapted from [27]*

Citrus production in South Africa is destined for three markets, namely the export, local and processing market, with the export market being the biggest contributor due to the commercial value of the exports. Figure 2.3 shows the market split over the years for citrus production from 2008-2019. From this graph it is evident that the biggest market for citrus production is the export market, followed by the processed market with the local market having the smallest contribution over the years. Local market consumption has stayed relatively constant over the years. Export market volumes and processing market volumes have fluctuated with this fluctuation showing a relative relationship between the two.

The exported citrus, which was 65% of South Africa's 2019 production volumes, is destined for a multitude of countries with the major export destinations being Europe, the Middle East and Asia. The largest volume contribution stems from oranges [27]. South Africa is currently the second largest exporter of citrus in the world, with Spain being the largest exporter of citrus globally.

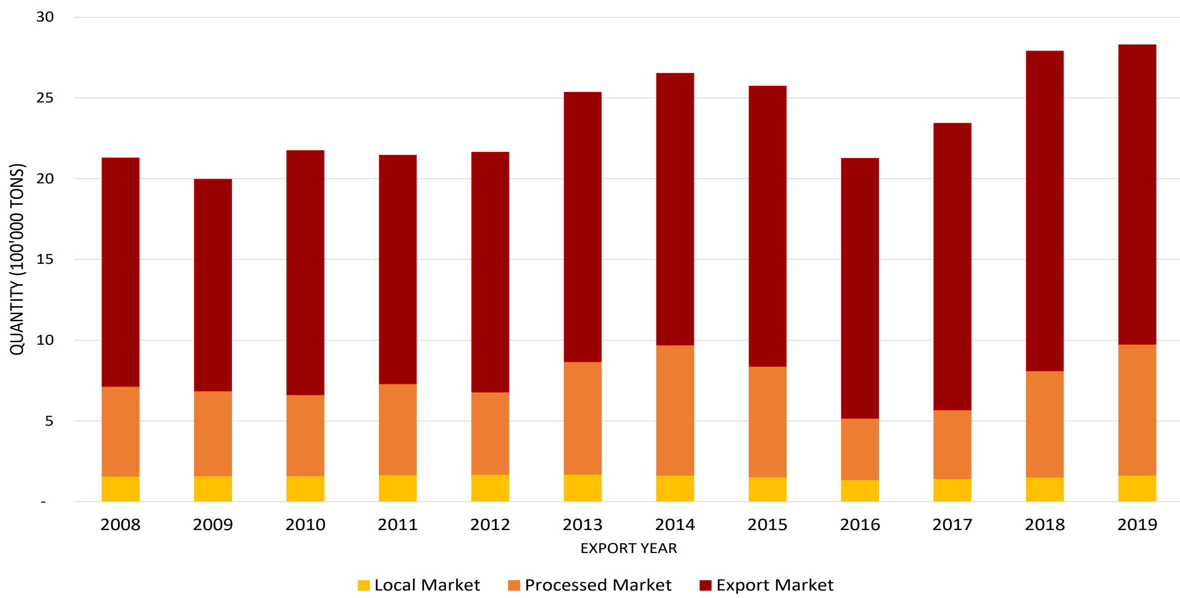

FIGURE 2.3: *Citrus production split by market for 2008-2019 in South Africa. Adapted from [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27]*

2.4 Citrus Pests and Diseases

South African citrus production is affected by a variety of pests and diseases. A pest is referred to as an insect or organism that can damage and cause illness to the plant [6, 62], and citrus diseases may either be fungal or bacterial infections that affect the plant and its fruit [62]. Poor management of pests and diseases has a commercial impact on citrus production. The fruit may become unsellable or may be of a lower quality, which affects the yield and value of the fruit. The exposure to certain export markets may also become limited if the fruit is infected with a phytosanitary pest [6].

There are three different categories of citrus pests, namely production, cosmetic and phytosanitary pests. Phystosanitary pests are the most common pests and are often referred to as international quarantine pests as export markets do not allow these pests into their countries due to the impact that they may cause on their local agricultural industry and economy.

Of the phytosanitary pests and diseases that South Africa is home to, the most important pests and diseases are citrus black spot, false codling moth, carob moth (only for Asia), mealybug and fruit fly, of which Mediterranean and Natal fruit fly are of the most significance due to their ability to disrupt production [6, 62].

2.4.1 Citrus Black Spot

Citrus black spot is a fungal pathogen that infects the leaves, twigs and fruit of citrus trees [9]. The disease is found in predominantly warm and wet or humid climates and is found on several continents, but is not known to occur in Europe, Central America or the Caribbean. Citrus black spot is known to occur in Kwa-Zulu Natal, Mpumalanga, Limpopo, North West and Eastern Cape provinces of South Africa, but is not known to be present in the Western Cape, Northern Cape and Free State provinces of South Africa [9]. All citrus except sour lemons, rough lemons and acid limes are susceptible to citrus black spot [62]. Infection of the citrus fruit by the pathogen causes lesions on the fruit, which reduces the appeal and quality of the fruit. Citrus black spot is a phytosanitary disease and its imports are regulated in several markets. Japan and India only allow the importation of fresh citrus that has no visible symptoms of citrus black spot [9]. For years the USA only allowed the importation of fresh citrus from CBS free areas, however, a proposed rule change by the USA Animal and Plant Health Inspection Service (APHIS) would allow citrus from CBS infected areas in South Africa to be imported into the USA [113]. The citrus will be imported under the condition that it is produced in accordance with a systems approach defined by APHIS [121], with exports expected to happen in the 2019 South African citrus export season [113]. Citrus black spot may cause premature fruit drop, loss in value due to a loss in fruit quality and higher production input costs resulting from the implementation of control programmes [62].

2.4.2 False Codling Moth

False codling moth is found across Southern Africa and is less problematic in the northern regions [78]. Fruit at all stages of development is susceptible to infestation by false codling moth. Adult false codling moths lay their eggs on the surface of the citrus fruit and immediately after hatching the larvae will penetrate the fruit. Infestation causes fruit drop and is also a gateway to secondary infestation by other pests and diseases [62]. All citrus is prone to infestation by false codling moth, however, Navel oranges are the most susceptible [78]. False codling moth is recognised as a phytosanitary pest in the European Union and must be treated thoroughly to ensure freedom of false codling moth before exportation [77]. Because false codling moth is an internal feeder, it is difficult to identify fruit that was infected shortly before harvest and so can be a source of post-harvest decay.

2.4.3 Fruit Fly

The Mediterranean and Natal fruit fly are the two most problematic fruit fly species to citrus due to their ability to cause export restrictions into certain countries and disrupt production. The Mediterranean fruit fly is one of the most invasive insects and has successfully spread and established itself in most parts of the world that have a sub-tropical environment [103]. Second to the Mediterranean fruit fly, is the Natal fruit fly, which also has significant invasive potential and thrives in cooler climates than the Mediterranean fruit fly [103]. Another fruit fly that has an impact on the export of citrus is the Oriental fruit fly. The Oriental fruit fly has established itself in the north of South Africa [77] and is found in Limpopo, Mpumalanga, North West, Gauteng and some parts of Kwa-Zulu Natal. Control measures implemented by the Department of Agriculture, Forestry and Fisheries do not allow the removal of host plants and its products from an area that is infested by the Oriental fruit fly to an area that is free from infestation without a removal permit [33]. Fruit flies affect the citrus by laying their eggs under the skin of mature citrus fruit. The larvae begin to feed on the fruit pulp after hatching, reducing it to an inedible mass [62].

2.4.4 Carob Moth

The carob moth is a minor pest in South Africa and is not a primary pest to citrus [77, 78]. It is, however, a phytosanitary pest to Asia and affects grapefruit more than other citrus. It is of significance as Asia is a large importer of South African grapefruit. The carob moth is commonly found where there is an infestation of mealybugs or if the citrus orchard is grown near a more preferred host such as pecans, acorns or pomegranates [78]. Carob moth damages the fruit by infesting the fruit with its larvae, which causes gumming of the fruit and the fruit to drop off the plant [78].

2.4.5 Mealybug

Mealybug is a pest that causes physical and cosmetic damage to citrus [77]. Mealybug may cause fruit drop or malformations on the fruit such as dents and lumpy shoulders, which may cause the fruit to become unsellable. The mealybug occurs sporadically in Southern Africa, but is regularly problematic in Kwa-Zulu Natal, Swaziland and the Eastern Cape. Certain export markets regard some species of mealybug to be a phytosanitary pest [79].

2.4.6 Steri-markets

Steri-markets have strict regulations and requirements for the importation of fruit into a country to ensure that pests and diseases from the exporting country are not brought into the importing country. Steri-markets require the exported fruit to be shipped at sub-zero temperatures, and for the fruit to have been kept at a target temperature for a specified period of time depending on the destination country, known as cold sterilisation treatment [62]. Different countries may also require the fruit to be pre-cooled for a specified period of time prior to shipment, and may require that either the target temperature is reached at the end of the pre-cooling period or the fruit is at target temperature for a set portion of the pre-cooling time. The cold sterilisation treatment can only begin when all the temperature sensors show that the target temperature or below has been reached [87]. The cold sterilisation treatment time commences once this target temperature has been reached and the vessel is loaded, with different importing countries requiring the target temperature to be maintained for a minimum number of days whilst in transit on the vessel. Certain parameters are set for which the temperature can fluctuate during cold sterilisation treatment to still be considered within steri-market protocols. If the temperature exceeds 0°, then it is in steri-breach and the treatment period is extended. If the temperature breaks 1.1°, then the cold treatment is nullified [62, 87]. Table 2.2 shows the time required for citrus to be pre-cooled per country and how long the citrus must be at the target temperature.

Country	Minimum Pre-Cooling Time	Minimum Time at Target Temperature before cold sterilisation commences	Minimum Days in Cold Sterilisation Treatment
USA	72 hours	Last 24 hours of pre-cooling	22 days
Japan, South Korea, China and Thailand	72 hours	No minimum	24 days, except Japan (12 days)
India, Indonesia, Taiwan, Sri Lanka, Jordan, Sudan and Mauritius*	No minimum	No minimum	12 days for India, 18 days for Indonesia and Taiwan, 22 days for Sri Lanka and Mauritius, 14 days for Jordan and 5 days for Sudan
Madagascar and Nigeria	Pre-cooling may not be required	No minimum	20 days for Madagascar and 14 days for Nigeria

*Citrus originating from an Oriental fruit fly infected area must undergo cold treatment

TABLE 2.2: *Summary of required pre-cooling time and time required at target temperature for steri-market countries importing citrus. Adapted from [86]*

2.5 South African Citrus Export Cold Chain

The citrus export process is a complex cold chain involving multiple stakeholders and processes that are influenced by both time and temperature [123], and can be described as the movement of citrus to a market from the production area using various transport and storage mediums, whilst maintaining the optimum fruit storage temperature and relative humidity [88]. The citrus export chain is a cold chain due to the fact that citrus is cooled to maintain the quality of the fruit. The cooling of the citrus slows down the ripening of the fruit to ensure it maintains its quality and also inhibit or reduce the rate of post-harvest diseases and pathogens developing [39]. Citrus fruit is more resilient to the cold as opposed to heat, therefore, once the citrus cold chain is initiated, the temperature must be maintained [62]. The temperature is maintained using a step-down approach whereby the temperature only decreases as the citrus moves along the cold chain [62]. This is done by either maintaining the current temperature or reducing it at a specific stage in the citrus export process. Not maintaining the temperature may result in a temperature break in the cold chain, which can have an impact on quality and food safety causing adverse downstream and upstream effects such as lower prices and income.

The citrus export cold chain can be divided into a set of sequential segments, which carry their own set of characteristics and requirements. The segments that form part of the citrus export cold chain from the orchard on the farm to the port of export are reviewed. Figure 2.4 shows the typical nodes or segments of the citrus export cold chain.

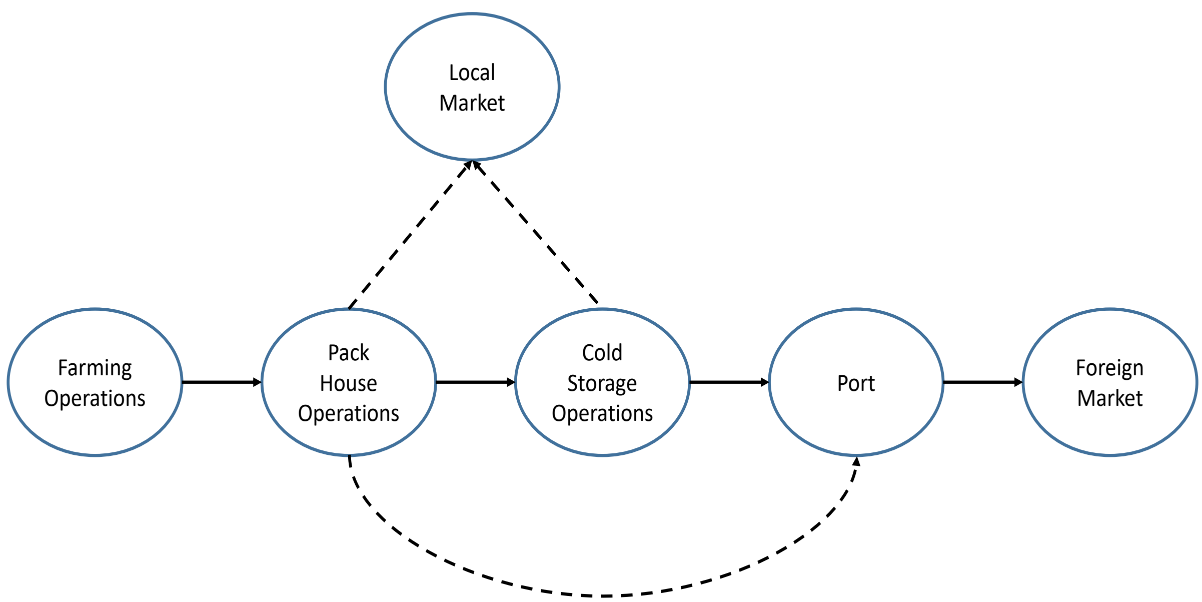

Figure 2.4: *Typical nodes in the citrus export cold chain*

2.5.1 Farming Operations

During farming operations, the citrus is picked from the orchard. Citrus harvesting takes into account the time of day, weather, market conditions (demand), expected yield and fruit quality

[62]. A harvest plan is usually drawn up to assist in harvesting by planning the volume of citrus that should be harvested and what sections of the orchard the citrus should be picked from. The citrus is harvested once it has reached its peak maturity, which is vital with citrus, as it does not ripen further once harvested. The maturity level of the fruit is determined through the use of a maturity index. Picking at the right time of day is crucial as it prevents the citrus from bruising, which it is more susceptible to do when wet [118]. Therefore, it is not advisable to pick when it is raining or during the early hours of the morning as the fruit may be wet from overnight dew. Fruit quality and market demand are important factors to consider as they have direct relationships to the commercial value of the fruit [62].

2.5.2 Pack House Operations

Once the citrus has been harvested from the orchard it is transported to the pack house. This should be done immediately after picking to avoid fruit dehydration [62]. This fruit is either delivered using picking trailers or bins (wooden or plastic) [67]. The fruit can either be sent directly to the washing area where it is cleaned, or it can first be sent to be de-greened before being washed. During de-greening the fruit is drenched to remove field heat and fungal spores. The fruit is then dried and moved into a de-greening chamber, and then exposed to ethylene gas to promote colouring of the fruit. After cleaning, the fruit is sorted to remove fruit that will be sent for processing and any infected fruit, which may cause infection to other fruit in the consignment. After sorting, the fruit is treated in a fungicide bath, dried, waxed and then dried again. Once these steps are completed the fruit is graded based on different sizes, which will determine if it is for the local or export market, and then packed and labelled. Citrus destined for the export market is packed into cartons and palletised [67]. The PPECB will then carry out the first inspection and inspect a sample of the fruit to be exported to ensure that it meets the minimum export requirements and specifications [53, 62, 67].

2.5.3 Cold Storage Operations

Once the fruit has been palletised in the pack house and passed inspection it is moved into a cold storage facility, which may be located inland or around the vicinity of the port of export or in the port itself. In the cold storage facility, the citrus is cooled in two stages [53]. During the first stage, the fruit pulp is brought down to optimum temperature as per the PPECB protocols. The cooling is usually done using forced air cooling (FAC), where fans are used to blow cold air over the fruit placed in cooling tunnels until the optimum temperature has been reached [53, 62]. If the fruit is destined for a steri-market, then it is inspected by the PPECB to ensure it is free of pests. If the citrus passes inspection, it is moved to a cold chamber to begin the cold sterilisation treatment process. The second stage of cooling involves moving the fruit into a holding room where the optimal temperature is maintained until transport to the port. Before being transported to the port, the cooling units of reefer containers or refrigerated vehicles are checked to ensure they are operating within the correct parameters, pallets are checked against prescribed standards along with the packaging, and the fruit temperature is measured again to ensure that it falls within the correct temperature range [53].

2.5.4 Transport to the Port and Vessel Loading

The citrus is then transported to the port in refrigerated containers (reefers) if it is a containerised consignment or in refrigerated vehicles if it is a conventional (break-bulk) consignment.

If the trip to the port will take longer than two hours, then a genset is required to maintain the temperature of the container by powering the containers refrigeration system. The PPECB allows for a container to be unrefrigerated for 6 hours with 4 hours dedicated to port activities and 2 hours reserved for transport [53]. Figures 2.5 and 2.6 show how the citrus is loaded onto a vessel for containerised and break-bulk shipments respectively. For containerised shipments, the reefer container is loaded directly onto the deck of the ship and the cooling unit is connected to the power supply to keep the reefer container refrigerated. If the shipment is a break-bulk shipment, then the citrus pallets are loaded directly into the hold of the vessel, which is refrigerated. Once in the port, either the container is taken to the stacks if it is a containerised consignment where it is plugged into a power source whilst awaiting transportation to the quay ready to be loaded onto the vessel or if it is a conventional consignment it is taken directly from the cold storage to the quay to be loaded onto the vessel.

FIGURE 2.5: *Example of a reefer container used for citrus shipments [100].*

2.6 The Role of Industry Organisations

Various industry organisations play a role in the exporting of citrus. This may either be in the development and accessing of markets to the regulation and implementation of policies and protocols. The main South African industry organisations that play a role are the Citrus Growers' Association of Southern Africa (CGA), the Perishable Products Export Control Board (PPECB) and Transnet.

The Citrus Growers' Association is an administrative body that represents growers who export citrus fruit. The functions of the CGA are to provide members with markets for citrus exports by developing new markets and keeping existing markets and channels open [28]. The CGA was established in 1997 after the deregulation of citrus exports [109]. Besides providing market

FIGURE 2.6: *Example of a citrus break-bulk shipment being loaded onto a vessel [130].*

access for members to export citrus, the CGA is also responsible for research, facilitating efficient logistics in the export process and communication between growers [28]. The functions all aide in the maximisation of the CGA's members' long-term profitability.

The PPECB is a national public entity and independent provider of cold chain management services and quality certifications for producers and exporters of perishable products. The PPECB is mandated and constituted under the Perishable Products Export Control Act (PPEC Act), No. 9, of 1983 and was established in 1926 [88]. Under the APS Act, No. 119 of 1990, the PPECB acts on behalf of the Department of Agriculture, Forestry and Fisheries (DAFF) to carry out inspection and food safety services. Under the European Commission Regulations 543 of 2011, the PPECB is recognised as an approved third country, which results in less frequent checks at the ports of import in the EU, as the South African system for inspection is deemed equivalent to that of the EU [88]. The PPECB plays a critical role in the export process as it ensures that the product being exported meets all internationally accepted quality levels and conforms to the necessary regulations and protocols. These inspections are necessary as it ensures that if a product does not conform to the export and import requirements of a country it is rejected before export, which reduces the amount of money potentially lost by the exporter [62]. The standards and protocols that need to be followed are published annually by the PPECB.

Transnet plays a significant role in the citrus export process through two of its divisions, namely Transnet Ports Authority (TNPA) and Transnet Port Terminals (TPT). TNPA is responsible for controlling and managing the South African ports through which citrus is exported and operates in the legislative and regulatory environment created by the National Ports Act 2005 (Act No. 12 of 2005) [106]. The main functions of the TNPA are split into two categories which are the provision of port infrastructure and the provision of maritime services and are carried out across eight commercial ports in South Africa [106]. TPT is responsible for the operations of the ports across the container, mineral bulk, agricultural, Ro-Ro and break-bulk sectors and terminals [107].

2.7 World Citrus Markets

South Africa, located in the Southern Hemisphere, produces and exports citrus during its autumn and winter months, which corresponds to the alternate spring and summer months in the Northern Hemisphere. Due to this alternate seasonal production, the biggest direct competitors to South Africa are located in the Southern Hemisphere as they compete for a share in the same market during the same season. Naturally, there will be competitors to South Africa in the Northern Hemisphere, however, this competition is more "indirect" as even though they compete in the same market, it is during a different period in the year.

According to 2019 International Trade Centre data, Spain is the biggest exporter by both value (US Dollar) and volume (tons) globally. South Africa ranks second to Spain globally in terms of both value and volume [57]. Spain and South Africa are the market leaders in citrus exports for the Northern and Southern Hemispheres respectively. Chile is the second biggest exporter of citrus by volume in the Southern Hemisphere and the tenth biggest exporter globally [57]. Figures 2.7 and 2.8 show the value and volume exported for the top 20 citrus exporting countries during 2019 by value and volume respectively. These top 20 countries by value represent 93.82% of the global citrus exports, with Spain and South Africa contributing to 35.87% of the global citrus exports in 2019 in terms of value. In terms of volumes, the top 20 countries by volume represent 93.85% of total citrus volume exported, with South Africa and Spain contributing 37.97% of total citrus exports globally by volume.

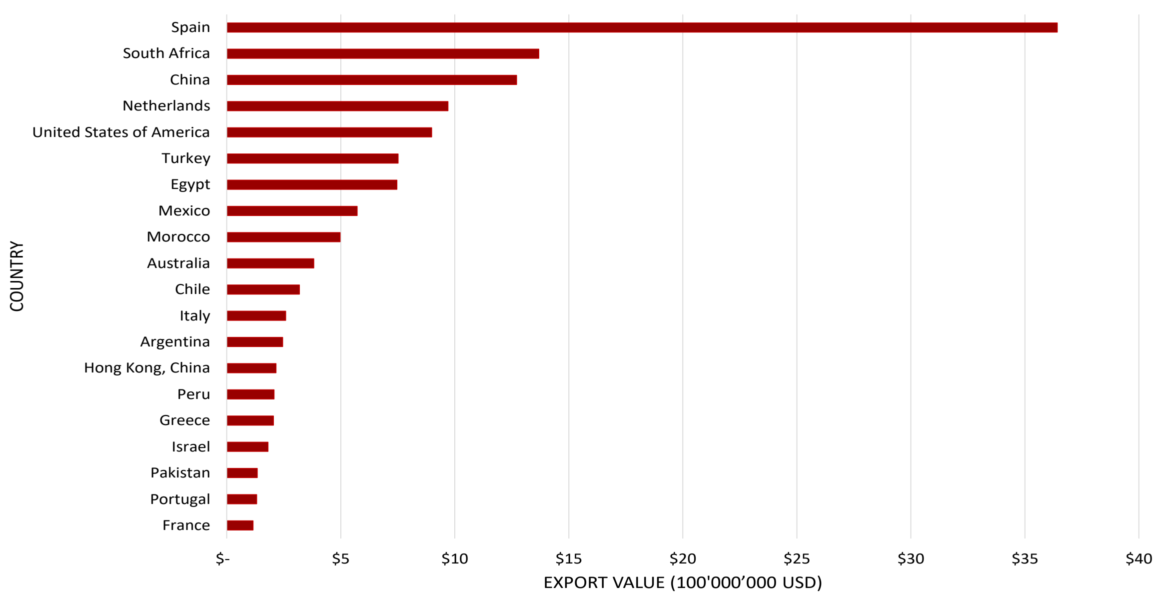

FIGURE 2.7: *Export value of the top 20 citrus exporting countries in 2019 [57]*

2.8 International Best Practices

With Spain being the biggest citrus exporter globally and Chile being the biggest direct competitor to South Africa, it is only prudent that the competitive advantages and best practices of these countries are reviewed.

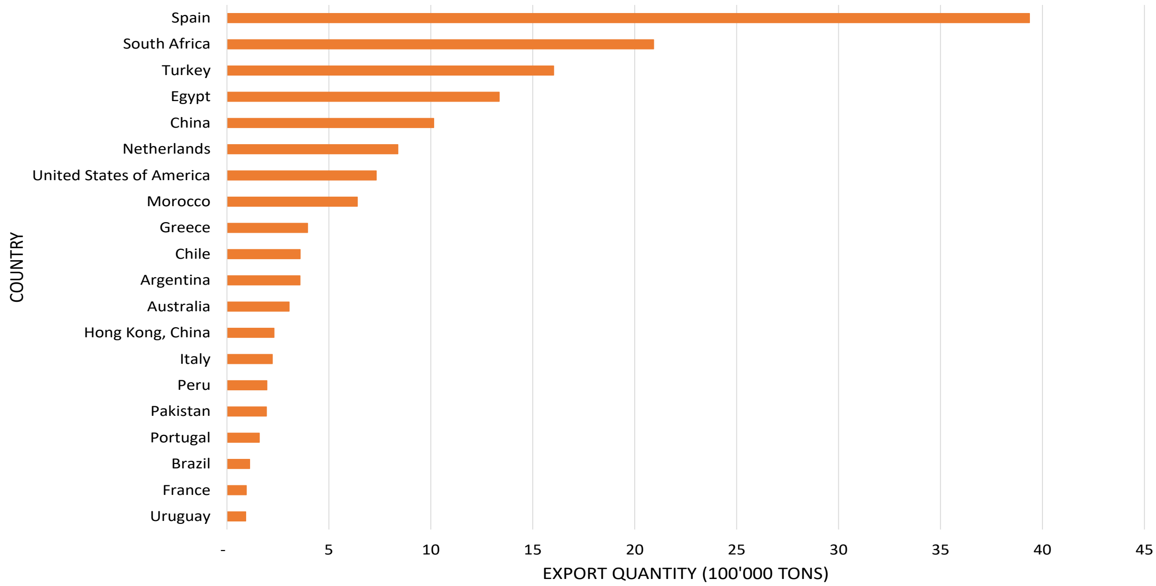

FIGURE 2.8: *Export quantity of the top 20 citrus exporting countries in 2019 [57]*

Along with significant growth in foreign trade over the years [53], Chile has also experienced tremendous growth in its citrus exports over the last years as seen in Figure 2.9 and Figure 2.10, which shows the trend of citrus exports from Chile. Chile's biggest market for citrus exports is the USA, which accounted for 84% of Chilean citrus exports in 2019 [11], which is significantly larger than the contribution of 7% by South Africa for the whole North American market [27]. The remainder of Chilean citrus exports go to Europe and the UK (7%) and the Far East (5%) with Russia, the Middle East, Latin America and Canada making up the balance [11, 12].

The Port of Valparaiso is one of the main ports in Chile and handles approximately 11 million tons of cargo and 1 million containers annually [114], and leads the export of fruit from Chile with 38.71% of fruit exported handled by the Port of Valparaiso in the 2016-2017 export season. The Port of San Antonio, Port of Arica, Port of Coronel and the San Vincent International Terminal handled the remainder of the fruit exports from Chile [111].

These large volumes handled by the Port of Valparaiso caused challenges for managing both capacity and congestion leading into the port. In terms of capacity there is an ever increasing requirement to handle more and more volume on larger ships in order to stay competitive as a result of other ports becoming more efficient or being commissioned.

To address the capacity issue, the Port of Valparaiso implemented a series of solutions in parallel. The first solution was to lengthen the area of the docking bay so that a greater number of larger vessels can be handled at once [60]. The second solution was to increase the height of its yard cranes so that an additional layer of containers can be stacked on top of each other. This resulted in a capacity increase of 20% without the need to increase surface area [60].

To address the challenge of congestion leading into the port, and to prevent trucks from having to pass through the city centre of Valparaiso, an alternative and innovative logistics model was implemented. The model included the development of a new access route to the port, called the Southern Access, which allows direct access to and from the port, thus eliminating the need to go through the city centre [116]. The model also included the development of ZEAL, an inland logistics support zone, which includes the ZAO Mandatory Activities Zone, RDA Customs Warehouse Enclosure and the Empty Containers Deposit. The ZAO Mandatory Activities Zone

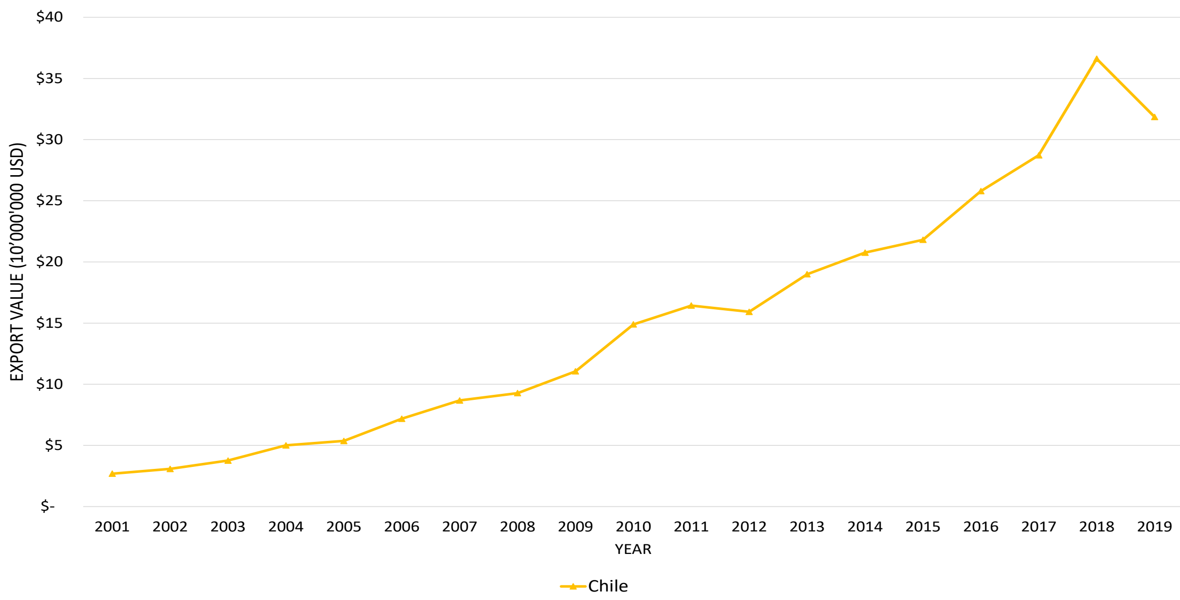

Figure 2.9: *Value of citrus exported from Chile over the years [57]*

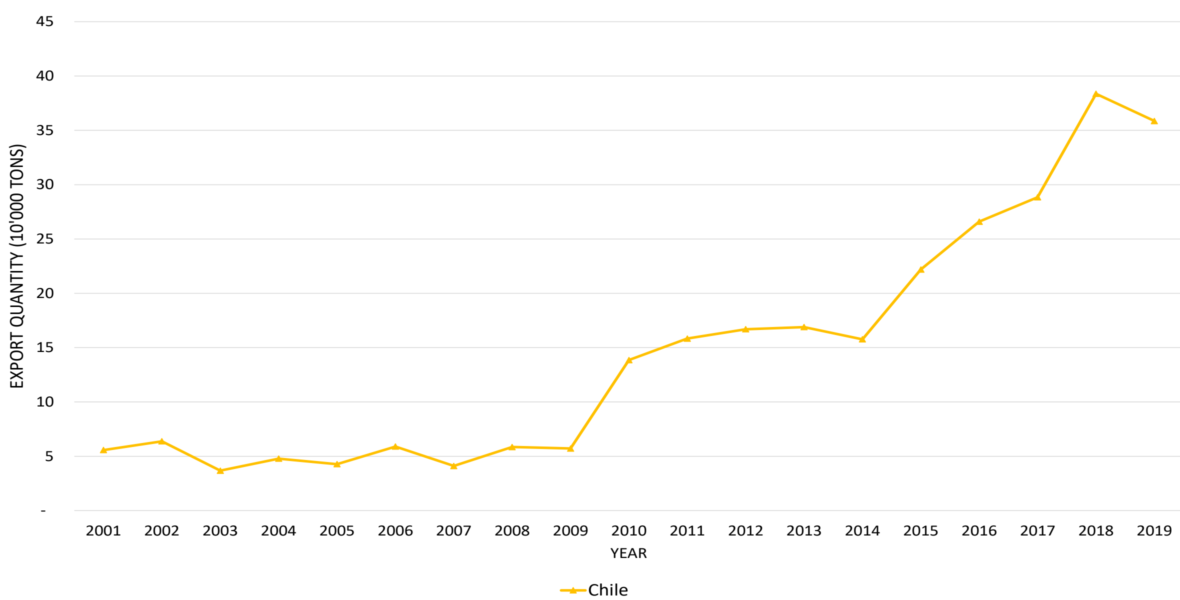

Figure 2.10: *Quantity of citrus exported from Chile over the years [57]*

is responsible for executing inspections by public bodies and coordinating the flow of cargo [116]. All inspections and paperwork is done at ZEAL before the truck is despatched to the port under surveillance. The RDA Customs Warehouse is used for the storage of cargo, and the Empty Container Deposit is used for housing empty reefer containers. ZEAL has effectively concentrated the operations of various stakeholders in the export supply chain, and is technically now the entrance to the port [53, 116]. With the concentration of these operations, a variety of benefits such as reduced lead times, improved information flow, reduced congestion and increased cargo traceability have been achieved, which has increased the efficiency of the export chain in Chile [116].

Over 90% of all citrus exports from Spain are destined for other EU member countries [122], which poses a significant advantage as it has a shorter route to market. As these exports are done overland using refrigerated vehicles, a low percentage of the exports is done through the ports in Spain [62]. Citrus exports from Spain have not seen the same significant growth as Chile over the years as seen in Figures 2.11 and 2.12, which shows the trend of Spanish citrus exports. The exports have been somewhat erratic with both growth and contractions in the volume exported being observed and experienced.

The fact that Spain is a member of the European Union provides it with significant advantages both in terms of regulations and market access. Being a member of the EU comes with the benefit of being supported by the EU's agricultural policies and production programmes, which many non-EU member producers consider to be a competitive advantage [3]. Such policies and practices include compensation for product withdrawal in a bid to stabilise prices, export refunds and incentives to encourage fruit processing. These policies have allowed the Spanish export market to stay protected, viable and competitive. Another practice implemented is the Protected Geographic Indication (PGI) Citricios Valencios programme, which is an EU quality scheme [3]. The quality scheme creates a relationship between the quality of the product and the specific geographic region from which the product hails [40]. The quality scheme was implemented in Valencia, Spain to protect citrus growers in the area by promoting the fruit as high quality that meets reputable standards [3, 62]. The PGI certification provides the consumer with ease of mind that the proper fruit treatment was applied during cultivation and harvest, and that the fruit consumed is only of the highest quality [3, 62].

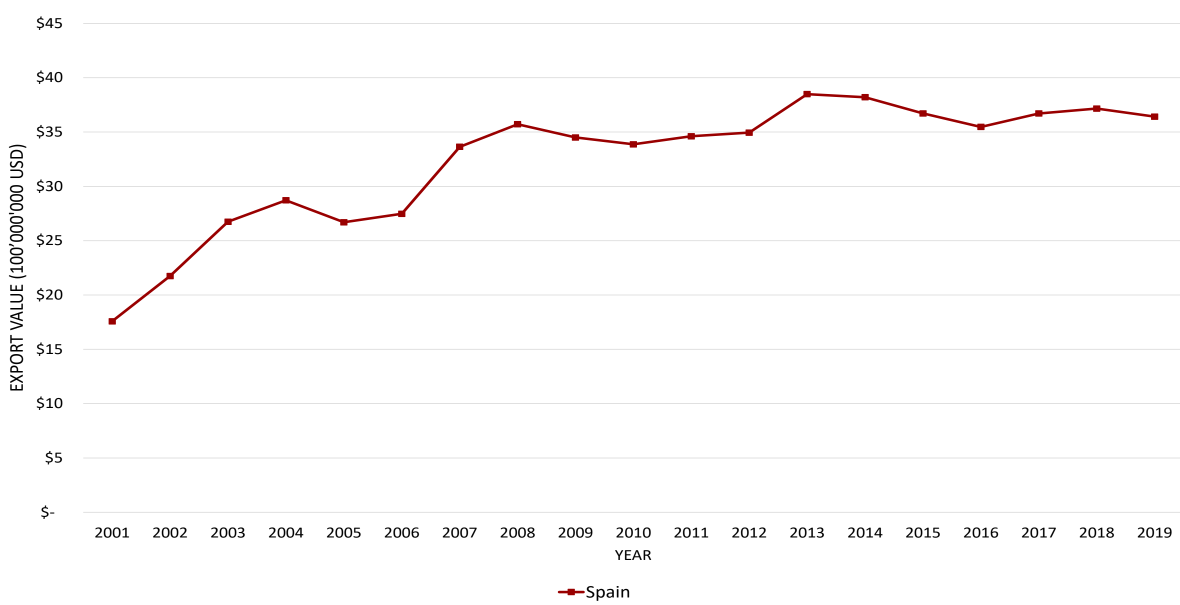

FIGURE 2.11: *Value of citrus exported from Spain over the years [57]*

A best practice implemented in the Port of Ngqura, South Africa, is the use of overhead scanners at the entrance to the port. As a truck drives through the entrance overhead scanners scan the truck's information and retrieves the information on its respective container content. Upon scanning, the truck is automatically directed to an allocated stacking area, thus increasing the speed and efficiency of entering the port [53].

APM's terminal in the Port of Rotterdam has implemented a state of the art autonomous system based around a sophisticated camera system that tracks each container by identifying it through pictures taken of the container [47]. Contributing to this highly efficient system is the use of a scheduling system to schedule loading and unloading of trucks. Trucks must schedule their

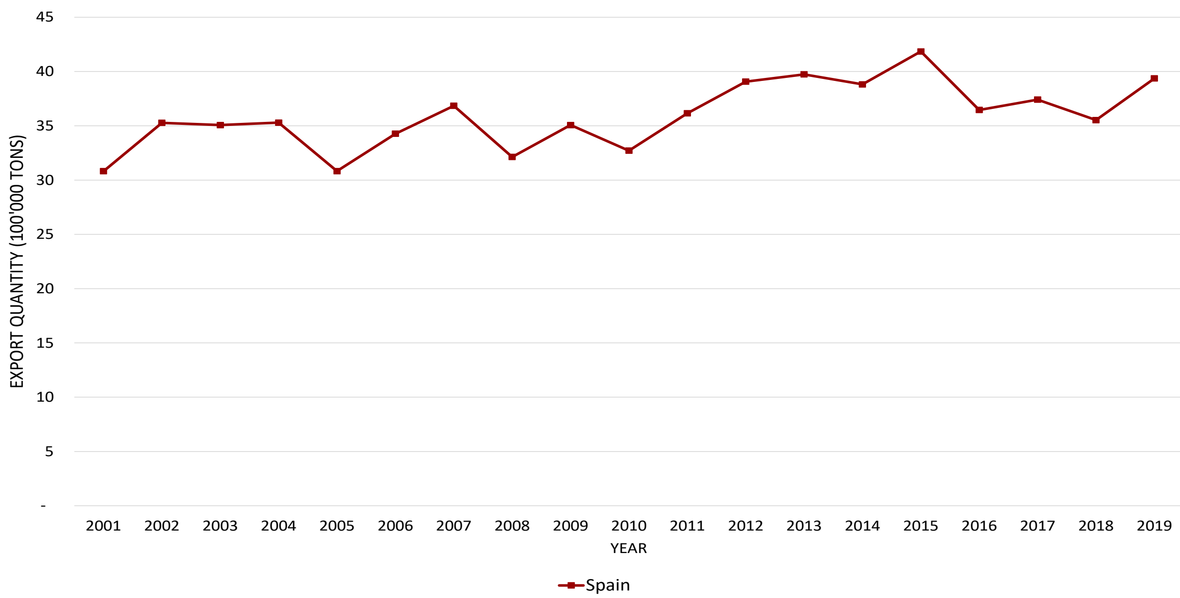

FIGURE 2.12: *Quantity of citrus exported from Spain over the years [57]*

arrival ahead of time and are given a 30 minute window in which they must arrive. Failure to adhere to this time window and slot will result in them losing their appointment [47]. This ensures that there is reduction in bottlenecks and congestion, and that vehicles can be loaded and unloaded in 20 minutes once being admitted into the port. Thus, ensuring the operation maintains its efficiency and momentum [47].

2.9 Previous Fruit Export Studies

Various studies have been performed on the fresh produce export cold chain by a multitude of individuals and institutions. The majority of the studies focus on the elements of the cold chain itself such as temperature and quality. Not as much focus has been placed on the studying of the infrastructure and commodity movements in the fresh produce export cold chain, thus strengthening the argument to research the infrastructure and commodity movements in the fresh produce export cold chain.

Studies relating to temperature in the export cold chain include a study on identifying available opportunities from a supply chain perspective to minimise temperature breaks in the export cold chains of certain fruits by Haasbroek in 2013 [53]. A study in 2018 by Khumalo [62] investigated if there are any temperature breaks in the export cold chain of navel oranges from South Africa to the United States of America, and a study by Blakey and Bower in 2009 [2] on the importance of maintaining the cold chain for avocado ripening quality. In 2019, Fedeli [43] and Conradie [29] completed separate studies in the fruit export cold chain to identify temperature breaks and provide recommendations for improvement. Fedeli focused on identifying the origins of temperature breaks in the pome and table grape export cold chains to the United Kingdom and the Netherlands from South Africa. Temperature studies were conducted both in the exporting and importing countries. Conradie focused on identifying temperature breaks in the clementine and navel orange export cold chains, with a specific analysis on the export cold chain from farm to port in the Western Cape of South Africa. Future studies emanating from these papers include measuring and analysing the temperature from earlier stages in the cold chain starting at the pack house or even point of harvest [53, 62] as well as analysing and measuring the temperature up until the end customer [43], analysing port operations to determine if opportunities exist there to reduce temperature breaks [53], and also to expand the studies to different fruits or varieties to see if the same results are observed [62].

In 2004, Fundira [48] did a transaction cost analysis on the grape and citrus export supply chain of South Africa to identify inefficiencies and recommend ways on how transaction costs can be reduced.

A study by Ortmann in 2005 [85] modelled the South African fruit supply chain to find the maximum possible volume that can be handled by certain sections of the supply chain and also determine the minimum cost of transporting fruit from pack houses to ports. The results showed that sufficient export capacity existed to handle the 2003 export volumes that were modelled. Future work proposed by Ortmann was the inclusion of rail and airfreight costs in the model and expanding the minimum cost model to include all the weeks of the year [85].

Van Dyk and Maspero, 2004, [123] wrote a paper on the analysis of the logistics infrastructure used by the South African fruit industry. The paper summarised key findings of a study initiated by the Deciduous Fruit Producers' Trust with the aim of enhancing the competitiveness of the fruit industry in South Africa. This aim was to be achieved by promoting effective and efficient operations in the fruit export supply chain and by making recommendations on the utilisation and investment into infrastructure. Future study recommendations include, amongst others, a cost-benefit analysis of using rail as a transport means from production regions to ports, investigating the viability of using Maputo to export some of the citrus volumes being handled at Durban, and the development of a mechanism to reduce congestion at ports by diverting volumes from export ports to ports of high capacity [123].

2.10 Conclusion

The literature review on the citrus export industry provides insight into how the citrus export cold chain fits into the greater fruit export cold chain in South Africa and the importance of the citrus export industry. Citrus exports is a major component of fruit and agricultural exports from South Africa, with a contribution of 60% and 21% respectively in the 2019 export season.

Citrus production has a large geographical presence within South Africa, and exports through ports located along the entire South African coastline, with the Port of Durban handling in excess of 50% of the citrus exports, making it the biggest exporting port of citrus in South Africa. Exports are the biggest market for citrus production, with 65% of all citrus production being exported in the 2019 export season.

From the literature, it is evident that various logistical and policy constraints, such as citrus imports may not originate from an CBS infected area when imported in the USA, and the last port of call for a specific export region impact the movement of citrus within and out of South Africa, which have to be taken into consideration in the modelling process. There are also multiple components in the citrus export cold chain that play unique roles and have varying impacts. Thus, it is critical that those components that are included or excluded are clearly defined in the modelling process. As mentioned previously, the study will only look at the cold chain between the farm gate and the port gate and will not include the processes in between as the focus is on allocating citrus volumes from a region to a port. The inclusion of the CBS policy constraint and the last port of call logistical constraint is considered and dealt with in the methodology. Lastly, previous studies have mainly focused on the temperature and quality of the citrus export cold chain and the importance of optimising this component due to the shelf-life sensitivity of the citrus. Very few studies have focused on the movement of citrus and infrastructure in the citrus export cold chain. This study addresses the gap to model the demand at a weekly basis as suggested by Ortmann [85], and the need to divert demand volume away from congested ports as proposed by Van Dyk and Maspero [123].

CHAPTER 3

Literature Review: Mathematical Models

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3.1 Introduction

The following chapter reflects on the literature supporting the study from a mathematical and statistical techniques and modelling perspective. Various different studies and techniques are covered from which arguments, assumptions and conclusions are drawn to be used in the study. This component of the literature review focuses on the mathematical and statistical techniques and models that may be utilised in the study. The reviewing of literature on mathematical models is important to understand what models are available, and how they may be applied, in investigating whether or not "forced" allocation is a feasible solution. It is important that the correct techniques and models are applied to achieve relevant results that provide necessary insights into the solution.

3.2 Mathematical Modelling

Mathematical modelling is the translation of beliefs on how the world functions into mathematical language [66]. This is done by using mathematical relationships to describe a decision problem and the models are often a simplified version of reality. These simplified versions are only useful if they are valid, which means characteristics of the decision problem are accurately represented [92]. Mathematical models have a wide range of objectives and include [66]:

- Aiding in the development of scientific understanding;
- Testing the effect of changes to a system;
- Being used as a tool to aid management decision making.

There are three categories of management science modelling techniques, with each having different characteristics, techniques and uses [92]:

1. **Prescriptive Models**: These models tell the user what to do, have known and well-defined functional relationships between the independent variables and the values of the independent variables are known to the decision maker. Types of techniques used include linear and non-linear programming, goal programming and integer programming, and network models.
2. **Predictive Models**: The functional relationship between the independent variables is unknown and ill-defined, values of the independent variables are known to the decision maker and the models make predictions as to what may happen. Techniques used for this include time series analysis, regression analysis and discriminant analysis.
3. **Descriptive Models**: Values of the independent variables are not known to the decision maker, the functional relationship between the independent variables is known and well-defined and the models describe the outcome of a system or operation. This uses techniques such as simulations, queuing theory and inventory models.

Prescriptive models, more specifically linear programming, were used in the executing of the allocation techniques and time series analysis and regression analysis, which are predictive models, were used for determining future export volumes.

3.3 Forecasting

Forecasting is the process of estimating what will happen in the future [93] and can be used for estimating future demand and supply. Three categories of models can be used to determine future values. The three categories are causal models, time series, and qualitative methods. Figure 3.1 shows the forecasting techniques that fall into each of these categories. The following techniques and models discussed are drawn from Makridakis and Wheelwright [72], Render, Stair and Hanna [93], Ragsdale [92], Wilson [125] and Winston [126]. Only the causal and time series forecasting techniques are relevant to the study and so are explained in detail. The detail of the qualitative models are not explained, however, they are still mentioned for the sake of completeness.

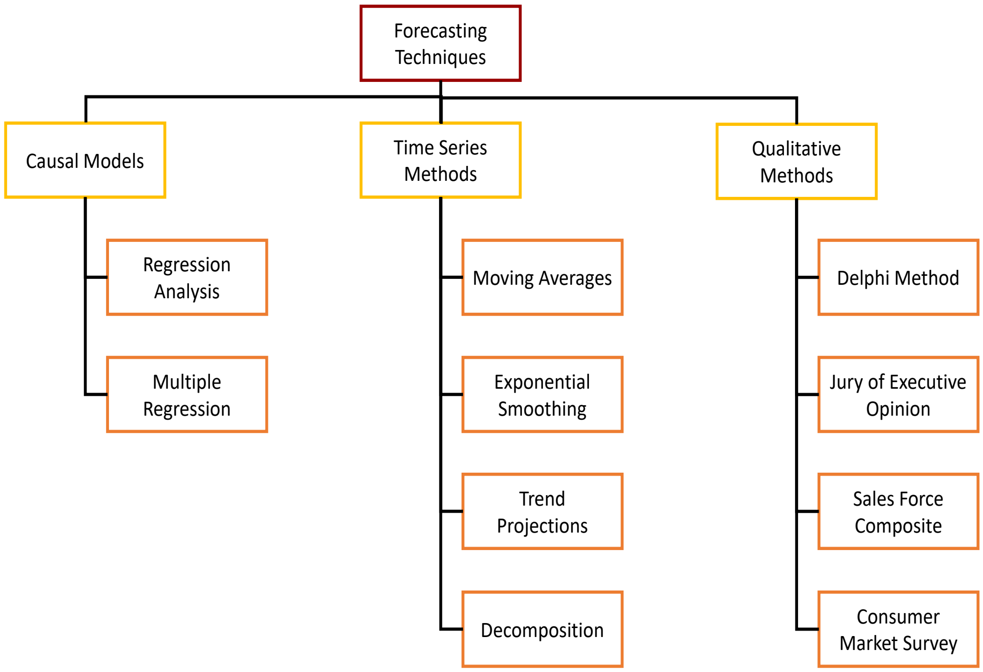

FIGURE 3.1: *Categories of forecasting models. Adapted from [93]*

3.3.1 Causal Models

With causal models statistical relationships between the dependent variable and the independent variable(s) are determined by analysing historical data [126]. This relationship is used to create a function that estimates the value of the dependent variable based on some value of the independent variable(s) [92]. With regression models an error term ε exists as the statistical relationship is not a perfect functional relationship between the variables and so there is some unsystematic variation in the dependent variable [92].

Simple Linear Regression Analysis

Simple linear regression models consist of the dependent variable and one independent variable. The estimated simple linear regression takes the form:

$$\hat{Y}_i = b_0 + b_1 x_{1i} + \varepsilon_i, \tag{3.1}$$

where b_0 is the intercept, which is a constant parameter, b_1 is the slope of the regression line and x_{1i} is the value of the independent variable at the i^{th} observation. The error term ε_i may be excluded in the estimated regression function if one expects the error term to average out to zero across the observations [126].

The line of "best fit" is used to estimate the values of the intercept and the slope of the regression equation. This is done by minimising the sum of the squared estimation errors or residuals to find the best values of the intercept and slope. The residuals are the difference between the actual values and the estimated values [92, 93, 126].

Multiple Regression Analysis

The multiple regression model builds on the simple linear regression model by incorporating more than one independent variable [92, 93, 126]. The estimated multiple regression equation is given by:

$$\hat{Y}_i = b_0 + b_1 x_{1i} + b_2 x_{2i} + \cdots + b_k x_{ki} + \varepsilon_i, \tag{3.2}$$

where b_0 is the intercept, which is a constant parameter, b_k is the slope of the regression line for the k^{th} independent variable and x_{ki} is the value of the k^{th} independent variable at the i^{th} observation. The error term ε_i may be excluded in the estimated regression function if one expects the error term to average out to zero across the observations [126].

The values of the population parameters (b_0, b_1,$\cdots$, b_k) are found by minimising the sum of the estimation errors using the method of least squares. When using multiple regression analysis it is important to use the smallest number of independent variables that adequately account for the dependent variable's behaviour [92]. This prevents the over-fitting of the data, causing unnecessary variables to be included, which may result in an erroneous conclusion.

Binary or Dummy Variables in Multiple Regression Analysis

Binary, dummy or indicator variables are used to indicate whether a particular condition is met. These variables are used when independent variables used cannot be shown numerically as they are qualitative or non-quantitative in nature [125]. If p possible values can be taken by the variable then $p-1$ binary variables are needed [92]. The binary variable is shown by:

$$X_{p_i} = \begin{cases} 1, & \text{if condition is true for the value of } p, \\ 0, & \text{otherwise.} \end{cases} \tag{3.3}$$

Binary variables are tested using the regression diagnostics to determine their significance and validity. Each indicator variable is interpreted by comparing it to the value of p that was not assigned an indicator variable [61], i.e. the value that is assigned 0 for each indicator variable. The comparison is made on the assumption that all other variables remain constant.

Seasonal Regression Analysis

In seasonal regression models binary variables, which are used to indicate if the condition is true or false, are used as the indicator variable to show if a value is observed in the seasonal period p or not [92]. If one has p number of seasonal periods then one needs $p-1$ indicator variables. The indicator variables are defined as:

$$x_{pt} = \begin{cases} 1, & \text{if } Y_t \text{ is from period } p, \\ 0, & \text{otherwise,} \end{cases} \tag{3.4}$$

where t is the time period for the observation.

The seasonal indicators are used in the multiple regression model to make the forecast as the indicator variables represent the independent variables. The reference variable on which all comparisons are made in the seasonal regression model is the period p that is not used to create an indicator variable.

Evaluating the Regression Model

Before a regression model can be used to make forecasts the results of the model are assessed, independent and dependent variables are tested to determine if a linear relationship exists, coefficients are interpreted and regression diagnostics are analysed.

Model assessment involves the analysis of the regression statistics to determine the accuracy of the regression model [93]. The following statistics are used:

1. *Standard Error of the Estimate*: This measures the variation in the data around the regression line [93] and is useful for evaluating uncertainty in the forecasts made [92], both in simple linear and multiple regression analysis. The standard error of the estimate is calculated as [92]:

$$S_\epsilon = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n-k-1}}, \tag{3.5}$$

   where $n-k-1$ are the degrees of freedom [93].

2. *Coefficient of Determination*: This is the proportion of variability in the dependent variable that is explained by the independent variable [93], and is used in simple linear regression analysis. The coefficient of determination is also referred to as the R^2 statistics and takes a value between 0 and 1 [92]. The closer the value is to 1, the better the function fits the data resulting in more accurate forecasts [92]. The R^2 statistic is calculated as the value of the error sum of squares over the total sum of squares deducted from one and is given by the following formulation [92]:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}. \tag{3.6}$$

3. *Adjusted-R^2 Statistic*: This is another goodness-of-fit measure, like the coefficient of determination, to determine if the addition of an independent variable improves the regression model or if it artificially inflates the R^2 statistic [92] in multiple regression analysis. Again a value between 0 and 1 is obtained, with a value closer to 1 showing a better fit of the function to the data. The adjusted R^2 is formulated as [92]:

$$R_a^2 = 1 - \left(\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}\right)\left(\frac{n-1}{n-k-1}\right), \tag{3.7}$$

   where n is the number of observations and k the number of independent variables.

Statistical Test for Population Parameters

The validity of the model is tested to determine if a relationship exists between the dependent and independent variables. The validity of the model is tested using either the t-statistic and p-value method or the F-test for the analysis of variance (ANOVA) [92, 93], which tests if the β_i for all independent variables are equal to zero simultaneously. The t-test is used primarily for simple regression models and the F-test for multiple regression models due to the possibility of multicollinearity being present in multiple regression models, which requires the t-statistic to be interpreted slightly differently in multiple regression models than in simple regression models [92]. Because only one independent variable exists in a simple regression model, the testing of the hypothesis using either the t-test or the F-statistics are equivalent [92].

To test the model validity using the F-test statistic, the following hypothesis is tested:

$$H_0 : \beta_1 = \beta_2 = \ldots = \beta_k = 0 \quad \text{(No relationship exists)} \tag{3.8}$$

$$H_1 : \text{At least one} \quad \beta_i \neq 0 \quad \text{(Relationship exists)}, \tag{3.9}$$

where β_i is the slope of regression for the independent variable i. If the null hypothesis H_0 cannot be rejected then there is no relationship between the independent variable and the dependent variables, and so the model is not valid. The null hypothesis is rejected if the calculated F-statistic is greater than the critical F-statistic [93]. The critical F-statistic is obtained from the F distribution table for the selected significance level and the degrees of freedom for the numerator and denominator [93]. The greater the value of F, the more variation in the dependent variable is explained by the regression equation. The F-statistic is calculated as the ratio of the mean squared regression and mean squared error ($F = \frac{MSR}{MSE}$).

The validity of the model using the t-statistic and p-value method is determined by testing the following hypothesis:

$$H_0 : \beta_i = 0 \quad \text{(No relationship exists)} \tag{3.10}$$

$$H_1 : \beta_i \neq 0 \quad \text{(Relationship exists)} \tag{3.11}$$

If the observed significance level (p-value) is less than the selected significance level then reject the null hypothesis. Most common levels of significance used are $\alpha = 0.01$ and $\alpha = 0.05$.

The t-statistic can be calculated as:

$$t_i = \frac{b_i - \beta_i}{S_{b_i}}, \tag{3.12}$$

where S_{b_i} is the standard error of b_i [92, 93]. The t-statistic is then used to calculate the p-value to determine if the null hypothesis should be rejected or not.

Diagnostic Tests

Diagnostic tests are used in regression analysis to determine if any of the assumptions required to perform regression analysis have been violated, thus making the model no longer valid [93]. The following assumptions need to hold in order to use the regression model [93, 126]:

1. Errors are independent;
2. Errors are normally distributed;
3. Errors have constant variance.

The following diagnostic tests are used to test if any violations of the assumptions are present:

1. Autocorrelation (simple and multiple regression analysis): Determines if consecutive observations are independent of each other. This is a very important diagnostic for time series data. Autocorrelation can be checked by plotting the residuals and analysing the

pattern. If the residuals change sign rarely (less than half the time) positive autocorrelation is probably present and so the independence assumption does not hold. If the residuals change sign often (more than half the time) negative correlation is probably present and so the independence assumption does not hold. If the residuals change sign about half the time then autocorrelation is probably absent and the independence assumption holds [126]. Another test that can be used for autocorrelation is the Durbin-Watson test for first-order correlation. The Durbin-Watson statistic is defined as [61]:

$$d = \frac{\sum_{i=2}^{n}(e_i - e_{i-1})^2}{\sum_{i=1}^{n} e_i^2}, \tag{3.13}$$

where e_i is the residual error.

The statistic d has a range of $0 \leq d \leq 4$ with values less than 2 and greater than 0 indicating positive first-order correlation and values greater than 2 and less than 4 indicating negative first-order correlation. Either a one-tail or a two-tail test can be conducted. For a one-tail test if d is less than d_l (lower critical value of the statistics d) there is enough evidence of positive first-order correlation. If d is greater than d_u (upper critical value of the statistics d) then there is not enough evidence of positive first-order correlation and if $d_l \leq d \leq d_u$ then the test is inconclusive. For negative first-order correlation to be present $d > 4 - d_l$. If $d < 4 - d_u$ there is not enough evidence of negative first-order correlation and if $4 - d_u \leq d \leq 4 - d_l$ then the test is inconclusive. For a two-tail test of first-order autocorrelation, $d < d_l$ or $d > 4 - d_l$ for autocorrelation to be present. If d falls between d_l and d_u or between $4 - d_u$ and $4 - d_l$ the test is inconclusive, and if d falls between d_u and $4 - d_u$ then there is no evidence of first-order autocorrelation [61]. The values for d_l and d_u are obtained from the Durbin-Watson statistics table.

2. Non-normality (simple and multiple regression analysis): Used to determine if the residuals or errors are normally distributed. This is done by graphing the residuals into a histogram and checking for a bell shaped curve with a mean close to zero, which indicates normality [61]. The mean of the error terms can also be calculated, with a value of zero indicating the residuals are normally distributed [80].

3. Heteroscedasticity (simple and multiple regression analysis): Checks if the variance is constant among the residuals. This is done by plotting the residuals against the predicted Y. Heteroscedasticity is not present if there appears to be no change in the spread of the plotted points [126]. White's test for heteroscedasticity can also be used. This test involves regressing the squares of the residuals against the independent variables, the square of the independent variables and the cross product of the independent variables from the original regression analysis and testing the following hypothesis at a 0.05 significance level:

$$H_0 : \text{Heteroscedasticity is not present} \tag{3.14}$$

$$H_1 : \text{Heteroscedasticity is present} \tag{3.15}$$

If the p-value is greater than the significance level, then do not reject the null hypothesis [80, 129].

4. Outliers (simple and multiple regression analysis): Checks for abnormally large or small observations. Outliers are checked using the standardised residuals. If the value of the standardised residual is smaller than -2 or larger than +2 it indicates the value is an outlier and must be dealt with accordingly [61].

5. Multicollinearity (multiple regression analysis only): Determines if there is any correlation between the independent variables, i.e one of the independent variables can be used to predict the outcome of another independent variable. Multicollinearity is present if there is no improvement in the adjusted R^2 when an additional independent variable is added to the regression model [92].

Prediction and Confidence Intervals

When predicting values there is always some uncertainty in the value of the prediction. The standard error of the estimate is a useful measure for measuring the level of uncertainty in the predicted value. This can be done by calculating a prediction interval for the predicted value at a specific confidence level using the standard error of the estimate. This prediction interval shows the range within which the actual future value will be from the predicted value at the specific confidence level [92]. A confidence interval for the mean value of the actual values at a specific confidence level can also be calculated, which shows the range in which the values are expected to be in relation to the mean [92]. As a rule of thumb, there is 68% chance of the actual value falling within ±1 standard errors, 95% chance of falling within ±2 standard errors and 99.7% chance of falling within ±3 standard errors of the predicted value or mean. A 95% confidence interval is the most commonly used interval. Prediction intervals generated by this rule of thumb values tend to underestimate the true uncertainty. The mean confidence interval always covers a smaller range than the prediction interval [92]. The prediction interval is calculated as:

$$\hat{Y}_h \pm t_{\left(1-\frac{\alpha}{2};n-2\right)} S_p, \tag{3.16}$$

where $t_{\left(1-\frac{\alpha}{2};n-2\right)}$ is the $1-\frac{\alpha}{2}$ percentile of a t-distribution with $n-2$ degrees of freedom and S_p is the standard error for prediction of an observation and is defined as:

$$S_p = S_\epsilon \sqrt{1 + \frac{1}{n} + \frac{(X_{1h} - \bar{X})^2}{\sum_{i=1}^{n}(X_{1i} - \bar{X})^2}}, \tag{3.17}$$

where S_ϵ is the standard error [92].

The confidence interval is calculated as:

$$\hat{Y}_h \pm t_{\left(1-\frac{\alpha}{2};n-2\right)} S_a, \tag{3.18}$$

where $t_{\left(1-\frac{\alpha}{2};n-2\right)}$ is the $1-\frac{\alpha}{2}$ percentile of a t-distribution with $n-2$ degrees of freedom and S_a the standard error for prediction of the mean and is defined as:

$$S_a = S_\epsilon \sqrt{\frac{1}{n} + \frac{(X_{1h} - \bar{X})^2}{\sum_{i=1}^{n}(X_{1i} - \bar{X})^2}}, \tag{3.19}$$

where S_ϵ is the standard error [92].

3.3.2 Extrapolation or Time Series Models

Extrapolation or time series analysis is the analysis of historical quantitative data and trends over a period of time to forecast future values [92]. These models assume that future values are a function of historical values [93]. Time series forecasting follows a five step process when executing the forecast:

1. The dataset is divided into two components, namely the historical and test datasets. The size of the test dataset should be at least 20% of the total time series dataset;
2. Graphing the historical dataset and selecting a suitable method(s) based on the observations on trend and seasonality;
3. Using the historical dataset to initialise the forecast, estimate trend and seasonal components (if any) and optimise the parameters to be used;
4. Executing the forecast on the test dataset;
5. Evaluating the methods using the fit and forecast accuracy measures selected on the test dataset and then selecting the best suited method based on this evaluation to make the forecast.

Classifying Time Series Data

Time series data typically consists of four components [93], namely, trend (T), seasonality (S), cycles (C) and random variables (R). Trend is the general movement of the time series data over time [92, 93]. This may be an upward or downward trend. Seasonality is a repeating or regular pattern that can be observed in the dataset [92, 93]. Seasonality can either be additive or multiplicative. With additive seasonality the effects are usually with the same order of magnitude. However, with multiplicative seasonality, the effects have an increasing order of magnitude [92]. Cycles are patterns observed in data that occur every x number of time units and are often tied to annual or business cycles [93]. Random variables are observations in the data caused by unusual or once-off events; they have no recurring pattern [93]. Pegel's classification can be used to classify if there is an evident trend in the data or if seasonality is present, which will aid in determining what forecasting technique should be used [72]. Pegel's classification of time series patterns is shown in Figure 3.2.

Smoothing Parameters

Three smoothing parameters exist, which are used in the different exponential smoothing techniques. Alpha (α) is the smoothing parameter that is used to weight how much of the past observations will be used to forecast the predicted value. Beta (β) is the parameter used to smooth the trend in the data and gamma (γ) is used to smooth seasonality in the data [72]. The parameters are optimised on the historical dataset using non-linear programming by minimising the value of the accuracy measure being used [92]. These optimised parameter values are then used in the forecast function to predict future values.

Moving Averages

Moving averages are one of the simplest and easiest forecasting methods for stationary data [92] and are used to smooth out variations over time when the demands or outputs stay fairly steady [93] and there is no trend or seasonality in the data. The moving average simply predicts the

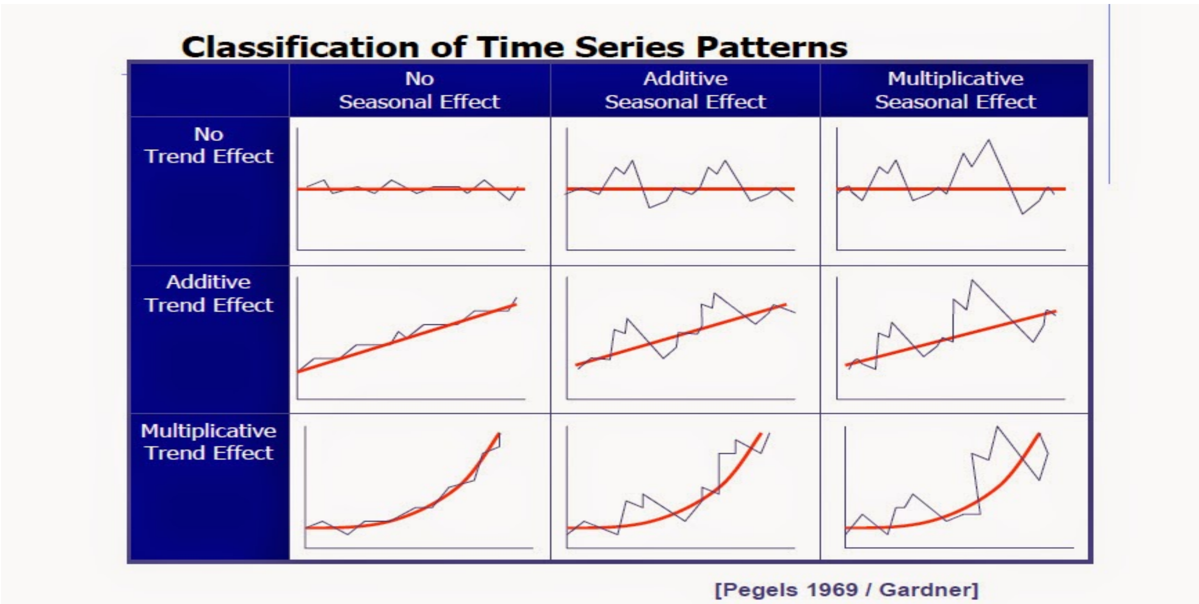

FIGURE 3.2: *Pegels classification of time series patterns [110]*

future value in period $t+1$ by using the average of the previous k observations and is given by:

$$\hat{Y}_{t+1} = \frac{Y_t + Y_{t-1} + \cdots + Y_{t-k+1}}{k}. \tag{3.20}$$

The weighted moving average is an enhancement on the simple moving average. The simple moving average simply assigns the same weights to all data periods, which may not necessarily result in the most accurate forecast [92]. The weighted moving average forecast function is given by:

$$\hat{Y}_{t+1} = w_1 Y_t + w_2 Y_{t-1} + \cdots + w_k Y_{t-k+1}, \tag{3.21}$$

where w_n is the weight of observation n and satisfies the conditions $0 \leq w_n \leq 1$ and $\sum_{n=1}^{k} w_n = 1$. The values of the weights can be determined for a given k by using non-linear programming to minimise the value of the accuracy measure being used [92, 93].

Exponential Smoothing

Exponential smoothing is another moving average technique that assigns weights to past data [92, 93]. This method is also usually suitable when there is no trend or seasonality observed. Exponential smoothing can be described using:

$$\hat{Y}_{t+1} = \hat{Y}_t + \alpha(Y_t - \hat{Y}_t), \tag{3.22}$$

where α is a smoothing parameter that can assume a value between $0 \leq \alpha \leq 1$ and $\hat{Y}_t$ is the predicted value of the previous period t. The forecast is executed by taking the value that was predicted for the previous period and adding an adjustment for the error made in the prediction of the previous period's value [92]. Smaller values of α produces forecasts that do not react quickly to changes [92] as more weight is given to historical data [93]. A higher α will assign a higher weight to more recent data [93] and so the forecasts are more reactive to changes in the data [92].

Stationary Data with Additive Seasonal Effects

This method is used when the time series shows no trend and has an evident seasonality component that does not have an increasing order of magnitude. This method can be formulated as:

$$\hat{Y}_{t+n} = E_t + S_{t+n-p}, \tag{3.23}$$

where

$$E_t = \alpha(Y_t - S_{t-p}) + (1-\alpha)E_{t-1}, \tag{3.24}$$
$$S_t = \beta(Y_t - E_t) + (1-\beta)S_{t-p}, \tag{3.25}$$
$$0 \leq \alpha \leq 1 \quad \text{and} \quad 0 \leq \beta \leq 1. \tag{3.26}$$

E_t is the base estimate for period t, S_t is the seasonal factor at period t and S_{t+n-p} is the seasonal factor for which the estimate must be adjusted by at period t to account for the seasonality. The constant p is the number of seasonal periods in the data.

In order to use this method the base estimates and seasonal factor for the first p time periods must be initialised. This initialisation can be done by using the following two equations [92]:

$$E_t = \sum_{i=1}^{p} \frac{Y_i}{p} \qquad t = 1, 2, \ldots, p, \tag{3.27}$$
$$S_t = Y_t - E_t \qquad t = 1, 2, \ldots, p. \tag{3.28}$$

Stationary Data with Multiplicative Seasonal Effects

This method is used for data that shows no trend, however, there is a seasonality component with an increasing order of magnitude. A modification of the additive seasonal model results in the following formulation for the multiplicative seasonal model:

$$\hat{Y}_{t+n} = E_t \times S_{t+n-p}, \tag{3.29}$$

where

$$E_t = \alpha\left(\frac{Y_t}{S_{t-p}}\right) + (1-\alpha)E_{t-1}, \tag{3.30}$$
$$S_t = \beta\left(\frac{Y_t}{E_t}\right) + (1-\beta)S_{t-p}, \tag{3.31}$$
$$0 \leq \alpha \leq 1 \quad \text{and} \quad 0 \leq \beta \leq 1. \tag{3.32}$$

E_t is the base estimate for period t, S_t is the seasonal factor at period t and S_{t+n-p} is the seasonal factor for which the estimate must be adjusted by at period t to account for the seasonality. The constant p is the number of seasonal periods in the data.

In order to use this method, the base estimates and seasonal factor for the first p time periods must be initialised. This initialisation can be done by using the following two equations [92]:

$$E_t = \sum_{i=1}^{p} \frac{Y_i}{p} \qquad t = 1, 2, \ldots, p, \tag{3.33}$$

$$S_t = \frac{Y_t}{E_t} \qquad t = 1, 2, \ldots, p. \tag{3.34}$$

Double Moving Average

This method is used when there is an evident trend in the data with no seasonality [92] and is calculated by taking the average of averages and is given by the function:

$$\hat{Y}_{t+n} = E_t + nT_t, \tag{3.35}$$

where

$$M_t = \frac{(Y_t + Y_{t-1} + \cdots + Y_{t-k+1})}{k}, \tag{3.36}$$

$$D_t = \frac{(M_t + M_{t-1} + \cdots + M_{t-k+1})}{k}, \tag{3.37}$$

$$E_t = 2M_t - D_t, \tag{3.38}$$

$$T_t = \frac{2(M_t - D_t)}{(k-1)}. \tag{3.39}$$

$$\tag{3.40}$$

M_t is the moving average for the last k time periods (including t), D_t is the average of the moving averages for the last k time periods (including t), E_t is the base estimate for period t and T_t is the trend estimate for period t [92].

Holt's Method

Holt's method or double exponential smoothing is an effective method commonly used for forecasting time series that has a linear trend and no seasonality [92, 126]. The forecast function for Holt's method is given by:

$$\hat{Y}_{t+n} = E_t + nT_t, \tag{3.41}$$

where

$$E_t = \alpha Y_t + (1-\alpha)(E_{t-1} + T_{t-1}), \tag{3.42}$$

$$T_t = \beta(E_t - E_{t-1}) + (1-\beta)T_{t-1}, \tag{3.43}$$

$$0 \leq \alpha \leq 1 \quad \text{and} \quad 0 \leq \beta \leq 1. \tag{3.44}$$

The base estimates and trend estimate for the first time period need to be initialised. This is done by setting the base estimate $E_1 = Y_1$ and the trend estimate $T_1 = 0$ [92].

The trend estimate or trend adjustment factor T_t tends to increase if the there is an upward trend in the data and E_t tends to be larger than E_{t-1}. The opposite is true if there is a decrease in the trend and E_t tends to be smaller than E_{t-1}, which results in a decreasing trend estimate [92].

Holt-Winter's Method for Seasonal Effects

Holt-Winter's method can be used for forecasting time series in which both trend and seasonality are present [92, 126]. Holt-Winter's method can be used for both additive and multiplicative seasonal effects. The Holt-Winter's Additive (HWA) techniques forecasting function is given by:

$$\hat{Y}_{t+n} = E_t + nT_t + S_{t+n-p}, \tag{3.45}$$

where

$$E_t = \alpha(Y_t - S_{t-p}) + (1-\alpha)(E_{t-1} + T_{t-1}), \tag{3.46}$$
$$T_t = \beta(E_t - E_{t-1}) + (1-\beta)T_{t-1}, \tag{3.47}$$
$$S_t = \gamma(Y_t - E_t) + (1-\gamma)S_{t-p}, \tag{3.48}$$
$$0 \leq \alpha \leq 1, \quad 0 \leq \beta \leq 1 \quad \text{and} \quad 0 \leq \gamma \leq 1. \tag{3.49}$$

The initialisation of the seasonal factor, base estimate and the trend factor for the period $t = p$ is done by setting the trend estimate to 0, setting the base estimate to $Y_p - S_p$ so that $E_p + S_p = Y_p$ and using the following equation to estimate the initial seasonal factor:

$$S_t = Y_t - \sum_{i=1}^{p} \frac{Y_i}{p} \qquad t = 1, 2, \ldots, p, \tag{3.50}$$

$$\tag{3.51}$$

which is the difference between the value observed in time period t and the average of the observations in the first p time periods.

The Holt-Winter's Multiplicative (HWM) technique for forecasting time series with a trend and an increasing order of magnitude in the seasonality is given by:

$$\hat{Y}_{t+n} = (E_t + nT_t)S_{t+n-p}, \tag{3.52}$$

where

$$E_t = \alpha\left(\frac{Y_t}{S_{t-p}}\right) + (1-\alpha)(E_{t-1} + T_{t-1}), \tag{3.53}$$
$$T_t = \beta(E_t - E_{t-1}) + (1-\beta)T_{t-1}, \tag{3.54}$$
$$S_t = \gamma\left(\frac{Y_t}{E_t}\right) + (1-\gamma)S_{t-p}, \tag{3.55}$$
$$0 \leq \alpha \leq 1, \quad 0 \leq \beta \leq 1 \quad \text{and} \quad 0 \leq \gamma \leq 1. \tag{3.56}$$

The initialisation of the seasonal factor, base estimate and the trend factor for the period $t = p$ is done by setting the trend estimate to 0, setting the base estimate to $\frac{Y_p}{S_p}$ so that $E_p \times S_p = Y_p$ and using the following equation to estimate the initial seasonal factor:

$$S_t = \frac{Y_t}{\sum_{i=1}^{p} \frac{Y_i}{p}} \qquad t = 1, 2, \ldots, p, \tag{3.57}$$

$$\tag{3.58}$$

which is the ratio of the value observed in time period t and the average of the observations in the first p time periods [92].

Trend Model

With trend models a predictor variable is used as an independent variable in a regression model for time series data. In this case the independent variable is time, and is a predictor variable as it has no cause-and-effect relationship with the time series [92]. Many trend models exist, however, only the linear and quadratic trend model are covered.

The linear trend model is simply a linear regression equation in which the ordinary least squares regression method is used to estimate the parameters to achieve the following forecast function:

$$\hat{Y}_{t+n} = b_0 + b_1 x_{1t}, \tag{3.59}$$

where b_0 is the intercept, b_1 is the slope of the line and x_{1t} is the time period t.

The linear trend model does not have the error term that exists in the linear regression model due to the fact that it is assumed the observed values will vary around the regression function $\beta_0 + \beta_1 x_1$ randomly and so the average expected error value is equal to 0 [92]. The linear trend equation is the equation of the line that passes through the time series that minimises the sum of the squared errors [92, 93].

The quadratic trend model is a modification of the linear trend model and is used when the actual values do not appear to be randomly scattered around the trend line [92]. To counter this a curved trend line may be fitted by using the following quadratic trend model:

$$\hat{Y}_{t+n} = b_0 + b_1 x_{1t} + b_2 x_{2t}, \tag{3.60}$$

where $x_{1t} = t$ and $x_{2t} = t^2$.

The linear and quadratic trend models will account for the trend in the time series, however, there may also be seasonality in the data, which may need to be taken into account. This seasonality may be accounted for by creating seasonal indices, which are then used to adjust the forecast [92, 93]. The seasonal indices for multiplicative seasonal effects with trend are found by calculating the ratio of the actual observed value to the calculated trend value for each time period t. The seasonal index for each seasonal period p is found by averaging the calculated seasonal index ratios of each time period t that falls into the seasonal period p. The seasonal indices calculated are then normalised such that the sum of the indices across all seasonal periods p equates to 1. The normalised seasonal indices are then used to adjust the forecast by multiplying the calculated trend value in time period t with the seasonal index value for its corresponding season period p [92]. Seasonal indices for additive seasonal effects are found by calculating the difference between the actual observed value and the calculated trend value for time period t. The seasonal index for each seasonal period p is found by averaging the corresponding seasonal indices for each time period t that falls into the seasonal period p. The forecast is adjusted by adding the corresponding seasonal index for time period t in seasonal period p to its calculated trend value. These seasonal indices calculated and trend parameters may not necessarily be the optimal values. The optimal values can be found by using non-linear programming to minimise the value of accuracy measure being used [92].

Decomposition

Forecasting using decomposition is a process where the linear trend and seasonal components are isolated isolated to produce more accurate forecasts [93]. Forecasting using decomposition involves a five step process [93]:

1. Seasonal indices are computed using centred moving averages. Using centred moving averages prevents incorrect interpretation of the variation being caused by the season and not by the trend.

2. The data is deseasonalised by diving each entry by its respective seasonal index.

3. The equation of the trend line is found using the deseasonalised data.

4. The trend line is used to forecast for future time periods.

5. The trend line forecast is then multiplied by the appropriate seasonal index to get the final forecast.

ARIMA - Box-Jenkins Methodology

Autoregressive Integrated Moving Averages (ARIMA) is a type of statistical model that is used for forecasting time series data. The Box-Jenkins methodology forecasts by only looking at the past pattern in the time series. Due to the process the method follows it is better suited to longer-range forecasting even though it is used for short-, medium-, and long-range forecasting [125]. The Box-Jenkins Methodology works by taking the observed time series and determining what "black box" would produce the observed time series from white noise as opposed to determining causal variables that could explain the observed times series if regression analysis was used [125]. White noise is a random set of numbers that have no relationship between consecutive values and previous values are not useful in predicting future values [125]. Essentially only three basic models exist, from which many variations are derived, which can be used to determine the "correct" black box. These three models are the moving-average (MA), autoregressive (AR) and mixed autoregressive moving average (ARMA) models [125]. The autoregressive integrated moving average (ARIMA) model is a model in which differencing has been used to make the time series stationary [125]. Non-stationary time series data is made stationary to remove the dominant pattern displayed by autocorrelations in non-stationary time series data [125]. Two tools, namely autocorrelation and partial autocorrelation, are used in determining the most appropriate model. Autocorrelation is the correlation between successive observations [125] and partial autocorrelation is the correlation between an observation and its respective lag when all other time lags are constant [125].

The Box-Jenkins method is an iterative process that involves four steps [125]:

1. Model Identification: The time series is tested to determine if it is stationary or non-stationary and if any necessary differencing modifications need to be done to make the data stationary. Autocorrelation functions (ACF) and partial autocorrelation functions (PACF) are calculated and graphed. This is used to identify a tentative ARIMA(p, d, q) model where p is the number of autoregressive terms, d is the order or number of differences needed to make the data stationary and q is the number of moving average terms or lagged forecast errors [119]. The level of differencing required is estimated by observing the plot of the ACF. If the time series data is non-stationary, the autocorrelations will be significantly different from zero at the start and then gradually fall towards zero. The order of differencing required is determined by applying the next differencing order, starting at a first order of difference, and evaluating the autocorrelation plot after each order until the autocorrelations become insignificant. The number of orders applied at this point is the value of d [125]. The following set of general rules is used to estimate the values of p and q in the tentative model [125]:

1.1. The model is an MA(q) type if the ACF stops abruptly at some point after q spikes.
1.2. The model is an AR(p) type if the PACF stops abruptly at some point after p spikes.
1.3. The model is an ARMA(p, q) type model if neither function stop abruptly, but rather decline toward zero in some fashion.

2. Parameter Estimation: The second step is the estimation of the parameters in the model. The estimation of the parameters is similar to fitting a regression function to a dataset. Non-linear estimation algorithms are used to estimate the parameters of the model [117]. Back forecasting is a technique used to obtain estimates of the initial residuals. Two passes are made through the data. The first is a backward pass to estimate prior values using the current estimates of the parameters, and the second is a forward pass using the forecasting equation that has been initialised using the estimated prior values [117].

3. Model Diagnostics: The models are checked to determine if the "correct" model has been selected. This is done using two methods. The first is by studying the ACF and PACF plots of the residuals. If they are within the confidence interval (Upper and Lower Limit) then the models are valid. The second is the Ljung-Box-Pierce Q statistic. The statistic is used in a chi-square test, which is performed on the autocorrelations of the residuals. The test statistic is given by:

$$Q_m = n(n+2)\sum_{k=1}^{m}\frac{r_k^2}{n-k}, \tag{3.61}$$

where n is the number of time series observations, k is the time lag to be checked, m is the number of lags that must be tested and r_k is the sample autocorrelation function of the k^{th} residual term [125]. The statistic Q has an approximate chi-square distribution with $m-p-k$ degrees of freedom in an ARMA (p, q) model if the orders have been correctly specified [125]. If the statistics Q is less than the critical value at the selected significance level and degrees of freedom, then the model selected is appropriate [125]. If the model is not appropriate then it must be updated and re-estimated until an appropriate model is found.

4. Forecast: Once an appropriate model has been selected the forecasts can be made and the associated probability limits calculated. It is important to note that as forecasts are made further into the future it is likely that the forecast errors will become larger, thus it is recommended that the model be updated as new observations become available and the model re-estimated using the process explained [125].

Formulation for the AR(p) model is given by the function [125]:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p} + \epsilon_t, \tag{3.62}$$

where ϕ_p are the respective autoregressive parameters and ϵ_t is the residual at time t [125]. By using backshift notation and the backshift operator B, which changes the time period t to time period $t-1$ and is defined by $BY_t = Y_{t-1}$, the autoregressive operator is defined as [131]:

$$\phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p, \tag{3.63}$$

which is used to simplify the autoregressive model to [131]:

$$(1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p)Y_t = \epsilon_t, \tag{3.64}$$

and is written more concisely as [131]:

$$\phi(B)Y_t = \epsilon_t. \tag{3.65}$$

The formulation for the MA(q) model is written as [125]:

$$Y_t = \epsilon_t + \theta_1\epsilon_{t-1} + \theta_2\epsilon_{t-2} + \cdots + \theta_q\epsilon_{t-q}, \tag{3.66}$$

where θ_q are the respective moving average parameters and ϵ_{t-q} is the residual at time $t-q$ [125]. Using backshift notation and the backshift operator B, which changes the time period t to time period $t-1$ and is defined by $B\epsilon_t = \epsilon_{t-1}$, the moving average operator is defined as [131]:

$$\theta(B) = 1 + \theta_1 B + \theta_2 B^2 + \cdots + \theta_q B^q, \tag{3.67}$$

which is used to simplify the moving average model formulation to [131]:

$$Y_t = (1 + \theta_1 B + \theta_2 B^2 + \cdots + \theta_q B^q)\epsilon_t, \tag{3.68}$$

which is written more concisely as [131]:

$$Y_t = \theta(B)\epsilon_t. \tag{3.69}$$

The formulation for the ARMA(p, q) model is given by the function [125]:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p} + \epsilon_t + \theta_1\epsilon_{t-1} + \theta_2\epsilon_{t-2} + \cdots + \theta_q\epsilon_{t-q}, \tag{3.70}$$

where ϕ_p are the autoregressive parameters, and θ_q are the moving average parameters, which must be estimated. Y_t is the time series observation and ϵ_t are the residuals. The formulation for the ARMA models is simplified using the autoregressive and moving average operators previously defined to obtain the following backshift formulation [131]:

$$\phi(B)Y_t = \theta(B)\epsilon_t. \tag{3.71}$$

The backshift formulation for an ARIMA model is defined as:

$$\phi(B)(1-B)^d Y_t = \theta(B)\epsilon_t, \tag{3.72}$$

where d is the differencing order used [131].

3.3.3 Qualitative Models

Qualitative models are a form of subjective forecasting. The method is subjective as past experiences and intuition are usually incorporated into the model [93]. The following four qualitative approaches exist [93]:

- Delphi Method,
- Jury of executive opinion,
- Sales force composite,
- Consumer market survey.

3.3.4 Measuring Forecast Accuracy

Various techniques exist that can be used to measure the fit and forecast accuracy of a forecast method. The fit accuracy refers to the accuracy of the method in forecasting the values on the historical dataset and the forecast accuracy refers to the accuracy of the method in forecasting the values on the test dataset. Forecast accuracy always takes preference over fit accuracy. A lower value is preferred when using the forecast accuracy measures [72]. If comparing forecast methods across different time series, only Theil's U and MAPE should be used due to different units of measurement possibly being used [72].

Mean Absolute Deviation

The mean absolute deviation (MAD) measures the average absolute forecast error values across all the forecast entries and is given by the formula [92]:

$$MAD = \frac{1}{n}\sum_t |Y_t - \hat{Y}_t|. \tag{3.73}$$

Mean Absolute Percentage Error

The mean absolute percentage error (MAPE) measures the average absolute forecast error values expressed as a percentage of the actual value across all the forecast entries and is given by [92]:

$$MAPE = \frac{100}{n}\sum_t \frac{|Y_t - \hat{Y}_t|}{Y_t}. \tag{3.74}$$

Mean Square Error

The mean square error (MSE) measures the average difference between the actual observed value and the forecasted value across all forecast entries. It is given by the following formulation [92]:

$$MSE = \frac{1}{n}\sum_t (Y_t - \hat{Y}_t)^2. \tag{3.75}$$

Root Mean Square Error

The root mean square error (RMSE) measures the square root of the average difference between the actual observed value and the forecasted value across all forecast entries. It is given by the following formulation [92]:

$$RMSE = \sqrt{\frac{1}{n}\sum_t (Y_t - \hat{Y}_t)^2}. \tag{3.76}$$

Theil's U

Theil's U is a ratio between the forecast method currently being analysed and the no-change model, or the naive forecast 1 (NF1) model. The naive forecast function is given by:

$$\hat{Y} = Y_{t-1}. \tag{3.77}$$

The ratio in Theil's U statistic is based on the ratio of the root mean square error of the two models and is compared across the models being used [72]. Theil's U statistic is given by:

$$U = \frac{\sqrt{\sum(Y_t - \hat{Y}_t)^2}}{\sqrt{\sum(Y_t - Y_{t-1})^2}}. \tag{3.78}$$

A Theil's U value equal to 0 shows that the selected method forecasts perfectly, if U<1 the selected method forecasts better than the consecutive period no-change model and if U>1 then the selected method does not forecast as well. If U=1 then the selected forecast method performs just as well as the consecutive period no-change model.

3.3.5 Selecting Appropriate Forecasting Models

Table 3.1 is a guide that can be used to select an appropriate forecasting model based on the most commonly used techniques. The tables indicates what forecasting technique can be used depending on the number of historical data points available, the pattern that is shown in the historical data and the horizon period of the forecast (short, medium or long term forecasting).

Forecasting Method	**Data Pattern**	**Number of Historical Observations**	**Forecast Horizon**
Naive	Stationary	1 or 2	Very short
Moving Averages	Stationary	Number equal to the periods in the moving average	Very short
Exponential Smoothing			
Simple	Stationary	5 to 10	Short
Holt's	Linear trend	10 to 15	Short to medium
Winter's	Trend and seasonality	At least 4 or 5 per season	Short to medium
Regression-Based			
Trend	Linear and non-linear trend with or without seasonality	Minimum of 10 with 4 or 5 per season if seasonality included	Short to medium
Causal	Can handle nearly all data patterns	Minimum of 10 per independent variable	Short, medium and long
Time Series Decomposition	Can handle trend, seasonal and cyclical pattens	Enough to see two peaks and troughs in the cycle	Short, medium and long
ARIMA	Stationary or transformed to stationary	Minimum of 50	Short, medium and long

Table 3.1: *Selecting an appropriate forecast model - a guide on the most common techniques. Adapted from [61]*

3.3.6 Past Forecasting Studies

The following is a reflection on studies that used forecasting techniques in the fresh produce industry.

Tahir [102] performed a trend analysis study on the quantity and value of citrus exports from Pakistan. Two different models, namely the linear and quadratic trend models were used in the study. The forecasts were performed on an annual level using time series data spanning a period of 22 years from 1990 - 2011, with forecasts being made for the period 2012 - 2016 using the better performing model. The evaluation of the two techniques using mean absolute percentage error, mean squared deviation and mean absolute deviation showed that the quadratic trend model was better suited to forecasting export quantity and value as opposed to the linear trend model [102]. The results of the forecast show that value and quantity show a positive increasing trend for citrus exports from Pakistan at a 95% prediction interval [102].

Yusuf and Sheu [128] forecasted Nigerian citrus and mango production in the medium term. The forecasts made are based on the assumption that previous trends in area planted and yield, along with normal weather patterns would hold. The forecasts were performed using a time trend model with an emphasis on the growth model [128]. The forecast model made use of a time series dataset spanning the period 1961-2003 and was split into various sub-datasets so that the growth rates during different structural changes in the economy could be determined [128]. Forecasts for the period 2004-2010 were made using the growth model.

A study by Hamjah [56] in 2014 forecasted the production volumes of major crops in Bangladesh using the Box-Jenkins ARIMA Model. The ARIMA models were fitted to time series data for Bananas, Mangoes and Guavas to predict future crop production values. The results of the study show that ARIMA(2,1,3) for mangoes on Log-transformed data, ARIMA(3,1,2) for bananas on Log-transformed data and ARIMA(1,1,2) for Guavas are best suited in forecasting their respective production volumes in Bangladesh [56].

Ahmad, Ghafoor and Badar [1] used a log-lin model to estimate the growth trend and ARIMA models to forecast the production and export volumes of kinnow from Pakistan [1]. Time series data spanning a period of twenty-two years was used and showed that kinnow production grew by 2.87% per year and kinnow exports grew by 4.71% per year, which are the instantaneous growth rates. The compounded growth, which shows the growth over the twenty-two year period, is 2.92% for kinnow production and 4.82% for kinnow exports [1]. ARIMA models were fitted to the time series dataset and it was determined that the ARIMA(3,1,2) is best suited for forecasting kinnow production volumes and ARIMA(2,2,2) is best suited for forecasting kinnow export volumes from Pakistan [1].

A study in 2016 by Goedhals-Gerber [50] used the Box-Jenkins methodology for ARIMA models to forecast the throughput of grain imports at the Port of Cape Town. The objective of the forecast was to determine if sufficient capacity exists in the bulk grain terminal or if there is a justification to increase the capacity based on the predicted volumes [50]. Short to medium term projections in grain exports are difficult to produce due to the volatility in demand resulting from the market conditions after deregulation. This volatility results in quantities varying randomly with no pattern, thus a method that can take this randomness into account in the projection is required, hence the use of the ARIMA model. It was found that the probable upper limits on the forecast fall within the capacity range and so sufficient capacity exists to handle the grain import throughput through the multipurpose terminal [50].

Parametric and non parametric models were used by Dieng [36] to determine which model is better suited to forecast vegetable prices in Senegal [36]. Three parametric models, namely the naive method, exponential smoothing and ARIMA are used in the comparison along with spectral analysis, which is the non parametric model. The evaluation of the forecasts produced by each model was based on both qualitative and quantitative criteria [36]. The percentage root mean square error (PRMSE) is the quantitative criteria used. The qualitative evaluation was executed using the 4x4 turning points (TP) contingency table, which led to three ratios being computed for evaluation, namely the ratio of accurate forecasts (RAF), the ratio of worse forecast (RWF) and the ratio of inaccurate forecasts (RIF). The results of the forecast evaluation show that parametric models should be employed with higher emphasis placed on using the ARIMA model to forecast vegetable prices in Senegal [36].

The prices of rice and six other crops were forecasted by Ruekkasaem and Sasananan [94] in Thailand using various time series methods. The moving average, least squares regression method, single exponential smoothing, double exponential smoothing and Holt-Winter's multiplicative method were used with the best method selected for each crop based on mean absolute percentage error, mean absolute deviation and mean square deviation. The prices for each crop were forecasted into the future using the selected method and different crop rotation schedules were set up and analysed to determine which schedule would result in the maximum profit increase to the current practice followed by the farmers. The schedules were based either on maximum profit realised, shortest harvesting cycle or least water use [94]. Linear programming was used to solve each schedule and took into account the resource limitations that are currently faced by the farmers.

Cassava production (tons) in Nigeria was forecasted by Oni and Akanle [84] using time series data that spanned a period of 54 years. The models used are all exponential smoothing models and included Holt's linear trend, simple exponential smoothing, exponential trend model, Holt's additive and multiplicative damped trend methods. The methods were evaluated using root mean square error, mean absolute deviation, mean percentage error and mean absolute percentage error. The results showed that the seasonality has no effect on the rising trend observed in the cassava production and the best method to use for forecasting the future production volumes is the exponential trend model [84].

Regression analysis was used by Sellam and Poovammal [98] to predict crop yields, which is a critical issue faced in agriculture [98]. The study used annual rainfall, area under cultivation and the food price index over an 11 year period to predict rice yield in India by determining if any of the environmental parameters have an explanatory relationship to the rice yield [98]. Sitienei, Juma and Opere [99] used regression analysis for predicting tea yield in Kenya. The regression model used tea yield as the dependent variable and the climatic variables, precipitation, and maximum and minimum temperature as the independent variables [99].

A study by Schoorl, Holt and Mayer [96] in 1986 used alternative forecasting methods to predict future production and supply volumes of all commercial horticulture crops by dividing the production regions in Queensland, Australia into seven different regions and assigning crops to one of five categories based on their growing life, storage shelf life and flexibility of harvest time [96]. Each category uses its own production model to estimate annual regional production volumes. The models used make use of a combination of the following factors [96]:

- Number of trees at different age levels;
- Yield per tree at each age level;
- Area under cultivation for each crop at each age level;
- Area under cultivation for each crop;
- Yield per hectare;
- Crop wastage in the field (%).

Each category uses a different combination of the above factors based on the characteristics defining the category to produce a production estimate for each crop.

Citrus crop forecasts for the period 2006-2021 in South Africa are calculated by Dux Business Solutions, through the Citrus Growers' Association of Southern Africa [14], to be used in long-term infrastructure planning and provide supply-side estimates [14]. The forecast is made on the assumption that the budwood (young branches of the plant with buds that has been prepared for grafting onto rootstock) sales are based on a growers expectations of future citrus demand [14]. The model makes use of budwood sales, hectares under cultivation, average yield per age category and hectare, the estimated percentage of budwood that does not reach maturity, and land and water capacity constraints to build a forecast model to estimate annual production tons [14].

3.4 Allocation Models and Related Properties

Allocation can be described as the process of sharing something amongst recipients, an example of which would be a finite resource. Two types of allocation exist, either on the demand side or on the supply side. According to Yuan, Zhu and Garcia-Diaz [127] capacity allocation is the allocation of capacity to achieve the best possible system performance from the service facilities (Supply Side) and demand allocation is the allocation of demand to these service facilities (Demand Side). Demand allocation is useful when service facilities operate as separate entities, as it solves the problem of high cost and low efficiency [127]. Allocation techniques have been applied to multiple industries and fields to solve a variety of problems. Allocation techniques may take on various forms and vary from rule or logic based approaches to mathematical models such as Linear Programming (LP) based models. Some common examples of allocation problems are:

- Transportation Problem,
- Power Generation Problem,
- Scheduling Problem.

3.4.1 Characteristics of Allocation Techniques

Allocation techniques have various properties that influence the outcome of the solution. Allocation techniques are usually either truth-inducing or manipulable [8]. The use of truth-inducing techniques does not allow for competing recipients demanding the resource to overstate their resource requirement [8] in order to ensure that they receive a more favourable allocation, thus ensuring that they receive their resource requirement or as close to as possible [69]. Manipulable allocation techniques are the opposite of truth-inducing techniques. These methods allow for an overstatement of resources required by the competing recipients to ensure a more favourable outcome [69]. Allocation models can also be individually responsive. With individually responsive allocation techniques an activity's allocation of a resource will strictly increase with their demand for the resource if the other activities' demand remains unchanged [71]. Under an individually responsive allocation model, if an activity receives a positive allocation of the resource but requires more, then one will be given additional resources unless all the resource has been claimed [73]. Allocation techniques are said to be efficient if one activity's resource allocation cannot be strictly improved without making another activity's allocation worse. An allocation model is also envy-free if an activity prefers their allocation given to that of another activity [95].

3.4.2 Allocation Techniques

Allocation techniques either follow a rule-based approach to allocating the resources to activities or it may be a mathematical model that assigns the resources to the activities. Linear programming is the most common mathematical technique used for solving allocation problems and is usually used to find the optimal solution based on the set of constraints. The most basic allocation problem is one in which there is one resource type with a finite quantity originating from multiple supply sources and has multiple activities to which the resource quantity can be allocated, and all activities require one unit of the resource for every one unit of output. The formulation for this problem is as follows [126]:

$$\text{Min} \quad \sum_{i \epsilon \mathcal{I}} \sum_{j \epsilon \mathcal{J}} c_{ij} x_{ij} \tag{3.79}$$

$$\text{s.t.} \quad \sum_{i \epsilon \mathcal{I}} x_{ij} \leq s_j \qquad \forall j \epsilon \mathcal{J}, \tag{3.80}$$

$$x_{ij} \geq 0 \qquad \forall i \epsilon \mathcal{I}, \forall j \epsilon \mathcal{J}, \tag{3.81}$$

where c_{ij} is the cost of assigning the resource to activity i from source j, x_{ij} is the quantity of the resource assigned to activity i from source j and s_j is the total quantity of the resource available at the supply source j.

The generalised resource allocation problem builds on this problem by adding an additional parameter. This parameter represents the amount of the resource required by one unit of the activity i. For example, if one unit of activity 1 requires two units of the resource then every time an allocation is made to activity 1, it will receive two units of the resource. The formulation of the supply constraints then changes to [59]:

$$\sum_{i \epsilon \mathcal{I}} d_i x_{ij} \leq s_j \qquad \forall j \epsilon \mathcal{J}, \tag{3.82}$$

where d_i represents the amount of resource required by one unit of the activity i.

This model forms the basis from which more complex models can be developed. Examples of such models would be the changing of the variable x_{ij} to a binary variable to indicate that either the resource is allocated to that activity or it is not. Another example would be the addition of multiple resource types that can be allocated to each activity from each supply source.

If the problem requires that all resources must be supplied to an activity, then the problem can be modelled as a generalised transportation problem, which is done by imposing demand and supply constraints on the model. Unlike the generalised resource allocation problem where the quantity of the resource allocated does not have to equal the quantity available, the transportation problem must be balanced. A balanced transportation problem is one in which total supply equals total demand [126]. If total demand is less than total supply then a dummy demand node is added and carries a demand value exactly equal to the excess supply [93]. A problem has no feasible solution if total supply is less than total demand, strictly speaking [126]. However, the problem can be balanced by adding a dummy supply node. The supply at the dummy node represents the unmet demand and usually has some penalty assigned to it [93, 126]. The generalised transportation problem is formulated as:

$$\text{Min} \quad \sum_{i\epsilon\mathcal{I}}\sum_{j\epsilon\mathcal{J}} c_{ij}x_{ij} \tag{3.83}$$

$$\text{s.t.} \quad \sum_{i\epsilon\mathcal{I}} x_{ij} = s_j \qquad \forall j\epsilon\mathcal{J}, \tag{3.84}$$

$$\sum_{j\epsilon\mathcal{J}} x_{ij} = d_i \qquad \forall i\epsilon\mathcal{I}, \tag{3.85}$$

$$x_{ij} \geq 0 \qquad \forall i\epsilon\mathcal{I}, \forall j\epsilon\mathcal{J}, \tag{3.86}$$

where c_{ij} is the cost of assigning the resource to activity i from source j, x_{ij} is the quantity of the resource assigned to activity i from source j, s_j is the total quantity of the resource available at the supply source j and d_i is the total resource quantity demanded or required.

According to Winston [126] the following three assumptions must be made to solve the resource-allocation problem using linear programming:

1. The quantity of an assigned resource must be non-negative;
2. Benefits obtained are proportional to resources assigned;
3. Benefits obtained from more than one activity are the benefits of the individual activities summed together.

The second set of allocation techniques that may be used follows set rules to allocate the resources to each activity. The types of rule-based approaches that can be used vary and may be based on different logics as required by the problem or the user [69]. As a result, numerous different approaches may exist. There are, however, a few common rule-based approaches, which are used to allocate the resources. The allocation methods discussed assume that the number of activities in the set are greater than or equal to two, and that the resource requirements for each activity have been ordered in a non-increasing (i.e. largest to smallest) sequence in the set [54]. The following allocation methods are commonly used:

1. *Proportional* - With proportional allocation the resources are allocated to each activity based on the activities proportional contribution to some factor, usually the total demand for the resources when demand exceeds the supply [69]. Thus, each activity is awarded a fraction of their demand [8]. Proportional allocations are manipulable as the activity (user) may overstate their requirement to secure a higher proportional fraction, which results in a higher resource allocation that is closer to their requirement [69]. The proportional allocation method can be formulated as [7, 54]:

$$x_i = \text{Min}\left\{d_i, \frac{d_i}{\sum\limits_{l=1}^{n} d_l} s\right\} \qquad \forall i\epsilon\mathcal{I}, \tag{3.87}$$

   where n is the number of activities, x_i is the resource quantity allocated to an activity, d_i is the total resource quantity demanded by an activity and s is the total resource quantity available that can be allocated.

2. *Lexicographic* - Lexicographic allocation techniques allocate resources to activities based on some predetermined priority sequence [69]. This method is a truth-inducing technique as there is no incentive for an activity to overstate their requirements as they will be allocated resources based on where they lie in the priority sequence. This method always tries to fill the quantity required of the resource with the highest priority first. The formulation for the lexicographic allocation technique is [54]:

$$x_i = \text{Min}\left\{d_i, \left(s - \sum_{l=1}^{i-1} x_l\right)\right\} \qquad \forall i \epsilon \mathcal{I}, \tag{3.88}$$

where x_i is the resource quantity allocated to an activity, d_i is the total resource quantity demanded by an activity and s is the total resource quantity available that can be allocated.

3. *Linear* - This technique allocates the quantity required to each activity minus some common deduction that is applied to all the activities [8]. This is based on the assumption that the smallest quantity required by an activity is greater than the common deduction. If the smallest quantity required by an activity is smaller than the common deduction, then the activity is assigned a zero allocation [7]. Linear allocation is a manipulable allocation method as the activity (user) may achieve a more favourable outcome if they overstate their requirements as the common deduction from their stated requirement may bring them closer to their actual requirement [8, 54]. Linear allocation problems are formulated as follows [8, 54]:

$$x_i = \begin{cases} d_i - \frac{1}{\tilde{n}}\text{Max}\left\{0, \sum_{l=1}^{\tilde{n}} d_l - s\right\} & \text{if } i \leq \tilde{n} \\ 0, & \text{otherwise,} \end{cases} \tag{3.89}$$

where $\tilde{n}$ is the largest integer less than or equal to n such that $d_{\tilde{n}} - \frac{1}{\tilde{n}}\text{Max}\left\{0, \sum_{l=1}^{\tilde{n}} d_l - s\right\} \geq 0$, x_i is the resource quantity allocated to an activity, d_i is the total resource quantity demanded by an activity and s is the total resource quantity available that can be allocated.

4. *Uniform* - Under a uniform allocation rule the resources available are uniformly allocated between the various activities [7]. If the quantity allocated to an activity is greater than the required quantity, then the surplus can be distributed among the remaining activities. This can be distributed based on some set rule and will only be done if there are activities that have a shortfall in the resource quantity allocated to them. This method is a truth-inducing method as the activity will not derive a more favourable outcome by overstating their resource requirements as they are assigned a uniform quantity [7]. The quantity assigned may only change if there is a surplus resulting from an activity not requiring their total allocation. The formulation for the uniform allocation method is as follows [8, 54]:

$$x_i = \begin{cases} \frac{1}{\hat{n}}\left(s - \sum_{l=\hat{n}+1}^{n} d_l\right) & \text{if } i \leq \hat{n} \\ d_i, & \text{otherwise,} \end{cases} \tag{3.90}$$

where $\hat{n}$ is the largest integer less than or equal to n such that $x_{\hat{n}} \leq d_{\hat{n}}$, x_i is the resource quantity allocated to an activity, d_i is the total resource quantity demanded by an activity and s is the total resource quantity available that can be allocated.

The following techniques are also used, however, not as commonly as the other techniques:

1. *Sorting Methods* - Sorting methods are used to assign resources to activities according to some predetermined ratio [64], which is used to drive the resource allocation process. Examples of such may be the benefits or costs associated with assigning resources to a specific activity. These methods may also take on numerous different logics to allocate resources to activities. Konur, Golias and Darks [64] present a sorting method that is based on the benefit-cost-ratio for each resource-activity pair. First-Submitted, First-Assigned (FSFA) and Ration-By-Schedule (RBS) were used by Kim and Hansen [63]. The FSFA is a greedy allocation algorithm that assigns resources to activities at the time that the request is placed for the resource. Future requests are not taken into consideration during the allocation process. The RBS approach allocates resources in a sequential manner by allocating the resource to the activity based on the order in which they are scheduled to be at a reference point at some point in time [63].

2. *Fixed Factor Allocation* - The fixed factor allocation technique presented by Li, Cai and Liu [69] is a combination of the lexicographic method and the proportional method. Activities are prioritised in a lexicographic fashion while the prioritised activity is also guaranteed a fixed proportion of available resources. The proportion of the available resources reserved for the prioritised activity is denoted by $0 \leq \alpha \leq 1$. If the prioritised activity requires less than its guaranteed allocation it will receive its requirement, however, if it requires more than its guaranteed allocation it will only receive its guaranteed allocation [69].

3.4.3 Applications of Allocation Models

The following section reflects on various studies that looked at capacity and demand allocations among a multitude of industries and supply chains.

Allocation methods have been applied to various different industries to solve a wide array of problems. Zografos and Martinez [132] developed an allocation method to improve port system performance by reallocating demand for services at the ports amongst the various ports in Ecuador. The belief behind the use of the allocation technique to determine what commodity volumes should flow through each port to satisfy commodity demand at the final destination is that overall transportation costs in the system will decrease without having to invest in the expansion of the ports [132]. The ports as a collective were studied as a system as many countries have multiple ports with some being over-utilised and others under-utilised. The allocation of commodity volumes to the different ports was executed using linear programming with the objective of minimising transportation costs in the system. The system's transportation cost with the use of the allocation model was compared with the system's transportation costs without the use of the allocation model and showed that there was a reduction in the overall transportation costs when the allocation model is used.

A study by Konur, Golias and Darks [64] compared the linear programming model for the resource allocation problem to sorting methods in the allocation of safety upgrades to on-grade railway-highway crossings (AGRHX). The objective of the allocation methods is to select the safety upgrades that should be allocated to each railway crossing amongst a set of alternatives such that the total benefits are maximised within the budget constraint. The sorting method approach used is based on the benefit-to-cost ratio of each upgrade-railway crossing pair.

Cachon and Lariviere [7, 8] and Li, Cai and Liu [69] performed studies on using allocation methods to allocate a supplier's capacity to retailers in a supply chain. In the studies, a single supplier supplies multiple retailers with the same product and only has a limited capacity from which the demand can be satisfied. In the studies by Cochan and Lariviere the allocation techniques are compared using an allocation game and so follows a game theoretic approach. The allocation game is used to determine if any of the allocation techniques induce the retailers to inflate their demand for capacity to ensure they receive a favourable outcome. The results show that retailers will inflate their demand if linear or proportional allocation is used by the supplier to allocate the capacity, but not with uniform allocation [7]. Uniform allocation actually suppresses the incentive to overstate the demand, as it does not result in a more favourable outcome. Li, Cai and Liu introduced the fixed factor allocation rule to allocate the supplier's capacity to the retailers. The fixed factor allocation method is compared to the lexicographic and proportional allocation methods and it is shown that the fixed factor allocation incorporates components of both these methods [69]. The results of the study show that the fixed factor allocation method has no effect on supply chain profit in sufficiently small and relatively large markets, but has an effect in medium markets if the factor is less than the particular threshold [69].

Kim and Hansen [63], and Vaze and Barnhart [124] both performed studies on the allocation of capacity in the aviation industry. Vaze and Barnhart developed a lower bound on the system wide delays that can be achieved whilst still ensuring all of the demand is satisfied when employing the demand management strategy [124]. The authors assumed the existence of a single monopolistic carrier and solved the aggregated timetable development and fleet assignment problem to ensure all the demand is satisfied and the same level of service currently experienced is maintained. The problem is solved using linear programming relaxation and heuristics and the problem is formulated as a large scale integer linear programming model [124]. The results of the study show that sufficient capacity exists in the system to handle the demand and that there exists room for improvement in the congestion levels. The study performed by Kim and Hansen [63] used two system-optimal assignment schemes and two ordered assignment schemes to allocate resources to airlines. The resource used is the available capacity in an airspace route in which an airline can fly [63]. The allocations are done to delay flights on the ground, which is much cheaper than delaying the flight in the air, thus the allocation techniques are used to minimise the increase in system costs resulting from the delays. The study compares and evaluate the increase in costs from the cost of the original flight plan (these are not included in the cost analysis as they are assumed to be the preferred route under normal circumstances) resulting from the en route capacity constraint causing delays [63]. The system optimal assignment uses cost submissions from airlines on the routes to simultaneously allocate resources to airlines with the objective of minimising costs. With the ordered assignment schemes the resources are allocated according to some order. The study makes use of the First-Submitted, First-Assigned (FSFA) and the Ration-By-Schedule allocation techniques. The FSFA is a greedy allocation technique and the lowest cost option for a route is formulated as:

$$r_n^*(j) = \text{arg Min}_{j \epsilon \mathcal{J}^A}(\Delta_{n,r(j)} + (d_{j,r(j)} - g_{0,n})) \tag{3.91}$$

where $r_n^*(j)$ is the lowest cost for route option n given the set of slots available $\mathcal{J}^A$, $d_{j,r(j)}$ is the departure time associated with each slot j belonging to route r, $\Delta_{n,r(j)}$ is the cost submission (measured in time units) made by the flight n on route r belonging to route j for using that route-slot pair before the ground delay is assigned, and $g_{0,n}$ is flight $n's$ original scheduled departure time. The results show that the sequential FSFA allocation scheme is more efficient than the system optimal schemes and may be perceived as more equitable. The results also show that the RBS approach may be less efficient for allocating resources, but results in greater equitable allocations [63].

Thompson, Nunez, Garfinkel and Dean [104] studied the allocation and reallocation of patients in a hospital during demand surges. The authors developed a decision support system, which is used for the proactive transfer of patients between floors when demand surges are anticipated. The problem involved multiple complexities and was modelled as a finite-horizon, discrete time, stationary Markov decision process to find an optimal capacity utilisation strategy [104]. The processes state is observed at a set point in time, known as the period, which is the time horizon split into fixed-length intervals. This set point in time is the beginning of the period. At this point in time a decision is chosen from a finite set and a cost is immediately incurred depending on what decision was chosen and the process state. This results in the transition probabilities for the next state, which is realised at the end of the period [104]. The process state is updated and the procedure is repeated. The results of the decision support system show that the allocation and reallocation of patients resulted in a reduction in average waiting time a patient experiences, from admission to being transferred to a floor, as a result of pre-emptively opening up capacity.

Li, Hendry and Teunter [68] performed a study on capacity allocation in a complex supply chain and aimed to optimise the allocation of capacity between facilities and products. The objective of the study was to optimally allocate capacity to different products in such a manner that overall profits in the system are maximised. The study incorporated both fixed cost elements in the supply chain as well as multiple factors that constrain capacity [68]. The results of the study showed that an integrated supply chain planning approach is much more effective than a decoupled approach.

A supply chain capacity allocation and scheduling study performed by Hall and Liu [55] modelled three different operational coordination issues between distributors and manufacturers. In the study a scenario is analysed whereby the manufacturer does not have enough capacity to satisfy demand, and so allocates capacity to the distributors. Based on these allocations the distributor must submit revised orders before the manufacturer schedules the orders, with the distributors having the option to share capacity. Based on this scenario, the authors model capacity constraints of the manufacturer as well as scheduling costs, and the capacity sharing problem faced by the distributors. The problem was modelled for an uncoordinated supply chain as well as for a coordinated supply chain, which allowed the value of additional profits for the entire system to be estimated when decisions made by the manufacturer and distributor are coordinated [55].

A study by Iyer, Deshpande and Wi [58] used demand postponement as a strategy to counter demand surges that may potentially arise, and analysed its performance thereof. The model used for postponing the demand would postpone demand from the regular period to a postponement period where the demand would then be fulfilled. A cost associated to the postponement of demand is also included in the model, which is used to re-reimburse the customer for postponing their demand. The model also took into account different methods of postponing the demand. Either all the demand for a certain percentage of customers can be postponed or a percentage of the demand for each customer can be postponed. The results show that the use of the postponement model may lead to overall cost reduction and capacity required in the system [58].

3.5 Conclusion

Mathematical models are used to test the effects of changes to a system and so can be used in the study to understand the changes to the citrus export cold chain as a result of “forced” allocation.

Different forecasting techniques are available, the use of which is dependant on the type of data being used and the accuracy of the model in predicting future values based on that respective data. Pegel's classification can be used to classify the data and select appropriate forecasting models that fit the characteristics of the historical citrus exports. Accuracy measures, such as mean square error and Theil's U, can be used to select the best suited technique from the list of potential forecasting models after Pegel's classification. The forecasting techniques reviewed, which range from causal techniques to time series techniques, can be used to predict future export volumes. Previous forecasting studies utilised a wide range of techniques to forecast fruit and vegetable production or export quantities, and so provide a starting point for determining suitable citrus export forecasting models.

Allocation models can be used both on the demand and supply side of the problem for allocating resources to activities, with a variety of techniques being available. Allocation techniques are broken down into rule or logic based techniques and mathematical techniques, with rule-based being the most common. The various techniques reviewed can be employed to allocate the citrus throughput capacity amongst the qualifying production regions in the modelling process.

CHAPTER 4

Methodology

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4.1 Introduction

This chapter deals with the analysis of the data sets that were provided for use in the study along with the development of the allocation model framework to generate proposed solutions.

Multiple models are utilised to determine the feasibility of using "forced" allocation to free up throughput capacity at the Port of Durban. The study utilises both predictive and prescriptive mathematical models to propose alternative solutions.

Forecasting, which is a predictive model, is used to forecast future export volumes that are used as inputs to determine possible allocation plans for the future.

Linear Programming (LP), which is a prescriptive model, is utilised to solve the optimal allocation of actual or predicted volumes in the citrus export cold chain to the ports, taking into account the imposed limitation on the throughput that the Port of Durban may handle, and the maximum volume a production region may export through the Port of Durban.

The development of the proposed solutions follows a six step approach. During Step S1, the allowable throughput scenario's are defined. Step S2 involves defining the data requirements and analysing the data. Step S3 is the extraction and analysis of (A) the 2019 actual citrus export volumes, and the forecasting of (B) the 2019 and (C) 2021 forecasted years citrus export volumes. Step S4 is the calculation of the theoretical excess capacity at the alternate ports for citrus exports. Step S5 is the formulation of the allocation model framework and Step S6, the last step, is the application of the allocation model framework to the citrus export volumes, and the analysis of the results generated. Figure 4.1 is a flow diagram that shows the overall solution approach followed.

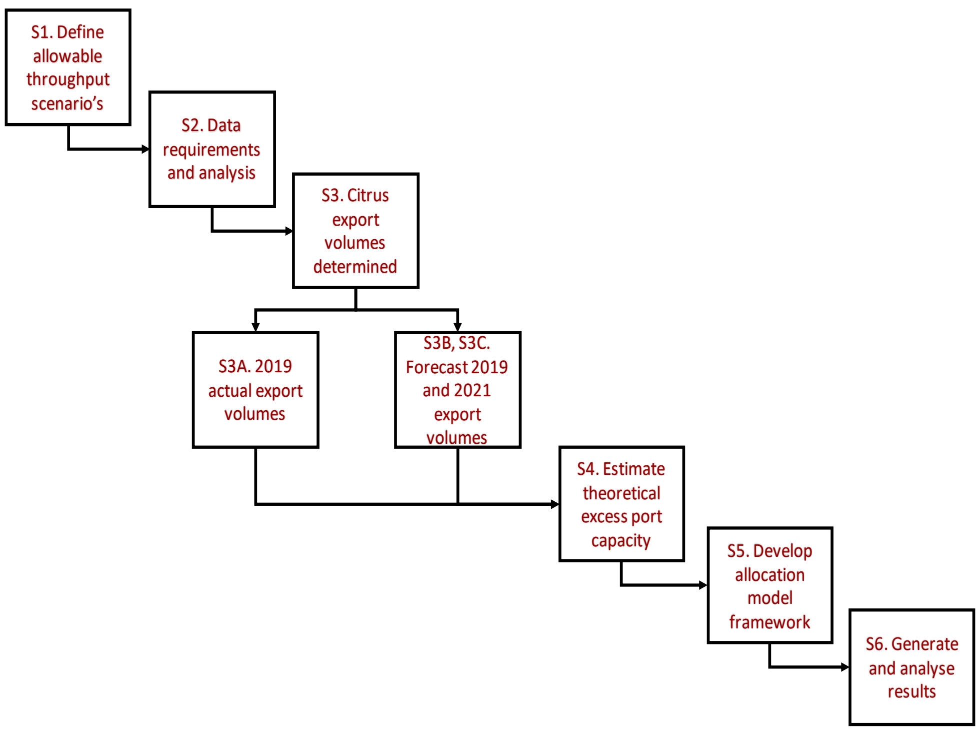

FIGURE 4.1: *Flow diagram of the overall solution approach*

Microsoft Excel [76] and *LINGO* [70] are the two software packages used. *Microsoft Excel* is used for the data and results analysis, and for the forecasting of future citrus exports. *LINGO* is used to execute the LP model for the reallocations.

4.2 Solution Approach and Scenarios Analysed

The feasibility of using "forced allocation" as a mechanism to free up throughput capacity at the Port of Durban is determined by limiting the allowable citrus throughput that the Port of Durban may handle in relation to the total citrus exports from the CGA production regions through the South African ports. As the demand for the citrus throughput capacity at the Port of Durban is higher than the allowable citrus throughput, the remaining volume must be reallocated. As the production regions are competing for the same citrus throughput capacity, allocation techniques are used to assign the total allowable citrus throughput amongst each of the production regions. The total allowable citrus throughput that may be handled at the Port of Durban, and the allocation given to each of the production regions, are used as constraints in a minimum cost transport problem to determine which ports should handle the citrus export volumes from the production regions and is solved using an LP model. The incremental changes in transport costs to the entire system and the availability of free capacity at the alternative ports to handle the additional citrus volume reallocated to them is used to determine the feasibility of the "forced" allocation mechanism, and if feasible, the best method to allocate the allowable citrus throughput amongst the CGA production regions competing for the allowable citrus throughput capacity.

The allowable citrus throughput, Step S1 in Figure 4.1, is based on the total citrus exports from the CGA production regions through the South African ports. For the best case scenario this would be that the Port of Durban handles as much volume as possible, which equates to its current citrus throughput or the "as-is" situation. As the study is focused on the effect of reducing throughput at the Port of Durban, this scenario is not analysed. The worst case scenario, which is the 0% scenario or Scenario 1, is that the Port of Durban cannot handle any citrus in the export season except for that volume that requires priority capacity at the Port of Durban as it cannot be reallocated elsewhere. Thus, it is not a pure 0% allowable throughput scenario. In addition to the worst case scenario, five other scenarios are analysed, and are based on limiting the citrus throughput relative to total citrus exports from the CGA production regions through the South African ports. Table 4.1 shows the allowable citrus throughput percentage for citrus exports at the Port of Durban per scenario.

Four different allocation techniques are utilised to assign the allowable citrus throughput at the Port of Durban to the CGA production regions competing for this citrus throughput capacity. The techniques used are proportional, lexicographic, linear and uniform allocation. These are rule-based techniques and the rules associated with each are used to set the parameters to allocate the allowable citrus throughput at the Port of Durban amongst the CGA production regions.

The combination of each of the throughput reduction scenarios with each of the allocation techniques results in 48 test cases that are analysed for the 2019 actual and forecasted datasets. For the 2021 forecasted values, an additional 24 test cases are analysed, which takes the total test cases analysed to 72. The best performing allocation technique for each scenario in the 2021 forecasted export season is used to propose possible export plans.

Scenario	**Allowable Throughput**
Scenario 1	0%
Scenario 2	10%
Scenario 3	20%
Scenario 4	30%
Scenario 5	40%
Scenario 6	50%

TABLE 4.1: *Allowable citrus throughput percentage to be handled at the Port of Durban per scenario relative to the total citrus exports for all CGA production regions*

4.3 Symbols Used

Table 4.2 is a schedule of the symbols that have been used in the research, along with their respective definitions. It is important to note that the symbols and notation used in the methodology chapter may differ to that used in the Literature Review to align with notation and symbols that are specific to the study. Table 4.3 and Table 4.4 are the numbers assigned to each production region and port respectively in the mathematical and statistical models used.

4.4 Unit of Measure Used

The modelling approach is based on the total volume throughput per week from each production region to the various ports in South Africa. Different units of measure are utilised in the study depending on the data set being used. The base unit of measure in the study is pallets; conversion factors are applied to the various datasets to convert the values to pallets. Table 4.5 shows the conversion factors used to convert one unit of measure into another. The twenty-foot equivalent unit (TEU) conversion factor is used to convert available capacity in TEU's into equivalent pallets and the cartons per pallet and kilograms per carton conversion factors are used to convert missing data fields in the data received by Company X. Using the CGA KIS statistics, a conversion factor of the average kilograms per pallet is derived based on the tons and pallets exported on the latest export year used in the historical dataset, which is the year 2018. This year is used as it is the closest representation of what the average weight per pallet will look like in the future; there has been no averaging out of the value by using historical data.

Break-bulk and reefer container volumes are aggregated into one figure and assumed to have all been transported via reefer container due to the fact that the datasets received and utilised do not distinguish between volumes transported via break-bulk in specialised reefer vessels and volume transported in reefer containers. Capacity analysis also shows that there is a shortage of container capacity and a surplus of break-bulk capacity. As such, the aggregation of the volumes would cause an over statement on the demand for container capacity and thus a greater reallocation amount required, which is alright as break-bulk volumes will always be shipped as break-bulk in reality, which has sufficient capacity. The removal of the break-bulk volume and the volume reallocated when the scenario is realised would leave an actual amount of containers to be exported through the Port of Durban that is less than allowable throughput. This would in theory open up more throughput capacity than required, thus creating an "artificial buffer" in the system, which should only be eliminated completely if no citrus is exported as break-bulk. As such, throughput volumes used in the study represent the total break-bulk and reefer container volumes, and estimated capacity available is only for container capacity and excludes break-bulk capacity.

Table 4.6 shows an example of how the aggregation of break-bulk and reefer container volumes into one figure results in an overestimation for required capacity, and thus, greater throughput capacity being released than required. The table shows a theoretical throughput per shipment mode at the port. Using the assumptions of the study, all volume is aggregated into one figure. This example requires that a theoretical 4% of the pallets shipped via container needs to be reallocated, which translates into 440 pallets needing to be reallocated based on total throughput or 400 pallets based on container throughput. As a result, 9,560 pallets shipped in containers will be allowed through the port, which is an actual reduction of 4.40% in pallets based on container throughput, but a 4% reduction based on total throughput as break-bulk will still go through the port even though it was included in the reallocation calculation. For the scenario where the

Symbol	Description
A_j	Total citrus throughput at port j
A_{jk}	Total citrus throughput at port j in week k
A_{ijk}	Total citrus throughput from production region i through port j in week k
B_j	Citrus volume to be reallocated away from port j
C_{ij}	Transport costs from production region i to port j
D_{ik}	Citrus volume that must be exported from a production region i in week k
E_{ijkn}	Volumetric index representing the percentage exports from production region i to port j in week k of export season n
F_{ij}	Total citrus volume that must be exported from a production region i to port j in the export season
G_{ijkn}	Citrus export volume from production region i to port j in week k of export season n
H_n	Total citrus export volume for export season n for all production regions combined
λ	Total number of weeks in a calendar year
κ	Total number of weeks in the calendar year that had export volume
M_{ijk}	Maximum volume that can be exported from production region i through port j in week k
N_{ijk}	Minimum volume that must be export from production region i through port j in week k
O_j	Total annual volume assigned priority capacity at port j
O_{jk}	Volume assigned priority capacity at port j in week k
P_{jk}	Citrus throughput capacity available at port j in week k
P'_{jk}	Adjusted citrus throughput capacity available at port j in week k
Π_j	Theoretical excess citrus capacity for exports at port j
Q_{ij}	Maximum citrus volume that can flow between a production region i to port j in an export season
R_j	Allowable citrus throughput at port j
R'_j	Adjusted allowable citrus throughput at port j
T_j	Allowable throughput percentage of the total citrus exports allowed through port j
U_j	Total container demand (exports and imports) at port j
V_{jk}	Index representing the citrus export volume of week k to the total citrus exports at port j
W_j	Excess port capacity available at port j
x_{ijk}	Citrus volume to be exported from a production region i to port j in week k
$\mathcal{I}$	Set of all production regions
$\mathcal{J}$	Set of all South African ports
$\mathcal{K}$	Set of all weeks in an export season
$\mathcal{N}$	Set of all export seasons
$\mathcal{Y}$	Set of all production regions excluding all the dummy regions
$\mathcal{Z}$	Set of all production regions excluding the dummy region "Unknown-DBN"

TABLE 4.2: *Name and description of symbols used in the methodology*

reallocation quantity is calculated on pallets shipped via container, the reduction based on total volume is 3.64%, but 4% based on pallets shipped via container, which is fine as the throughput reduction is applicable to reducing only container throughput volume, not total throughput

Production Region	Region Number i
Senwes	1
Letsitile	2
Hoedspruit	3
Nelspruit	4
Limpopo River	5
Onderberg	6
Nkwalini	7
Southern KZN	8
Pongola	9
Burgersfort Ohrigstad	10
Eastern Cape Midlands	11
Patensie	12
Sundays River Valley	13
Western Cape	14
Boland	15
Orange River	16
Vaalharts	17
Unknown-Coega/PE	18
Unknown-CPT	19
Swaziland	20
Zimbabwe	21
Unknown-DBN	22

TABLE 4.3: *Region numbers assigned to each production region ($i \epsilon I$) in the mathematical and statistical models*

Export Port	Port Number j
Port of Durban	1
Port of Coega/PE	2
Port of Cape Town	3

TABLE 4.4: *Port numbers assigned to each export port ($j \epsilon J$) in the mathematical and statistical models*

Conversion	Citrus
Kilograms per equivalent carton*	15kg
Equivalent cartons per pallet [52, 65, 120]	70
Standard pallets per TEU [32]	10
Average Kilograms per pallet in the 2018 export season [26]	1,196

*Shared by Company X.

TABLE 4.5: *Conversion factors used to convert to different units of measure*

volume. The aggregation of the break-bulk and containerised volumes is expected to result in an overestimation of less than 10% each year. According to Brooke [4, 5] citrus transported via break-bulk as a percentage of total citrus export volume was 9.66% in the 2018 export season and projected to be 8.08% in the 2019 export season. The Port of Durban exported 6.4%, the Port of Cape Town 2.49% and the Port of Coega/PE 0.76% of citrus via break-bulk in the 2018 export season, with the 2019 export projections being 5.57%, 1.95% and 0.56% respectively. As such, the theoretical overestimation at the Port of Durban is expected to be between 5.57% and 8.08% for the 2019 export season, with the following years expected to be less than this as industry trends show the demand for break-bulk decreasing in the future as seen in Figure 1.7.

	Reduction Required	Container Throughput	Break-bulk Throughput	Total Throughput
Scenario requirement	4.00%			
As-is throughput		10,000	1,000	11,000
Based on total throughput	(440)			
To-be allowable throughput		9,560	1,000	10,560
Actual reduction %		4.40%	0.00%	4.00%
Based on container throughput	(400)			
To-be allowable throughput		9,600	1,000	10,600
Actual reduction %		4.00%	0.00%	3.64%

TABLE 4.6: *Theoretical example showing how the aggregation of break-bulk and reefer container volumes into one figure results in an overestimation for demand and a greater quantity of throughput capacity being freed up than required.*

4.5 Data Requirements, Analysis and Preparation

This section describes Step S2 of the solution approach in Figure 4.1, which includes the analysis and preparation of the data required to model the problem. Data used in the study was sourced from four sources, namely Company A [32], Company X [42], the CGA Key Industry statistics (CGA KIS) [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27] and the National Ports Plan 2019 Update [105]. The data supplied by Company A and Company X are not available in the public domain, however, the CGA KIS and National Ports Plan 2019 Update are.

As mentioned, the allocation model framework is applied to the 2019 actual citrus export volumes and the 2019 and 2021 predicted citrus export volumes. As such, different datasets are required for each of these years. The citrus export volume for the 2019 actuals is derived from the dataset supplied by Company X. The 2019 and 2021 predicted export volumes are derived from a combination of both the dataset supplied by Company X and the CGA KIS. Estimated port capacity for the remaining South African ports, excluding the Port of Durban, is derived from the National Ports Plan 2019 Update, and the transport costings used are from the data supplied by Company A.

4.5.1 Company X Data Analysis

The data provided by Company X, used in Step S3A, S3B and S3C of Figure 4.1, is the historical weekly export quantity from each production region, through each port to its export destination by citrus type. Export quantities are shown in pallets, mass, cartons and equivalent cartons. The years provided were 2016-2020. Data could only be provided for the full years 2017-2019, as the 2020 export season had not yet been completed and Company X had only started collecting data in this detailed format from the middle of 2016. As such, the 2016 and 2020 export data are excluded due to their incompleteness.

Data analysis of the datasets provided by Company X show that all the required data fields are available, however, within the required fields there are some missing entries. In the exporting port field, some entries do not have an exporting port listed or are labelled as “unknown”. In the production region field there are "unknown" entries. The country of destination field has "unknown" entries, and also shows entries for which South Africa is the importing country.

Analysis of anomalies show that some entries have values in the carton quantity field, but not in the pallet quantity field and/or mass field. No negative entries were found in the dataset.

4.5.2 Company X Data Preparation and Refinement

To be able to use the dataset in the study it was refined to deal with the unknown and missing entries and prepare it into the correct format. The following approach was used:

1. If a data entry has a value in the carton quantity field but not in the pallet quantity field and/or mass field, then calculate the missing value using the conversion factors in Table 4.5. If an entry shows zero in all the quantity fields, exclude this entry from the analysis.
2. The following rules are used to flag the final exit port and production region:
   - 2.1. If the exporting port field shows the port name then flag the exit port as this port name, and if any of these entries have an unknown entry in the production region field then change the production region name to "Unknown-DBN" for exports through the Port of Durban, "Unknown-CPT" for exports through the Port of Cape Town and "Unknown-Coega/PE" for exports that went through either the Port of Coega or the Port of Port Elizabeth. These are dummy nodes that are used to represent their origin. For the Port of Durban, this indicates that this volume requires priority capacity at the Port of Durban as it cannot be reallocated as its true origin is not known. This volume is excluded from the cost analysis. To ensure that the volumes from the dummy node for the other ports still get exported through their respective port, the dummy node is assigned a zero costing to export through its respective port, and a large costing to export through an alternate port.
   - 2.2. If the exporting port field does not have an exporting port recorded, flag the exit port using the production region and Table 1.2 to use the preferred port for that region.
   - 2.3. If the exporting port and production region are both unknown then assign the Port of Durban as the exit port and change the production region name to "Unknown-DBN". This approach is taken as the study is focused only on exports passing through the Port of Durban and so excluding this volume may potentially result in an understated reallocation being required if all of this volume was exported through the Port of Durban in reality. By assigning all the volume to the Port of Durban, it may mean that a potentially overstated amount may need to be reallocated. However, in terms of the objective of the study, this is the best approach as it will mean additional throughput may be released, essentially creating a buffer in the system at the Port of Durban. These export volumes are accounted for by assigning priority capacity to this export volume at the Port of Durban first, and then running the reallocation model. These volumes are excluded from the cost analysis.
3. Those entries that require priority capacity assignment at the Port of Durban must be flagged. These are the entries where the production region is not known and the Port of Durban has been assigned as the exit port.
4. A region number must be assigned to each production region as per Table 4.3, which is used as a standardised reference in the modelling and forecasting process.

5. For those entries where the destination country is not known, no adjustments are made as the destination country is not in the scope of the study. Entries in the dataset that showed South Africa as the export destination country are still included as these are most likely shipments that were scheduled to be exported, but were instead traded between exporters and moved to the local market [41]. The quantities, however, may still have been shipped to another South African Port and still handled in the port, thus their quantities are accounted for.

6. A sub dataset is created that shows only the volumes that have Durban as the exit port and shows the volumes that are available for reallocation (excludes priority capacity assignment volumes). This is the dataset from which the allowable throughput at the Port of Durban is calculated and thus the volume to be reallocated to another port. The maximum allowable throughput that may flow between a region and the Port of Durban is also calculated from this dataset. The main dataset is used to determine the total citrus export volumes that need to be exported from each production region per week.

The data provided by Company X is used to create the 2019 actual datasets. Due to the historical size of the dataset provided by Company X, it is insufficient to be able to accurately forecast future volumes on its own. As such, a combination of datasets from different sources, such as the 2019 CGA KIS [26], are used in conjunction with the data provided by Company X to forecast the predicted export volume.

4.5.3 Citrus Growers' Association Key Industry Statistics Data Analysis

Due to the limitation on the historical size of the dataset provided by Company X, the Citrus Growers' Association of Southern Africa Key Industry Statistics (CGA KIS) [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27] for various years was used to obtain data that is used in conjunction with the data provided by Company X to forecast future values. This data was used in Step S3A, S3B and S3C of the solution approach in Figure 4.1,

The CGA KIS data is very limited as it only shows the total annual citrus export, local consumption and processed volumes (combined equals the total production volume) for South Africa by citrus type. There is no split between production region, week, export port or destination.

Data analysis of the CGA KIS data from 2003-2019 showed no signs of negative or missing entries or anomalies. Some years showed a discrepancy between the sum of the local, export and processed volumes and its corresponding published total. The largest absolute difference as a percentage of the total volume for a year is less than 0.001%, which is insignificant and is ignored as this is most probably due to a rounding error. No further corrective action is taken on the dataset.

4.6 Forecasting Predicted Export Volumes

The modelling approach used requires that the citrus export volumes be broken down by week, CGA production region and exit port, and so the forecasted export volumes also need to be calculated in this fashion. This step corresponds to Step S3B and S3C in Figure 4.1. Figure 4.2 is a framework of the forecasting approach taken to predict future export volumes.

A combination of the datasets provided by Company X and the data extracted from the CGA KIS was utilised to determine the forecasted export values. The datasets are used in conjunction

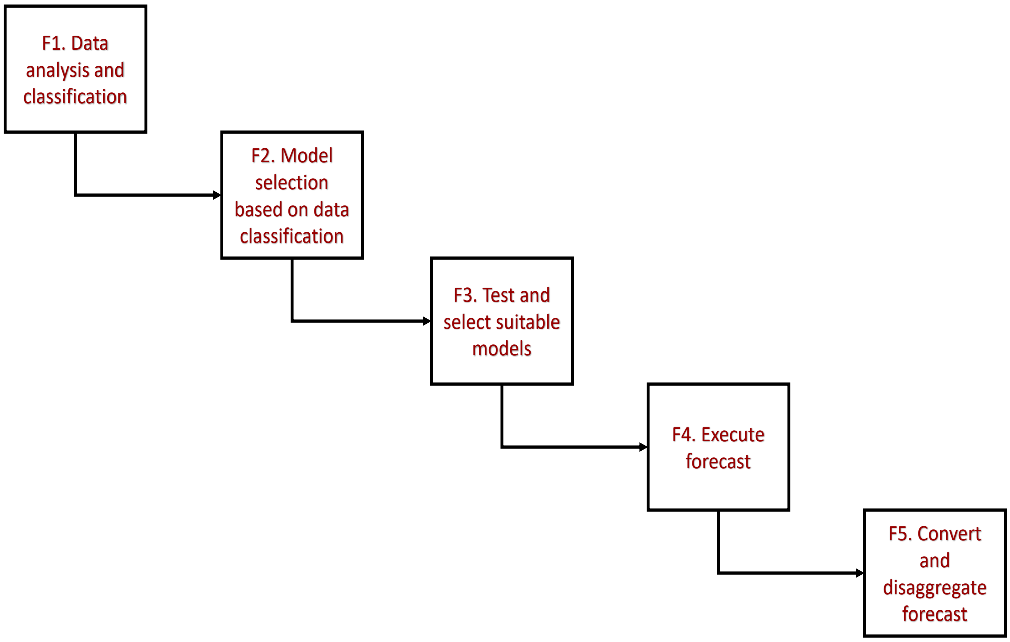

FIGURE 4.2: *Framework of the forecasting approach taken*

with each other due to unique limitations of each dataset. The dataset provided by Company X shows the production region, port and week breakdown, however, its historical data is very limited. The CGA KIS show the historical export volumes, however, it does not show the breakdown per production region, week and exit port. As such, data is extracted from both of these datasets to build a forecast model for predicting future export volumes. The CGA KIS export data is used to predict future export volumes, and the data provided by Company X is used to create indices that are used to disaggregate the consolidated annual forecasted export volumes by production region, week and exit port.

The first step (Step F1 in Figure 4.2) in forecasting the predicted export volumes requires that the dataset be split into two datasets, namely the historical dataset and the test dataset, which are used to determine the fit and the forecast accuracy of the forecast model respectively. The export data extracted from the CGA KIS is the aggregated citrus tons exported from the CGA production regions for the period 2003-2018. A requirement of forecasting is that the test dataset be at least 20% of the dataset. As such, the years 2003-2014 form the historical dataset and the years 2015-2018 form the test dataset. Pegel's classification (Figure 3.2) and Table 3.1 are used to determine suitable forecasting models (Step F2 in Figure 4.2).

The identified models are tested (Step F3 in Figure 4.2) based on the lowest mean square error of the test dataset, giving forecast accuracy preference over fit accuracy, to determine which model(s) are suited to do the forecast. Theil's U is also used as another goodness-of-fit measure in the selection process. The mean squared error is used over the mean absolute deviation as it is considered a better measure. Together these measures, along with Theil's U, make up original accuracy measurement techniques and are not derivatives of other techniques. The mean square error is utilised as it takes into account the magnitude and direction of the errors, and places a higher weighting on larger outliers which are undesirable, thus indicating an unsuitable model, which may not be shown in other measure, such as mean absolute error. The selected forecasting method is used to predict citrus export volumes, (Step F4 in Figure 4.2), for the years 2019 and 2021 using the full dataset from 2003-2018 (historical and test datasets are combined for executing the final forecasts).

The allocation model framework requires that the export volumes be shown in pallets, and not tons as forecasted using the CGA KIS data (Step F5 in Figure 4.2). The average kilogram per pallet in the 2018 citrus export season, which is shown in Table 4.5, is used to do this conversion.

Once the predicted annual citrus export volumes in pallets have been forecasted, the annual volume is broken down into a volumetric file that shows the export volume by production region by week by exit port (Step F5 in Figure 4.2). To do this, the data provided by Company X is utilised to create an index that represents the weekly export volume from a production region through a specific port as a percentage of the total export volumes. As such, the sum of the indices to be used equals one. The dataset provided by Company X post data categorisation and refinement is used. The data provided by Company X is very limited, with only three full years of historical data being available, of which two correspond to historical or test years (2017 and 2018) and one year corresponding to a forecast year (2019), which allows for a very limited calculation to be made. As such the indices are based on the combined export volumes for the 2017 and 2018 export years, and is applied to all the forecasts as these years will give the closest representation of what the future breakdown would look like. The formulation for the generalised volumetric index is as follows:

$$E_{ijkn} = \frac{G_{ijkn-1} + G_{ijkn-2}}{H_{n-1} + H_{n-2}}, \tag{4.1}$$

$$\text{with} \quad \sum_{i\epsilon\mathcal{I}} \sum_{j\epsilon\mathcal{J}} \sum_{k\epsilon\mathcal{K}} E_{ijkn} = 1, \tag{4.2}$$

$$0 \leq E_{ijkn} \leq 1, \tag{4.3}$$

where E_{ijkn} is the volumetric index that represents the weekly citrus exports from a production region i to a South African port j in week k in the export season n. G_{ijkn-1} and G_{ijkn-2} are the weekly export volumes from a production region i to a South African port j in the previous export season and the export season preceding that export season, and H_{n-1} and H_{n-2} are the corresponding total annual citrus export volumes for the same respective export seasons.

4.7 Estimated Port Capacity at Alternate Ports

This section corresponds to Step S4 in Figure 4.1. Port capacity is based on the number of containers its infrastructure can move in the period, regardless of whether the container is an imported container or an exported container. Secondly, a variety of commodities are exported and imported, both in standard dry containers and in reefer containers. Due to this fact, the available capacity is shared and is not assigned specifically to a commodity or an import/export. Lastly, a port has a specific design capacity, which is the maximum theoretical number of containers it can handle in a period. Due to these factors, it is not possible to determine exactly how much capacity would be available and possibly assigned to citrus exports at each port in a specific period.

For the purpose of the study, the capacity at the Port of Durban is assumed to be insufficient, with different scenarios of allowable citrus throughput, and thus required throughput reduction being used to determine the citrus volume that must be reallocated. The remaining ports in

South Africa are assumed to have sufficient capacity to handle the citrus volumes that are reallocated to them. However, a high level estimation of throughput capacity available to citrus is completed to validate whether the quantity to be accommodated at the other ports is still within the ports theoretical capacity constraints or if the theoretical capacity at the port should be increased for citrus.

Due to the availability of sufficient data, the high level available capacity estimation is calculated on the total design capacity for containers and the total container throughput. The number of plug points in the stacks is excluded from the calculation as the availability of such plug points is dependant on a variety of factors, which are not in the scope of the study. The theoretical excess container capacity available for handling additional citrus throughput at the alternative ports is calculated as the share the citrus export volumes have in the excess port capacity available, and is calculated as follows:

$$\Pi_j = \frac{A_j}{U_j} * W_j, \tag{4.4}$$

where Π_j is the theoretical excess citrus capacity for exports in a given year, A_j is the current total citrus volume exported through the port for a given year, U_j is the total container demand (exports and imports) at the port for a given year and W_j is the excess port capacity available in a given year.

The calculation is done on an annual level due to the design capacity being calculated on an annual level, the national ports capacity data being available on an annual level and the citrus reallocation percentage and quantity being calculated as a seasonal figure and not as a weekly figure. The demand and capacity analysis and projections shown in the National Ports Plan 2019 Update [105] are utilised for the purpose of this calculation. The demand and supply shown includes both exported and imported volumes, which is a result of imports and exports sharing the same infrastructure and port throughput being calculated on total container moves. The data available groups the ports based on their location. For container volumes, the central ports are made up of the Port Elizabeth, Coega and East London ports, and the western ports are made up of the Port of Cape Town. Their respective design capacities are available, however, the demand shown is an aggregation of the respective central and western ports. As the western ports consist of one port this is not an issue, however, the central port consists of three ports. For the purpose of the study Coega and Port Elizabeth's volumes are aggregated into one figure due to their proximity to each other and both being citrus export ports. Including the East London figure may result in an over estimation of available capacity, since East London is not considered a citrus export port, and so an adjustment is required. The adjustment is made by excluding the East London capacity, but leaving total demand unchanged as this would result in an underestimated, worst case availability of capacity.

4.8 The Allocation Model Framework

This section corresponds to Step S5 in Figure 4.1. The allocation model framework follows a two step process. The first step involves allocating volumes that require priority capacity at the Port of Durban. These are the volumes that have the Port of Durban as the exit port and have an unknown production region and so cannot be reallocated. This is known as the preallocation. The preallocation involves taking those volumes that require priority capacity and assigning them capacity at the port first and is formulated as:

$$x_{ijk} = O_{jk} \qquad i = 22, j = 1, \forall k \epsilon \mathcal{K}, \tag{4.5}$$

where x_{ijk} is the allocated citrus volume that will be exported from the production region i through port j in week k and O_{jk} is the citrus volume demand that must be assigned priority capacity in week k at port j before the reallocation model is run. As such, the capacity available at the Port of Durban for the remaining citrus volume to be exported from each production region is reduced and so the constraint in the reallocation model must be adjusted accordingly.

Citrus volume is only allocated priority capacity at the Port of Durban with no priority capacity being assigned to the other ports. This is to ensure that the capacity used at the alternative ports sums correctly without having to do any manual adjustment. If the "Unknown-Coega/PE" and "Unknown-Cape Town" production regions are assigned priority capacity, then the capacity used after the reallocation would have to be manually adjusted to account for this volume exported through the respective ports. Instead, these production regions are not assigned priority capacity to be used in the preallocation model, but rather included in the citrus volume that must be assigned in the reallocation model. These regions are assigned a cost of zero to export through their respective port and a high cost to export through an alternative port, which forces it to be assigned to its preferred port, namely the Port of Coega/PE and Port of Cape Town respectively.

Once the preallocation has been completed, the allocation of the remaining volumes from each production region to the ports within the imposed constraints can be executed. Denote $\mathcal{Z} = \mathcal{I} - \{22\}$, as the set of production regions excluding the dummy production region "Unknown-DBN". A Linear Programming (LP) optimisation model is used to determine what citrus volume should be exported from each region through the respective ports each week by minimising the transport cost incurred in the system, and is referred to as the reallocation model. The model is formulated as:

$$\text{Min} \quad \sum_{i \epsilon \mathcal{Z}} \sum_{j \epsilon \mathcal{J}} \sum_{k \epsilon \mathcal{K}} C_{ij} x_{ijk} \tag{4.6}$$

$$\text{s.t.} \quad \sum_{j \epsilon \mathcal{J}} x_{ijk} = D_{ik} \qquad \forall i \epsilon \mathcal{Z}, \forall k \epsilon \mathcal{K}, \tag{4.7}$$

$$\sum_{k \epsilon \mathcal{K}} x_{ijk} \leq Q_{ij} \qquad \forall i \epsilon \mathcal{Z}, \forall j \epsilon \mathcal{J}, \tag{4.8}$$

$$\sum_{i \epsilon \mathcal{Z}} x_{ijk} \leq P'_{jk} \qquad \forall j \epsilon \mathcal{J}, \forall k \epsilon \mathcal{K}, \tag{4.9}$$

$$x_{ijk} \leq M_{ijk} \qquad \forall i \epsilon \mathcal{Z}, \forall j \epsilon \mathcal{J}, \forall k \epsilon \mathcal{K}, \tag{4.10}$$

$$x_{ijk} \geq N_{ijk} \qquad \forall i \epsilon \mathcal{Z}, \forall j \epsilon \mathcal{J}, \forall k \epsilon \mathcal{K}, \tag{4.11}$$

$$x_{ijk} \geq 0 \qquad \forall i \epsilon \mathcal{Z}, \forall j \epsilon \mathcal{J}, \forall k \epsilon \mathcal{K}, \tag{4.12}$$

$$x_{ijk} \epsilon \mathbb{Z} \qquad \forall i \epsilon \mathcal{Z}, \forall j \epsilon \mathcal{J}, \forall k \epsilon \mathcal{K}, \tag{4.13}$$

where x_{ijk} is the allocated quantity of citrus that will be exported from CGA production region i to port j in week k, and C_{ij} is the transport cost from CGA production region i to port j. D_{ik} is the demand quantity of citrus that needs to be exported from CGA production region i in week k. Q_{ij} is the maximum quantity that can flow between a CGA production region i to the port j for the entire export season. P'_{jk} is the adjusted capacity available at port j in week k to export citrus after accounting for the citrus volume that is assigned priority capacity at the port, which is deducted from the available port capacity. M_{ijk} is the maximum quantity of citrus that can be exported from a CGA production region i through port j in week k. N_{ijk} is the minimum quantity of citrus that must be exported from a CGA production region i through port j in week k. Equation 4.7 ensures that the total citrus export quantity at each region for each week is allocated to ports and Equation 4.8 ensures that the total quantity exported between a region and a port is not greater than the quantity that is allowed to flow between each region and that port for the export season. Equation 4.9 ensures that the total quantity assigned to a port in a given week does not exceed its adjusted available capacity. Equation 4.10 ensures that the quantity allocated to a port each week from a region does not exceed that maximum quantity that can flow on that route for that specific week, and Equation 4.11 ensures that a specified minimum quantity is allocated to a specific port from each region each week. The last two equations are non-negative and integer constraints.

The allocation model framework is executed across the export season per week for the different scenarios, which represent the available citrus throughput capacity at the Port of Durban, and the allocation technique used. These scenarios are executed by changing the demand D_{ik} and capacity parameters, Q_{ij} and P'_{jk}, in the reallocation model.

4.9 Allocation Model Framework Input Files

Using the refined dataset from Company X and the forecast datasets, various input files are created that represent the constraints, parameters and variables in the allocation model. The files are used to calculate the "as-is" situation as well as the "to-be" situation, so that comparisons can be made and the feasibility of the "forced" allocation model determined.

4.9.1 Priority Capacity Demand (O_{jk})

The weekly priority capacity demand O_{jk} is the volume per week k that will be assigned priority capacity at port j before the reallocation model is run. Citrus export volume is only assigned priority capacity at the Port of Durban with no priority capacity being assigned at the other ports such that:

$$O_{jk} \geq 0 \qquad j = 1, \forall k \epsilon \mathcal{K}, \tag{4.14}$$

$$O_{jk} = 0 \qquad j \neq 1, \forall k \epsilon \mathcal{K}, \tag{4.15}$$

$$O_{jk} \epsilon \mathbb{Z} \qquad \forall j \epsilon \mathcal{J}, \forall k \epsilon \mathcal{K}. \tag{4.16}$$

The seasonal priority capacity demand O_j is then simply the total priority capacity demand over all the weeks k at port j such that:

$$O_j = \sum_{k \epsilon \mathcal{K}} O_{jk} \qquad \forall j \epsilon \mathcal{J}. \tag{4.17}$$

4.9.2 Seasonal Reallocation Quantity (B_j)

The seasonal reallocation quantity B_j is the quantity that must be reallocated away from the port for the entire export season based on the total citrus exports from the CGA production regions. As the study is only focused on reallocating citrus volumes away from the Port of Durban to alternate ports, the alternate ports are assigned a reallocation quantity of zero such that:

$$B_j \geq 0 \qquad j = 1, \tag{4.18}$$

$$B_j = 0 \qquad j \neq 1, \tag{4.19}$$

$$B_j \epsilon \mathbb{Z} \qquad \forall j \epsilon \mathcal{J}. \tag{4.20}$$

The seasonal reallocation quantity for the Port of Durban is calculated as:

$$B_1 = \text{Max} \begin{cases} A_1 - T_1(\sum_{j\epsilon\mathcal{J}} A_j) \\ 0, \end{cases} \tag{4.21}$$

$$\text{with} \quad 0\% \leq T_1 \leq 100\%, \tag{4.22}$$

where, B_1 is the quantity to be reallocated from the Port of Durban in the export season, A_j is the current citrus throughput exported through each port j and T_1 is the allowable throughput percentage of citrus exports in relation to total citrus exports from the CGA production regions that may be exported through the Port of Durban.

Once this reallocation quantity (B_1) has been determined, the adjusted target throughput for the season at the Port of Durban (R'_1) and the volume that is allowed to be exported from each CGA production region through the Port of Durban (Q_{i1}) can be determined using the respective allocation techniques and rules.

4.9.3 Network Cost (C_{ij})

The research analyses the incremental change in the estimated road transport cost in the citrus export cold chain as a result of the reallocations. This is done by comparing the "as-is" case with the "to-be" case. In terms of the transport costing used, it is shown as a rate per pallet from a CGA production region to a South African port. Due to the fact that CGA production regions encompass a large geographical area with multiple producers, and the fact that the data available only shows production data on a regional level and not by producer, it is thus not possible to determine exact transport costings, hence estimates are used in the study. The transport cost is estimated by calculating the distance by road from each region to each port and then multiplying this by an average cost per kilometre, which was supplied by Company A. In order to calculate the road distance, a single point of origin is required to represent the region from which the distance can be determined using *Google Maps* [51]. The following approach is used to determine the single point of origin for each region:

1. If the region is not a location in South Africa, then the border post most likely to be used to enter South Africa on the way to a specific port is used as the single point of origin.

2. If the region name corresponds to the name of a town/city, then that town/city name is used as the single point of origin.

3. If the region name does not correspond to a town/city, but rather a larger geographical area, then literature is reviewed to determine the major town/city in that region, which is then used as the single point of origin.

The Port of Durban, Port of Cape Town and Port of Coega are used as the end destinations in calculating the distance per route. The Port of Port Elizabeth uses the Port of Coega costing as a representative figure, as the Port of Coega and Port of Port Elizabeth are seen as one port in the study.

The distance is then multiplied by the cost per kilometre to determine the cost per route for a single one-way trip. The cost per pallet per route is calculated by dividing the cost per route by the average number of pallets transported in a single one-way trip per vehicle.

An average cost per kilometre is supplied by Company A for both loads within South Africa and for cross boarder loads, however, only the cost for within South Africa is used as the distances for regions outside of South Africa are calculated from the border post when entering South Africa. The transport cost provided is not adjusted for the growth over the years as each region-port pallet costs would be adjusted by the same percentage each year and so is not a variable that is considered to impact the reallocation model. Not adjusting the costing allows for the same comparison base to be maintained. According to the Customer Service Manager of Company A [32] the majority of citrus is exported in forty-foot equivalent units, which would equate to 20 pallets being transported in a standard forty-foot equivalent container per trip.

Only the transport cost is taken into account due to the fact that if a shipment is destined for a steri-market and requires cold treatment it will still under go this cold treatment even if it is exported from a different port. Secondly, the decision to containerise the load, either inland or at the port, by the exporter and producer is assumed to remain the same whether or not they were to use the Port of Durban.

4.9.4 Regional Demand (D_{ik})

The regional demand D_{ik} is the total citrus volume that needs to be exported from each CGA production region i for each of the export weeks k in the export season and was obtained from the data supplied by Company X post data categorisation.

4.9.5 Maximum Seasonal Regional Supply (Q_{ij})

The maximum seasonal regional supply Q_{ij} is the maximum volume that can be exported from a CGA production region i through port j in an export season. Only those production-region combinations that use the Port of Durban are constrained with a maximum seasonal regional supply of volume that they may export through the Port of Durban. No maximum seasonal regional supply constraint is applied to the other ports, as it is preferred that more volume be exported via these ports. The maximum regional supply for the dummy region "Unknown-DBN" ($Q_{22,j}$) is zero because the demand was already given priority allocation in the preallocation model and is no longer considered in the reallocation model. Furthermore, the maximum seasonal regional supply for the remaining two dummy regions ($Q_{18,1}$) and ($Q_{19,1}$) are also set to zero to prohibit export through the Port of Durban. For the purpose of excluding the dummy regions from the other production regions, denote subset $\mathcal{Y} = \mathcal{I} \backslash \{18, 19, 22\}$. The region-port combinations that use an alternate port are assigned some large number $\mathcal{M}$ such that:

$$Q_{ij} = 0 \qquad i = 18, 19, 22, j = 1, \qquad (4.23)$$
$$Q_{ij} \geq 0 \qquad i \epsilon \mathcal{Y}, j = 1, \qquad (4.24)$$
$$Q_{ij} = \mathcal{M} \qquad i \epsilon \mathcal{Z}, j \neq 1, \qquad (4.25)$$
$$Q_{ij} \epsilon \mathbb{Z} \qquad i \epsilon \mathcal{Z}, j \epsilon \mathcal{J}. \qquad (4.26)$$

For the region-port combinations that use the Port of Durban as the export port, the maximum seasonal regional supply for each region is calculated by using the respective allocation techniques to distribute the allowable citrus throughput for the Port of Durban in the export season amongst the production regions to represent the maximum volume they may export through the Port of Durban. This maximum volume is used as a constraint in the linear programming reallocation model when determining the optimal allocation of export volumes to the ports from each production region.

The allowable citrus throughput R_j at the Port of Durban is the total volume that may be handled at the Port of Durban in the export season and is calculated as:

$$R_j = \text{Max}(0, A_j - B_j) \qquad j = 1, \qquad (4.27)$$

where A_j is the current throughput at the port for the export season and B_j is the quantity that needs to be reallocated away from the port in the export season. However, the volume that needs to be assigned priority capacity will be assigned throughput from this allowable citrus throughput value, and so the throughput available for the remaining citrus export volumes will be less. As such, the allowable citrus throughput needs to be adjusted accordingly to represent that throughput available to the CGA production regions after the volumes requiring priority capacity have been assigned. The adjusted allowable citrus throughput R'_j at the Port of Durban is calculated as:

$$R'_j = \text{Max}(0, A_j - B_j - O_j) \qquad j = 1, \qquad (4.28)$$

where O_j is the seasonal priority demand volume that has been assigned priority capacity at port j. The priority demand is deducted as it has already been allocated priority capacity at the port.

The allowable citrus throughput R_j and the adjusted citrus throughput R'_j is set a lower bound of zero as a port cannot handle negative throughput.

From the literature studied, four common rule-based allocation techniques are used to calculate the maximum volume a CGA production region may export through the Port of Durban. The allocation techniques used are proportional, lexicographic, linear and uniform (without surplus distribution). These allocation techniques are rule-based approaches and traditionally are used to assign capacity to a set of competing resources demanding the capacity. The methodology of each of the allocation techniques is followed to assign the adjusted allowable citrus throughput for the Port of Durban amongst the competing CGA production regions. To use the allocation techniques mentioned, the CGA production regions are ordered in a non-increasing sequence based on exported pallet volume. The notation for the allocation techniques is changed in the methodology to align with the notation of the paper. As such, the notation may differ to that which has been used in the Literature Review.

Proportional Allocation

With the proportional allocation technique the maximum seasonal regional supply is calculated by allocating the adjusted allowable citrus throughput R'_1 at the Port of Durban amongst the

CGA production regions, excluding the dummy production regions. This allocation is done on the proportion of the CGA region's export pallet volume at the Port of Durban to the total export pallet volume of all the CGA production regions exporting through the Port of Durban. The proportional allocation model to allocate the adjusted allowable citrus throughput to the CGA production regions at the Port of Durban is formulated as:

$$Q_{i1} = \text{Min}\left\{F_{i1}, \frac{F_{i1}}{\sum_{l=1}^{m} F_{l1}} R_1'\right\} \qquad \forall i \epsilon \mathcal{Y}, \tag{4.29}$$

where Q_{i1} is the volume of citrus exports allowed to be exported through the Port of Durban from each production region i, $m = |\mathcal{Y}|$ is the total number of production regions excluding the dummy production regions. R_1' is the adjusted allowable citrus throughput at the Port of Durban, and F_{i1} is the total export demand volume from CGA production region i through the Port of Durban.

Lexicographic Allocation

For the allocation of the adjusted allowable citrus throughput at the Port of Durban to determine the maximum seasonal regional supply for each CGA production region under a lexicographic rule, the adjusted allowable citrus throughput is allocated based on the ranking of the CGA production region on its citrus export volume through the Port of Durban. The dummy production regions are excluded from the lexicographic allocation calculations. This citrus export ranking is based on pallets shipped and is ranked highest to lowest. The allocation of the adjusted allowable citrus throughput at the Port of Durban to the CGA production regions under a lexicographic rule is formulated as:

$$Q_{i1} = \text{Min}\left\{F_{i1}, \left(R_1' - \sum_{l=1}^{i-1} Q_{l1}\right)\right\} \qquad \forall i \epsilon \mathcal{Y}. \tag{4.30}$$

Linear Allocation

Calculating the maximum seasonal regional supply that may be exported between a production region and the Port of Durban under a linear allocation technique involves allocating the total citrus volume that needs to be exported from a CGA production region through the Port of Durban less some common deduction, which is based on the adjusted allowable citrus throughput at the Port of Durban. If the common deduction is greater than the volume that needs to be exported from a CGA production region then that region is assigned an allocation of zero pallets that can be exported through the Port of Durban. The linear allocation technique for calculating the maximum regional seasonal supply excludes all dummy production regions and is formulated as:

$$Q_{i1} = \begin{cases} F_{i1} - \frac{1}{\tilde{m}}\text{Max}\left\{0, \sum_{l=1}^{\tilde{m}} F_{l1} - R_1'\right\} & \text{if } i \leq \tilde{m} \\ 0, & \text{otherwise,} \end{cases} \tag{4.31}$$

where $\tilde{m}$ is the largest integer less than or equal to $m = |\mathcal{Y}|$ such that $F_{\tilde{m}1} - \frac{1}{\tilde{m}}\text{Max}\left\{0, \sum_{l=1}^{\tilde{m}} F_{l1} - R'_1\right\} \geq 0$.

Uniform Allocation

Under a uniform allocation technique, the adjusted allowable citrus throughput is uniformly allocated amongst the CGA production regions. For the purpose of the study, there will be no distribution of the surplus volume if a CGA production region is assigned more throughput capacity than they need to export in the season. The uniform allocation model to calculate Q_{i1} for those production regions exporting through the Port of Durban excludes all dummy production regions and is calculated as:

$$Q_{i1} = \begin{cases} \frac{1}{\hat{m}}\left(R'_1 - \sum_{l=\hat{m}+1}^{m} F_{i1}\right) & \text{if } i \leq \hat{m}, \\ F_{i1}, & \text{otherwise,} \end{cases} \tag{4.32}$$

where $\hat{m}$ is the largest integer less than or equal to $m = |\mathcal{Y}|$ such that $Q_{\hat{m}1} \leq F_{\hat{m}1}$.

4.9.6 Port Throughput Capacity Available Per Week (P_{jk})

The port throughput capacity available per week P_{jk} is the citrus throughput that can be handled in week k at the port j. As the study is focused on allocating volumes away from the Port of Durban, only the port throughput capacity available weekly based on the total allowable citrus throughput R_j at the Port of Durban needs to be calculated. For the alternate ports, the weekly capacity is assumed to be sufficient and available to handle the additional volume allocated to it. No constraint is imposed on the capacity at the alternate ports and so the capacity available is assigned some large number $\mathcal{M}$ such that:

$$P_{jk} \geq 0 \qquad j = 1, \forall k \epsilon \mathcal{K}, \tag{4.33}$$

$$P_{jk} = \mathcal{M} \qquad j \neq 1, \forall k \epsilon \mathcal{K}, \tag{4.34}$$

$$P_{jk} \epsilon \mathbb{Z} \qquad \forall j \epsilon \mathcal{J}, \forall k \epsilon \mathcal{K}. \tag{4.35}$$

The port throughput available each week at the Port of Durban can be calculated using the threshold breach approach or the factor reduction approach.

With the threshold breach method, a single seasonal breach value is calculated, which represents the available capacity each week. Two options exist to calculate the threshold breach value. The threshold breach value can be calculated by dividing the allowable citrus throughput R_j at a port for the export season by κ, which is the total number of weeks in a calendar year using:

$$P_{jk} = \frac{R_j}{\kappa} \qquad j = 1, \forall k \epsilon \mathcal{K}. \tag{4.36}$$

Alternatively, it can be calculated dividing the allowable citrus throughput R_j at a port by λ, the number of calendar weeks that had export volume using:

$$\hat{P}_{jk} = \frac{R_j}{\lambda} \qquad j = 1, \forall k \epsilon \mathcal{K}. \tag{4.37}$$

With this method, the threshold breach value acts as the available port throughput and any additional throughput above this breach level will need to be reallocated. Using these options will, however, result in an over reallocation, as this method forces the port to handle only up until a set volume for the export season. It results in a flat line figure of throughput capacity available and so is not utilised in the study.

The fixed factor reduction approach adjusts the current weekly port throughput by some common factor. Two options exist under the factor approach, either the volume that needs to be reallocated for the export season is deducted from the current citrus throughput each week as a common deduction, with the weekly quantity deducted being the reallocation quantity divided by the number of calendar weeks in the export season. The weekly available port capacity is thus calculated as:

$$P_{jk} = (A_{jk}) - \left(\frac{B_j}{\kappa}\right) \qquad j = 1, \forall k \epsilon \mathcal{K}. \tag{4.38}$$

where, P_{jk} is the available throughput that can be handled at the port in week k, A_{jk} is the current throughput each week at the port, B_j is the reallocation quantity for the export season and κ is the total number of calendar weeks in the export season. This option, however, yields an infeasible result as some weeks may need to reallocate more volume than their current throughput or may have no volume to reallocate. A lower limit for the allowable port throughput P_{jk} cannot just be set to zero in this case to negate the problem of negativity, because it will lead to an under reallocation in these respective weeks where the reallocation quantity is higher than the current throughput in the week, and may result in less than the total intended reallocation quantity B_j for the export season being reallocated.

The other option is to reduce the current weekly citrus port throughput by a proportional ratio of the reallocation amount, which is based on the contribution each week has to the total citrus exports through the Port of Durban.

The first step involves calculating the index that represents the contribution each week's citrus export volume has in relation to the total citrus export volume at the Port of Durban and is calculated as:

$$V_{jk} = \frac{A_{jk}}{\sum_{k\epsilon\mathcal{K}} A_{jk}} \qquad j = 1, \forall k \epsilon \mathcal{K}. \tag{4.39}$$

where, V_{jk} is the index representing a certain week's export volume in relation to total export volume at the port.

Once this has been calculated, the weekly port capacity available for citrus is calculated using:

$$P_{jk} = A_{jk} - (V_{jk} * B_j) \qquad j = 1, \forall k \epsilon \mathcal{K}. \tag{4.40}$$

where, P_{jk} is the available throughput that can be handled at port j in week k, A_{jk} is the current throughput at the port for week k, V_{jk} is the weekly contribution index and B_j is the reallocation quantity for the export season. This method yields a feasible result that splits the reduction quantity proportionally across the weeks and so is utilised in the study as the method to determine weekly port throughput capacity available for citrus.

Once the available throughput that can be handled each week has been determined, it must be adjusted to account for the export volumes that are assigned priority capacity during the preallocation phase. This is done by deducting the export volume that has been assigned priority capacity each week from the available port capacity. However, in some instances the volume requiring priority capacity is bigger than the available port capacity in a week, which results in a negative port capacity being available. This is not possible as a negative port capacity cannot exist. Thus, the constraint is relaxed, and it is assumed that the priority capacity will be exported through the port, however, no other volume may be exported, and so the adjusted available port capacity is set as zero for that week. Even if the volumes are reallocated in a real life scenario, no other volumes would be allowed to be exported, and so the lower bound on the adjusted available port capacity is set as zero. The adjusted weekly available port capacity is calculated as:

$$P'_{jk} = \text{Max}(0, P_{jk} - O_{jk}) \qquad j = 1, \forall k \epsilon \mathcal{K}. \tag{4.41}$$

4.9.7 Minimum Weekly Throughput (N_{ijk})

The minimum weekly throughput N_{ijk} is the minimum volume that needs to be exported from a CGA production region i through a specific port j in week k. i.e. cannot be reallocated to another port. For the purpose of the study, it was proposed that the last port of call, which is a logistical constraint, be included. With this constraint, all Eastern hemisphere countries are assigned the Port of Durban as their last port of call and all Western hemisphere countries are assigned the Port of Cape Town as their last port of call. If the country received its export through a port that is the same as its assigned last port of call then this volume cannot be reallocated in the model. This, however, resulted in an infeasible solution as the minimum volume was sometimes greater than the available port capacity for citrus.

Lastly, the only potential policy constraint restricting the reallocation would be the restriction on moving host plants from an Oriental Fruit Fly infected area to an area free of infection, as well as the restriction on imports of citrus from CBS infected areas to the USA. These constraints are respectively excluded as the study is not moving host plants, but rather the fruit itself, and the production area is not being changed for export to a country, only the exit port. Thus, no minimum flow constraint is imposed when volumes are being allocated from each CGA production region i to each port j in week k in the reallocation model.

4.9.8 Maximum Weekly Throughput (M_{ijk})

The maximum weekly throughput M_{ijk} is the maximum volume that can be exported from CGA production region i and the preferred port j in a given week k. For those region-port combinations that used the Port of Durban as the export port, the maximum volume is the volume that was actually exported or is forecasted to be exported from the CGA production region through the Port of Durban. This is done to ensure that no more than what was actually exported through the Port of Durban is assigned to the Port of Durban. For the region-port combinations that use the other ports there is no maximum weekly constraint as it is preferred that more volume be assigned to the alternate ports to reduce volumes assigned to the Port of Durban and so is assigned some arbitrary large number $\mathcal{M}$. The maximum weekly throughput is formulated as:

$$M_{ijk} = A_{ijk} \qquad \forall i \epsilon \mathcal{Z}, j = 1, \forall k \epsilon \mathcal{K}, \tag{4.42}$$

$$M_{ijk} = \mathcal{M} \qquad \forall i \epsilon \mathcal{Z}, j \neq 1, \forall k \epsilon \mathcal{K}. \tag{4.43}$$

4.10 Conclusion

The methodology chapter defines the main modelling approach followed, which is summarised in Figure 4.1. The data requirements are defined, along with the steps on categorising and refining the data into the required format. The allowable port throughput scenarios to be used in the allocation model framework were defined, and are scheduled in Table 4.1.

The steps followed in classifying the historical citrus export data is explained, with Pegel's classification technique (Figure 3.2) and Table 3.1 being used as the tools to identify potential forecasting models based on the characteristics of the historical citrus exports, of which the best suited model will be selected using the mean square error and Theil's U goodness-of-fit measure. The process for disaggregating the annual citrus forecast into the required format is explained. The method for estimating available port capacity at the alternate ports for citrus is explained, and the limitations around this estimation highlighted.

The allocation model framework, which is used to execute the "forced" allocation, is explained. The allocation model framework includes both the preallocation and reallocation models along with the techniques used to allocate the adjusted allowable port throughput capacity amongst the production regions. The reallocation model is solved as a minimum cost transport problem using linear programming. The reallocation model limits the capacity at the Port of Durban according to the parameters set, and assigns the volume of citrus export from regions to citrus ports in a way that minimises the overall transport cost of the system. The preallocation model enforces the assignment of priority demand at the Port of Durban, while priority demand at the other ports is managed within the reallocation model. The reallocation model does not preserve any other previous region-port allocations. It can therefore be classified as a semi-greenfields approach as only priority demand is fixed beforehand, but all other allocations are optimised for the given goal. A brown fields approach would be to also preserve the existing flows to the ports of Cape Town and Port Elizabeth/Coega, and only reallocate the excess demand at the Port of Durban. This could be achieved by also fixing these demand flows in a preallocation step. The brown fields approach falls outside the scope of this study as it does not align with the desired regional corridors as proposed by industry. The allocation model framework has been written specifically for the Port of Durban, as the focus of the study is on addressing the capacity challenges at the Port of Durban. The formulation of the allocation model framework can, however, be adjusted to be applicable to other ports or more than one port at the same time, by changing the respective index on the variables and constraint and solving such a model.

CHAPTER 5

Results

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5.1 Introduction

The results chapter expands on the Methodology chapter in implementing the research solution approach as set out in Figure 4.1. Steps S1, S2 and S5 are general methodology steps that included defining the allowable throughput scenarios (S1), defining the data requirements and analysing the data (S2), and developing the allocation model framework (S5). These steps are done once off and are the foundation of the steps to follow. The results chapter focuses on steps S3 (A-C), S4 and S6, which are to determine the actual export volumes in the 2019 export season (S3A), the forecasted export volumes in the 2019 and 2021 forecasted export seasons (S3B and S3C), estimate the theoretical excess port capacity for citrus (S4), and generate and analyse the results (S6). The chapter also addresses the validity and reliability of the research methodology.

5.2 2019 Actual Export Volumes

The export volumes for the 2019 actual year (Step S3A of Figure 4.1) were obtained from the datasets provided by Company X and is used as the base year in the study. The values used to represent the 2019 actual export season are the values post the data categorisation and refinement (§4.5.2), with the resulting values shown in Table 5.1. Analysis of the data shows that the biggest throughput contributor is the Sundays River Valley production region, both in terms of total throughput, and the throughput assigned to the Port of Coega/PE. The Western Cape and Letsitele are the biggest throughput contributors to the Port of Cape Town and Port of Durban respectively. Figure 5.1 is a network flow map showing the citrus exports from each production region through each port in the 2019 actual export season. From this map it is evident that the network flows in the citrus export cold chain currently follow a criss-crossing network pattern. The Port of Cape Town exported 303,248 pallets (19.68%) of the export volume, the Port of Coega/PE 364,273 pallets (23.64%) and the Port of Durban exported 873,483 pallets (56.68%) of the citrus export volume. From these export volumes, 257 pallets require priority capacity at the Port of Durban, which equates to approximately 0.02% of the total export volumes from all the CGA production regions combined. Table 5.2 shows the throughput contribution for each port pre and post data categorisation and refinement, of which 0.51% unknown origin data had to be recategorised according to the steps in §4.5.2. The symbol "-" in Table 5.1, and in subsequent tables, represents the value zero (0).

Production Region	Port of Cape Town	Port of Port Elizabeth/Coega	Port of Durban	Total
Sundays River Valley	20,761	229,707	22,766	273,234
Letsitele	1,997	191	223,700	225,888
Senwes	2,282	352	198,064	200,698
Western Cape	157,504	9,911	9,583	176,998
Hoedspruit	665	297	136,697	137,659
Patensie	12,229	104,535	7,588	124,352
Limpopo River	2,681	34	82,713	85,428
Boland	59,799	7,052	4,280	71,131
Nelspruit	1,127	195	66,208	67,530
Onderberg	455	239	52,795	53,489
Burgersfort Ohrigstad	2,388	166	31,208	33,762
Eastern Cape Midlands	11,358	10,140	6,265	27,763
Orange River	26,900	254	158	27,312
Nkwalini	45	-	17,732	17,777
Southern KZN	36	-	8,246	8,282
Pongola	-	-	4,962	4,962
VaalHarts	2,708	403	209	3,320
Unknown-Coega/PE	-	797	-	797
Unknown-CPT	313	-	-	313
Unknown-DBN	-	-	257	257
Swaziland	-	-	52	52
Total	**303,248**	**364,273**	**873,483**	**1,541,004**

TABLE 5.1: *Current pallet volumes exported through each South African port from each CGA production region in the export season for the 2019 actual export year without reallocation - ranked highest to lowest in total*

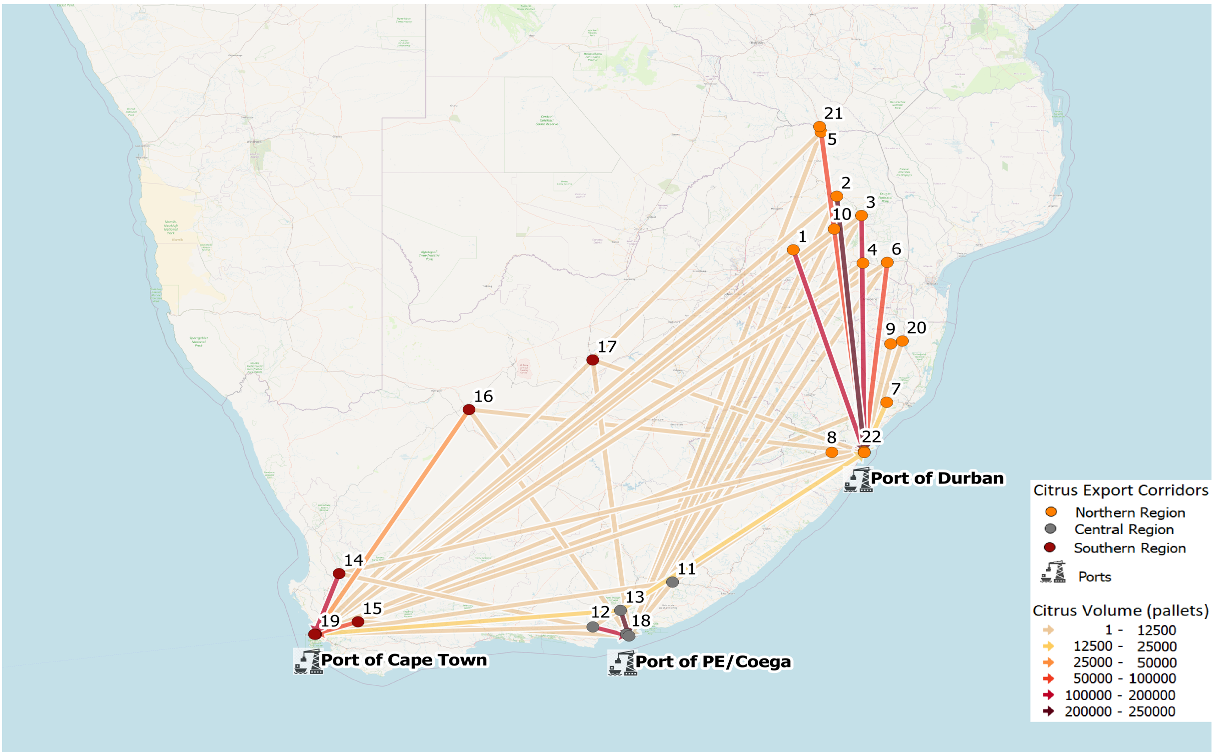

FIGURE 5.1: *A flow map showing the citrus exports from each production through each port for the 2019 actual export season*

Port	Pre Categorisation	Post Categorisation
Unknown	0.51%	0%
Cape Town	19.53%	19.68%
Coega/Port Elizabeth	23.49%	23.64%
Durban	56.47%	56.68%

TABLE 5.2: *Actual pallet volume contribution at each port pre data categorisation and post data categorisation for the 2019 actual export year*

5.3 Forecasted Export Volumes

The following section is part of Step S3B and Step S3C of Figure 4.1, which is to forecast the 2019 and 2021 export volumes. Step F1 of the forecasting process given in Figure 4.2 deals with the analysis and classification of the data used in the forecasting process. As such, the export years 2003-2014 are used as the historical dataset, and the years 2015-2018 the test dataset for the evaluation of the techniques. The entire export dataset for the years 2003-2018 is used to forecast the citrus export tons for the 2019 and 2021 export seasons using the best suited forecasting technique based on the forecast evaluations.

5.3.1 Selecting Suitable Forecasting Techniques

Graphical analysis of the historical dataset and the use of Pegels classification, Figure 3.2, which is Step F2 of Figure 4.2, shows that there is a positive linear trend in citrus exports, no seasonality or cycles are present, and that there are no outliers observed as seen in Figure 5.2.

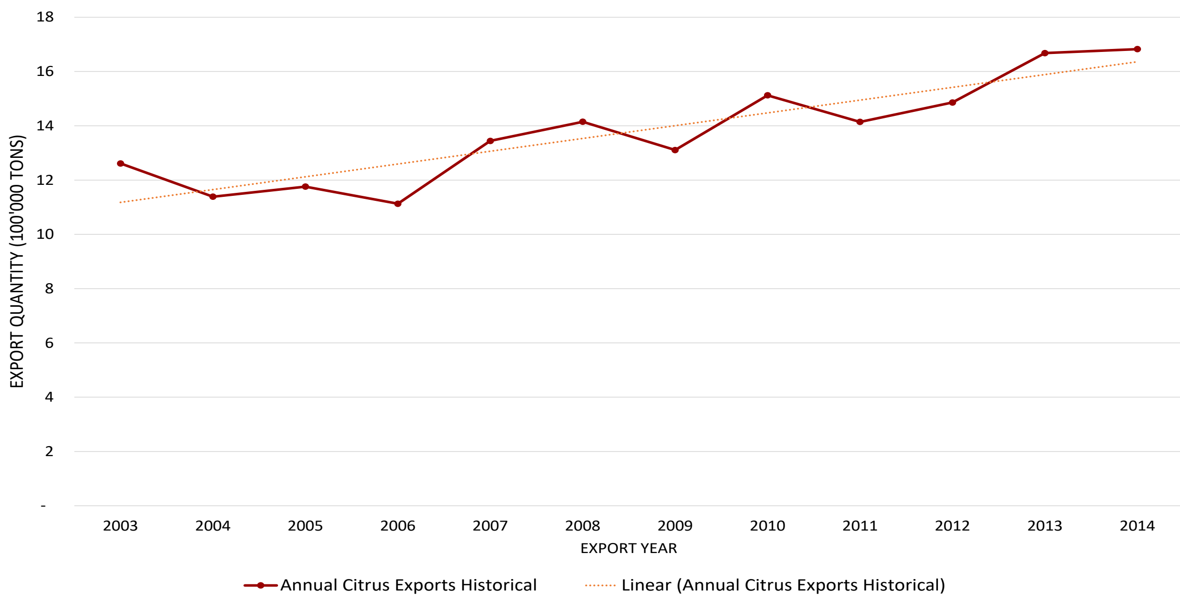

FIGURE 5.2: *Tons exported from the CGA production regions per year in the historical dataset. Adapted from [15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27]*

As such, the potential forecasting methods, based on Pegels classification and the guide in Table 3.1, that can be used for forecasting citrus exports from the CGA production regions are:

- Naïve (NF1) no change model (used for comparing Theil's U)
- Holt's method
- Linear regression model using time as the independent variable
- Double moving average
  - Two period double moving average using the export year as the period
  - Four period double moving average using the export year as the period

Certain models in this guide are excluded such as ARIMA as the data is not stationary and less than 50 historical observations are available. Time series decomposition and Winter's exponential smoothing are excluded as there is no seasonality in the data. Moving averages are excluded as the data is not stationary, however, the double moving average is included as this forecasting model is able to deal with non-stationary data. The NF1 model should be used only on stationary data, however, it is included for comparison reasons as this is one of the most basic and simplistic forecasting methods available.

5.3.2 Forecasting Technique Evaluation

The forecast techniques used are evaluated for accuracy (Step F3 of Figure 4.2) based on the mean square error and Theil's U across all techniques. The linear regression model using time as the independent variable was also evaluated on the respective diagnostic tests to determine if any of the assumptions of the regression model are violated.

The naïve (NF1) no change model is included for the primary purpose of comparing it to the other forecasting techniques used, to determine if they perform better than the NF1 model.

Interestingly, the NF1 model performed better than the two period double moving average model, however, it did not perform better than the remaining models utilised. Figure 5.3 and Figure 5.4 show the forecast versus actual of the NF1 and two period double moving average respectively. The NF1 model captures the trend nicely in the historical dataset, however, as expected there is a lag in the peaks and troughs on the forecast versus actuals. The model does not forecast well when the forecast versus the actuals are compared in the test dataset due to the model flat lining the forecast and assuming the latest entry in the historical dataset is representative of what the exports would look like in the future. The NF1 model both under and over forecasts on the historical and test datasets. The two period double moving average forecast model captures the trend relatively well. Peaks and troughs are present, however, they are lagged and are not as in proportion to the actual peaks and troughs due to the averaging out of the values. The two period double moving average both under and over forecasts on the historical dataset, however, it over forecasts on the test dataset.

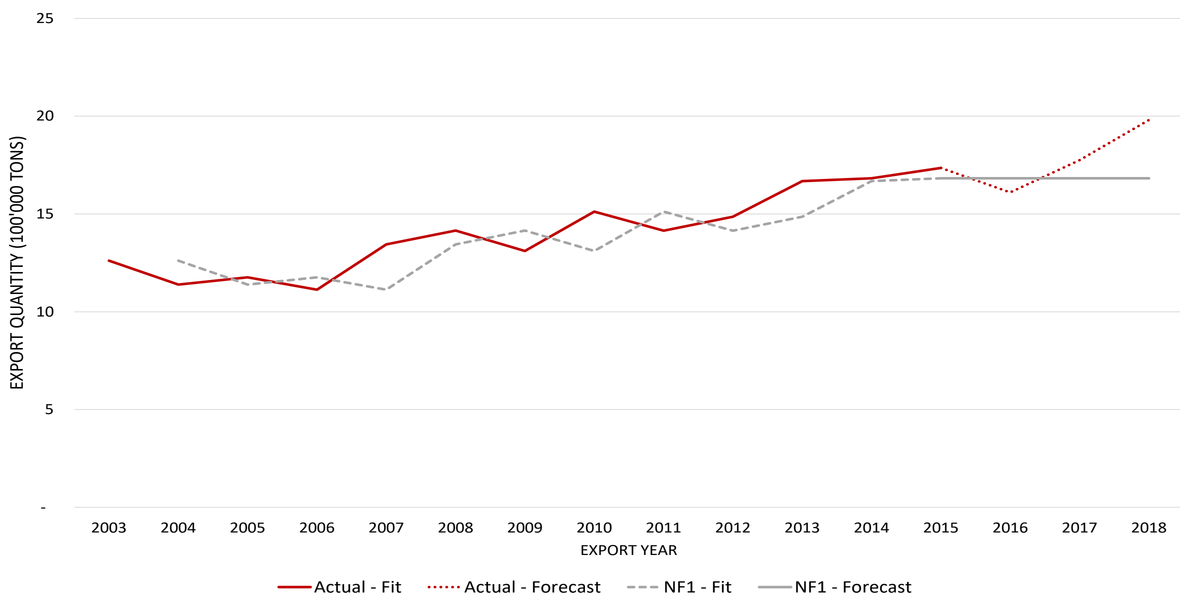

FIGURE 5.3: *Actual versus forecasted citrus export tons using the naïve (NF1) no change model for the export years 2003-2018*

Diagnostic testing of the linear regression model with time as the independent variable shows that the independence assumption holds as the residuals change sign about half the time as seen in Figure 5.5, which is the plot of the residuals over time. This is also confirmed with the Durbin-Watson test. A Durbin-Watson critical value of 2.773 was calculated. For this specific instance of $n = 1$ and $k = 12$, the lower and upper critical values are 0.971 and 1.331, which indicate that autocorrelations is absent, and so the independence assumption holds. Heteroscedasticity is not present and the variance is constant based on the results of White's test, which yielded a p-value of 0.479 and so the null hypothesis cannot be rejected, therefore indicating heteroscedasticity is not present. Even though a funnel formation is observed in Figure 5.6, which is the plot of the residuals versus the forecasted citrus export values, it is not present as this funnel formation is only fromed because of two outlying observations; the remaining observations maintain a relatively constant variance. There are no outliers present as the standardised residuals all fall within -2 or +2 as seen in Table 5.3. The normality assumption does hold as the mean of the residuals is zero, which indicates the residuals are normally distributed. Therefore, the linear regression model with time as the independent variable is a valid model. The linear regression model with time as the independent variables both under and over forecasts. The model does not

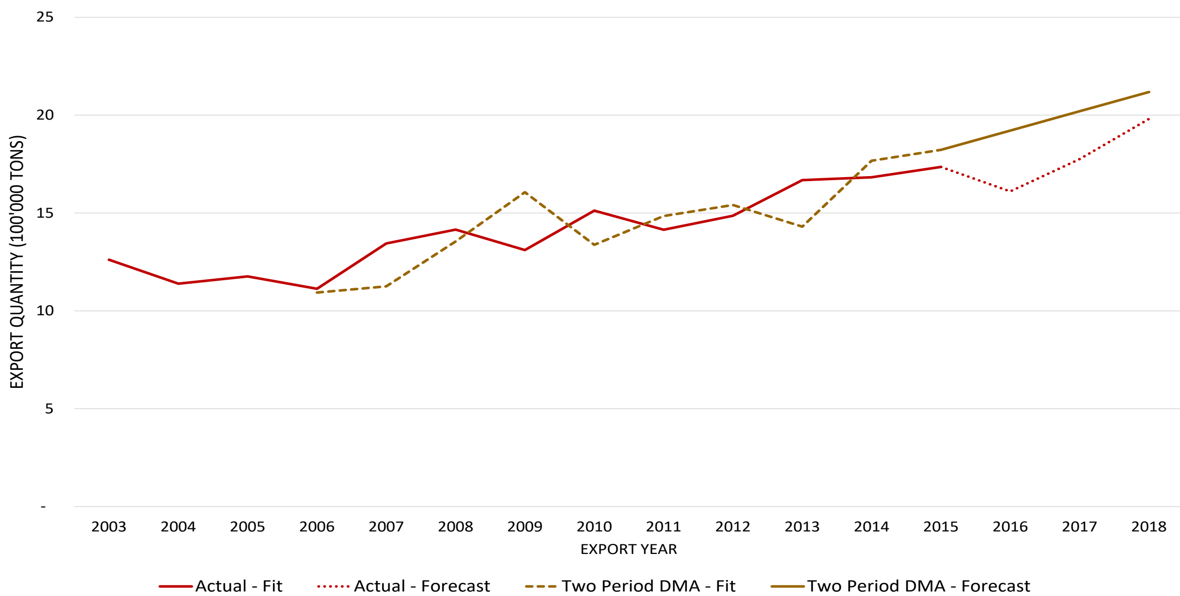

FIGURE 5.4: *Actual versus forecasted citrus export tons using the two period double moving average model for the export years 2003-2018*

capture the peaks and troughs very well, however it does capture the upward trend of increasing exports over the years as seen in Figure 5.7.

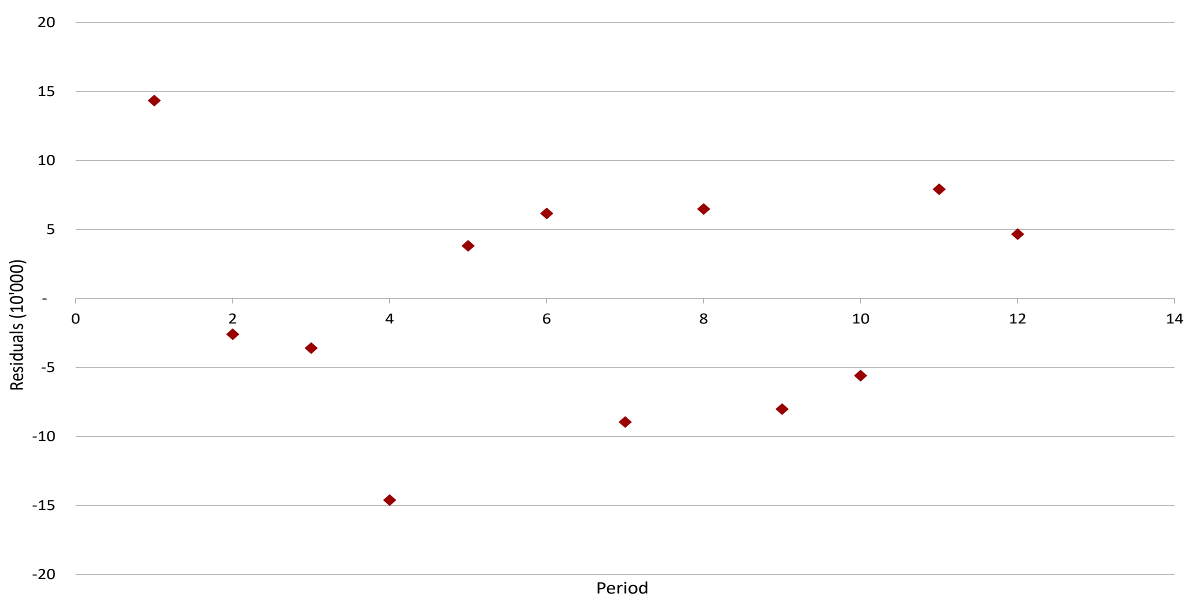

FIGURE 5.5: *Plot of the residuals over time for the linear regression model with time as the independent variable*

The remaining two models, namely Holt's and the four period double moving average model, were the two best performing models. Figure 5.8 and Figure 5.9 show the forecasts of each of these models respectively. The forecasts using Holt's method show that the trend is captured well. The peaks and troughs are evident, however, they are not as pronounced, and there is an evident lag in the peaks and troughs of the forecast versus the actual. The model both under and over forecasts. The four period double moving average model captures the trend

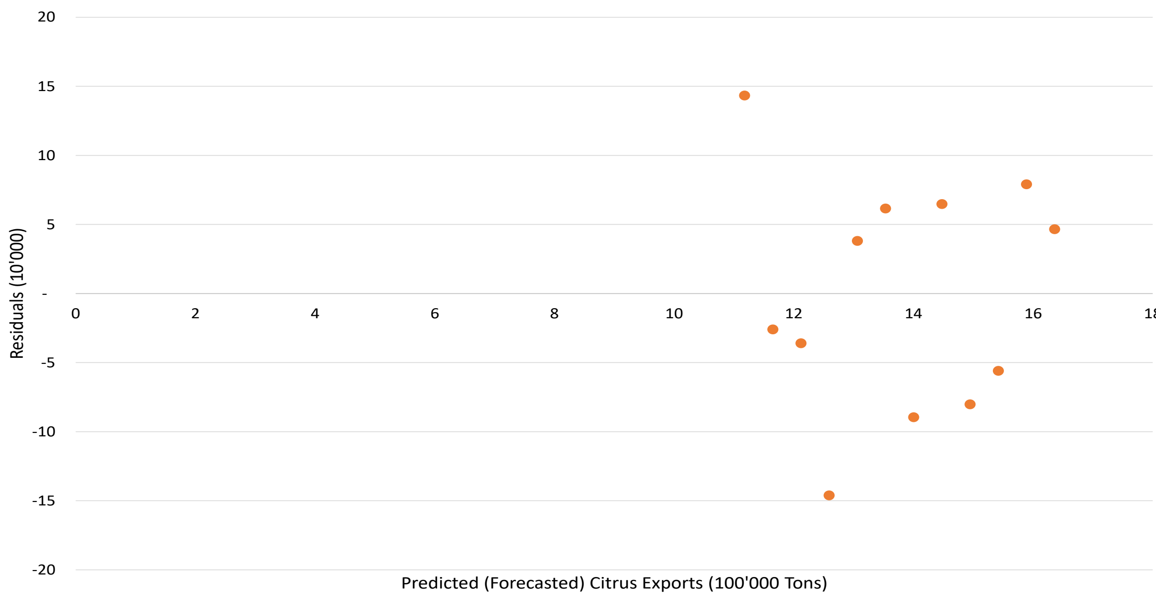

FIGURE 5.6: *Plot of the residuals versus the forecasted citrus export volumes for the linear regression model with time as the independent variable*

Observation	Export Year	Standardised Residual
1	2003	1.69
2	2004	-0.31
3	2005	-0.42
4	2006	-1.72
5	2007	0.45
6	2008	0.73
7	2009	-1.05
8	2010	0.76
9	2011	-0.94
10	2012	-0.66
11	2013	0.93
12	2014	0.55

TABLE 5.3: *Standardised residuals of the forecasted citrus exports volumes in each export year using the linear regression model with time as the independent variable*

well, however, the peaks and troughs are not captured well when the forecast is compared to the actuals as there is a lag in the peaks and troughs. There is both under and over forecasting on the historical dataset, and both under and over forecasting in the test dataset, with over forecasting being more evident. Based on Theil's U, both models are better at forecasting citrus export volumes than the NF1 model, however, the four period double moving average performs better than Holt's method based on the mean square error when the optimised alpha and beta parameters as per Table 5.4 are applied for Holt's method. Table 5.5 and Table 5.6 show the results of the mean square error and Theil's U accuracy measures for the forecasting techniques used. Based on the fact that the four period moving average has the best forecasting accuracy, it is used as the best suited forecasting model to forecast the citrus export tons for the 2019 and 2021 export seasons.

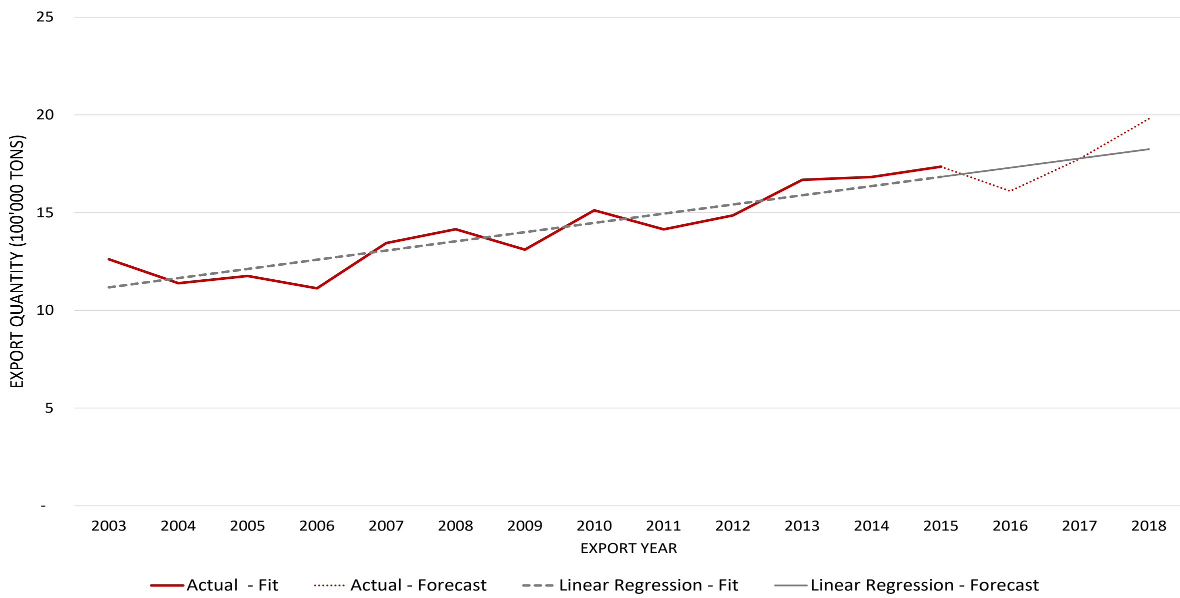

FIGURE 5.7: *Actual versus forecasted citrus export tons using the linear regression model with time as the independent variable for the export years 2003-2018*

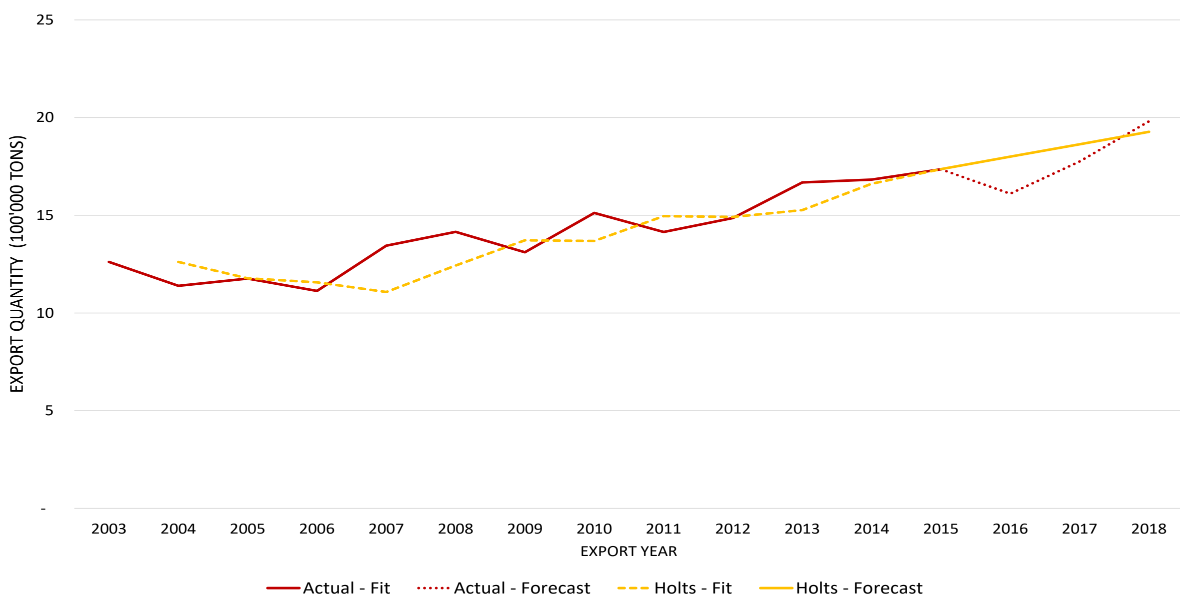

FIGURE 5.8: *Actual versus forecasted citrus export tons using Holt's model for the export years 2003-2018*

Parameter	**Value**
Alpha (α)	0.53
Beta (β)	0.30

TABLE 5.4: *Optimised smoothing and trend parameters used in Holt's model for forecasting citrus export tons from 2003-2018*

5.3.3 2019 and 2021 Forecasted Citrus Export Volumes

The forecasted export volumes using the four period double moving average method for the 2019 and 2021 forecasted export seasons (Step F4 of Figure 4.2) are shown in Figure 5.10 and

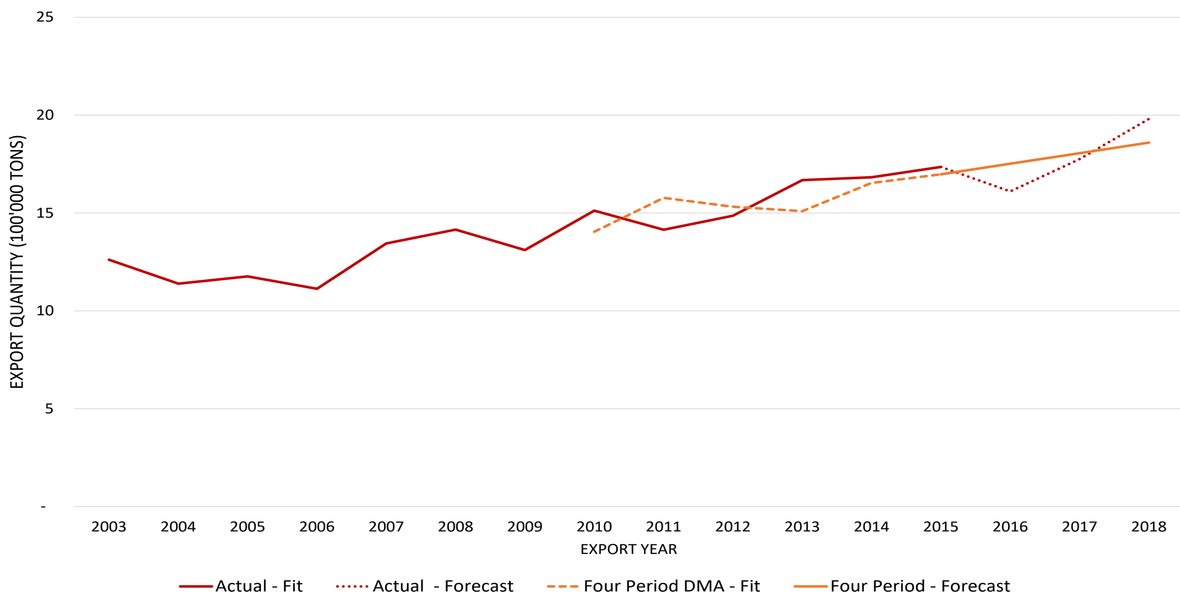

FIGURE 5.9: *Actual versus forecasted citrus export tons using the four period double moving average model for the export years 2003-2018*

Forecast Technique	Fit Accuracy	Forecast Accuracy
Naïve (NF1)	16,209,510,136.91	26,315,033,838.50
Two Period Double Moving Average	26,811,094,191.51	45,821,926,832.50
Linear Regression	6,613,549,836.23	10,372,149,896.04
Holt's	14,028,326,619.04	11,661,596,506.53
Four Period Double Moving Average	13,281,195,561.98	9,244,712,075.60

TABLE 5.5: *Fit and forecast accuracy results based on the mean square error for the four valid forecasting techniques*

Forecast Technique	Fit Accuracy	Forecast Accuracy
Naïve (NF1)	1.00	1.00
Two Period Double Moving Average	1.29	1.32
Linear Regression	0.64	0.63
Holt's	0.93	0.67
Four Period Double Moving Average	0.91	0.59

TABLE 5.6: *Fit and forecast accuracy results based on Theil's U for the four valid forecasting techniques*

Table 5.7. Step F5 of Figure 4.2 is the conversion and disaggregation of the forecasts. Before the forecasts can be used they are converted from tons into pallets using the conversion factor found in Table 4.5. The volumetric indices (E_{ijkn}) for the 2017 and 2018 export season are calculated using Equation 4.1 and can be found in Appendix A. These indices are used to disaggregate the annualised pallet export volumes into the weekly export volumes from each CGA production region to each port. The port breakdown is used primarily to determine the projected baseline of what must be exported through the Port of Durban, so that the quantity to be reallocated can be determined. The allocation model framework is used to find the optimal allocation of the export volumes in the citrus export cold chain. Table 5.8 shows the annual pallet demand to be exported from each region for the 2019 and 2021 forecast years. As a result of an index

being used to break down the aggregated annual volumes, the projected volume contribution to be handled at each port in both the 2019 forecasted and 2021 forecasted seasons is the same. The Port of Cape Town is predicted to handle 18.10%, the Port of Coega/PE 26.67% and the Port of Durban 55.23% of the volumes prior to the "forced" allocation being implemented.

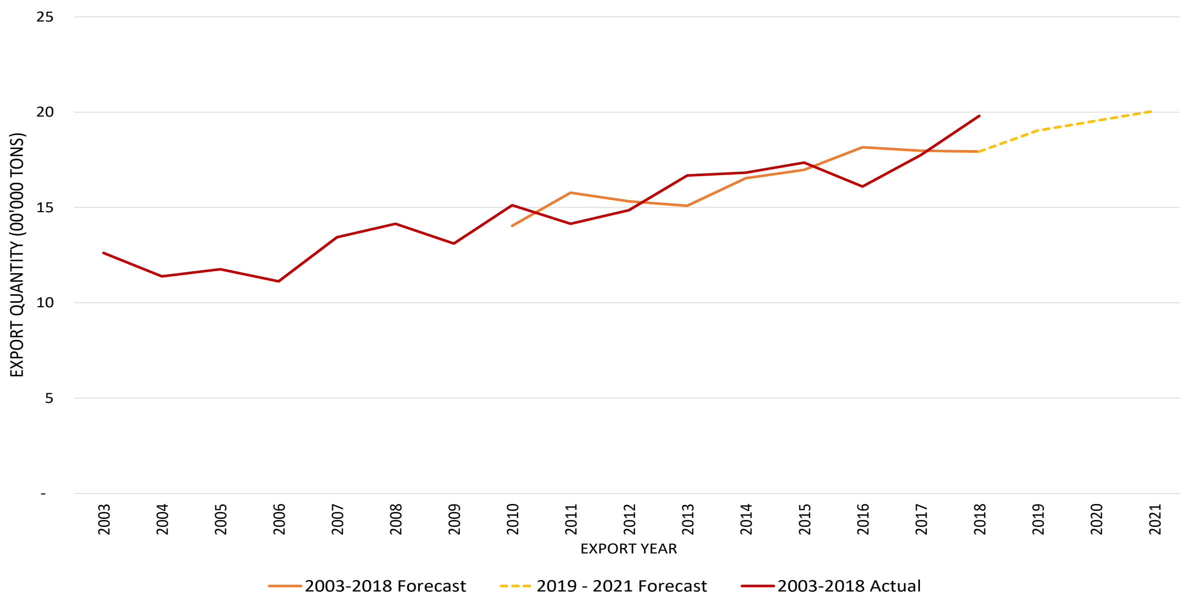

FIGURE 5.10: *Forecasted citrus export volumes for the export years 2019-2021 using the four period double moving average model*

Export Year	Forecasted Export Tons
2019	1,903,491
2021	2,006,136

TABLE 5.7: *Forecasted citrus export tons using the four period double moving average model*

The comparison of the 2019 actual citrus exports versus 2019 forecasted citrus exports show that on an aggregated annual level, the forecasted export volumes are quite similar to the actual values with the forecast being overstated by approximately 3.28%. However, when the volume is broken down into the weekly export volume from each CGA production region to each port, the accuracy is diminished. This is due to the fact that an average of two years is used to determine the index, and so certain historical elements in the oldest year may carry through that are not necessarily evident in the youngest year. Such an example is that of the Zimbabwe region, which is seen in the 2017 export season, but not in the 2018 export season nor in the 2019 actual export season. Also, because the recording of data is less accurate in the historical datasets, there is a tendency for the "unknown" region volumes, and thus the volume requiring priority, to be over forecasted. For the 2019 forecasted volumes, the volume requiring priority capacity is over stated by approximately 547.5% versus the 2019 actual volumes requiring priority capacity at the Port of Durban. The resulting impact is that less volume is allowed to flow through the Port of Durban than in a real life scenario, which effectively creates a buffer if these volumes are going to be exported through another port, which may realise more benefits than drawbacks. If they are exported through the Port of Durban, then their capacity has already been provisioned. Another challenge faced is that of rounding errors in some historical datasets, however, these rounding errors are so small in the greater scheme of things that they are negligible and so are ignored. The accuracy of the forecasts will improve once more historical data is available

Production Region	2019 Forecast	2021 Forecast
Sundays River Valley	277,781	292,761
Senwes	240,674	253,646
Letsitele	232,846	245,402
Western Cape Cape	178,056	187,657
Patensie	125,558	132,334
Hoedspruit	124,822	131,552
Limpopo River	102,121	107,632
Boland	71,880	75,755
Onderberg	55,504	58,504
Nelspruit	48,297	50,904
Burgersfort Ohrigstad	37,905	39,951
Eastern Cape Midlands	32,128	33,861
Orange River	27,687	29,181
Nkwalini	17,538	18,486
Southern KZN	6,892	7,265
Pongola	4,709	4,964
VaalHarts	4,685	4,935
Unknown-DBN	1,664	1,753
Unknown-Coega/PE	444	466
Unknown-CPT	318	332
Swaziland	32	34
Zimbabwe	6	6

TABLE 5.8: *Annual citrus export pallet demand to be exported from each CGA production region in the 2019 and 2021 forecasted export season*

showing the breakdown by week, port and region, as outliers can thus be ignored or averaged out. Based on the current dataset available, the forecasts may not be as accurate as desired, however, they are deemed suitable for the study as the primary focus of the study is on the allocation model framework, and not the forecasting of citrus export volumes.

5.4 Estimated Port Capacity at Alternate Ports

The results of the high level estimation of the theoretical port capacity available for citrus exports at the alternate ports (Step S4 of Figure 4.1), which is calculated using data extracted from the National Ports Plan 2019 Update [105] and Equation 4.4, is shown in Table 5.9 and Table 5.10. This estimation is used as a validation to determine whether or not the reallocated citrus volume can be handled at the alternate ports within these theoretical port throughput constraints. More theoretical excess capacity is available at the Central Ports, which is ideal as this is the next closest port to the Port of Durban, which may mean more volume will be reallocated to these Ports instead of the Western Ports. This may potentially result in a smaller increase in transport cost as opposed to when more volume would have to be reallocated to the Western Ports.

Central Ports - Containers (Million TEU's)	2019 Actual	2019 Forecast	2021 Forecast
East London design capacity	0.2	0.2	0.2
Port Elizabeth design capacity	0.6	0.6	0.6
Coega design capacity	2	2	2
PE/Coega total design capacity	2.6	2.6	2.6
Central Ports total demand (U_j)	0.9	0.9	1
PE/Coega available throughput capacity (W_j)	1.7	1.7	1.6
Total current citrus throughput (A_j)	0.04	0.04	0.05
Total throughput other commodities	0.86	0.86	0.96
Citrus contribution to total demand	4.05%	4.72%	4.47%
Theoretical excess capacity available for citrus exports	0.07	0.08	0.07
Theoretical excess pallet capacity available for citrus	**688,090**	**801,650**	**715,650**

TABLE 5.9: *Estimated annual theoretical port throughput capacity available for citrus exports at the Port of Coega and Port Elizabeth*

Western Ports - Containers (Million TEU's)	2019 Actual	2019 Forecast	2021 Forecast
Cape Town design capacity	1.5	1.5	1.5
Cape Town total demand (U_j)	1.1	1.1	1.1
Cape Town available throughput capacity (W_j)	0.4	0.4	0.4
Total current citrus throughput (A_j)	0.03	0.03	0.03
Total throughput other commodities	1.07	1.07	1.07
Citrus contribution to total demand	2.76%	2.62%	2.76%
Theoretical excess capacity available for citrus exports	0.01	0.01	0 .01
Theoretical excess pallet capacity available for citrus	**110,280**	**104,760**	**110,410**

TABLE 5.10: *Estimated annual theoretical port throughput capacity available for citrus exports at the Port of Cape Town*

5.5 Allocation Model Framework Application

The allocation model framework, discussed in §4.8 which is Step S5 of Figure 4.1, is split into two steps, namely the preallocation model and the reallocation model. The preallocation model must be executed before the reallocation model. For the 2019 actual export season the Zimbabwe production region {21} is not included in the sets $\mathcal{I}$, $\mathcal{Y}$ and $\mathcal{Z}$ as no citrus export volume existed for this production region. The Zimbabwe production region {21} is, however, included in the 2019 and 2021 forecasted export years due to historical elements in the dataset used in the forecasting of citrus export volumes. *Microsoft Excel* was used to determine the quantity requiring priority capacity allocation and execute the preallocation model using Equation 4.5. *Microsoft Excel* was also used to create the model input files for the reallocation model. The calculation of the maximum seasonal regional supply for each allocation technique and allowable port throughput per scenario was also calculated using *Microsoft Excel*. *LINGO* was used to execute the LP, which was formulated in §4.13, and generate the results of the reallocation model.

5.5.1 Preallocation of Priority Capacity Demand (O_{jk})

During the preallocation, the citrus export demand volumes requiring priority capacity at the Port of Durban are assigned capacity first before the remaining citrus export volumes are allocated. The seasonal citrus export volumes requiring priority capacity allocation at the Port of Durban (O_1) in the preallocation model is shown in Table 5.11. The citrus volumes requiring priority capacity allocation at the Port of Durban each week (O_{1k}) are shown in Table D.1.

As previously mentioned, due to the historical observations being carried through into the index used to determine the regional and weekly flows, the forecasted volumes requiring priority capacity are over forecasted.

Export Year	Pallets
2019 Actual	257
2019 Forecast	1,664
2021 Forecast	1,753

TABLE 5.11: *Citrus export volumes requiring priority capacity allocation (O_j) at the Port of Durban in the preallocation model*

5.5.2 Seasonal Reallocation Quantity (B_j)

Once the preallocation model is done, the reallocation model can be executed for the remaining volumes based on the allowable citrus volumes that may be exported through the Port of Durban in each scenario as defined in Table 4.1. Table 5.12 shows the seasonal reallocation quantity (B_1) in pallets, which is calculated using Equation 4.21, that must be reallocated from the Port of Durban for each scenario in each of the export seasons analysed.

Scenario	2019 Actual	2019 Forecast	2021 Forecast
Scenario 1	873,483	879,074	926,478
Scenario 2	719,383	719,920	758,741
Scenario 3	565,282	560,765	591,004
Scenario 4	411,182	401,610	423,267
Scenario 5	257,081	242,455	255,530
Scenario 6	102,981	83,300	87,792

TABLE 5.12: *Pallet throughput reduction required (B_j) per scenario at the Port of Durban for each year analysed*

5.5.3 Network Cost (C_{ij})

The transport cost assigned per each region-port combination is based on a transport cost per pallet. This is calculated first by determining the kilometres via road from the designated centre of origin for each region to the port, multiplying it by the average cost per kilometre and then dividing by the number of pallets on an average one-way trip. The kilometres from each production region to each port and its designated centre of origin is listed in Table 5.13. The corresponding transport cost per pallet based on a cost per kilometre of R16 per kilometre for trips within the borders of South Africa is shown in Table 5.14. The production region Swaziland has two origins for calculating the road distance cost as volumes enter at different border crossings with South Africa depending on the port that the volumes are destined for. The transport costs for the dummy nodes “Unknown-CPT” and “Unknown-Coega/PE” are included and are assigned a high transport cost ($\mathcal{M} = 99,999$) to export via a port other than their assigned port to force the reallocation model to export their volumes through their respective port. This ensures that the capacity they require is included in the total capacity required at the respective ports after the reallocation.

Production Region	Origin	Port of Durban	Port of Coega/PE	Port of Cape Town
Boland	Worcester	1,536	662	112
Burgersfort Ohrigstad	Burgersfort	736	1,371	1,742
Eastern Cape Midlands	Fort Beaufort	769	190	903
Hoedspruit	Hoedspruit	815	1,481	1,851
Letsitele	Letsitele	850	1,468	1,838
Limpopo River	Musina	1,083	1,544	1,914
Nelspruit	Nelspruit	696	1,372	1,743
Nkwalini	Nkwalini	175	1,049	1,679
Onderberg	Malelane	740	1,436	1,807
Orange River	Groblershoop	1,090	803	777
Patensie	Patensie	992	105	706
Pongola	Pongola	388	1,254	1,694
Senwes	Groblersdal	705	1,237	1,608
Southern KZN	Richmond	105	795	1,607
Sundays River Valley	Kirkwood	918	74	778
Swaziland	Lavumisa (DBN) and Oshoek border crossing (CPT and PE)	371	1,297	1,665
VaalHarts	Hartswater	777	809	1,071
Western Cape	Citrusdal	1,626	817	177
Zimbabwe	Beitbridge border crossing	1,103	1,564	1,934
Unknown-Coega/PE	Dummy Node	99,999	-	99,999
Unknown-CPT	Dummy Node	99,999	99,999	-

TABLE 5.13: *Road transport kilometres from each assigned single point of origin for each production region to each port.*

Production Region	Port of Durban	Port of Coega/PE	Port of Cape Town
Boland	1,229	530	90
Burgersfort Ohrigstad	589	1,097	1,394
Eastern Cape Midlands	615	152	722
Hoedspruit	652	1,185	1,481
Letsitele	680	1,174	1,470
Limpopo River	866	1,235	1,531
Nelspruit	557	1,098	1,394
Nkwalini	140	839	1,343
Onderberg	592	1,149	1,446
Orange River	872	642	622
Patensie	794	84	565
Pongola	310	1,003	1,355
Senwes	564	990	1,286
Southern KZN	84	636	1,286
Sundays River Valley	734	59	622
Swaziland	297	1,038	1,332
VaalHarts	622	647	857
Western Cape	1,301	654	142
Zimbabwe	882	1,251	1,547
Unknown-Coega/PE	99,999	-	99,999
Unknown-CPT	99,999	99,999	-

TABLE 5.14: *Transport cost (ZAR) (C_{ij}) per pallet from each assigned single point of origin for each production region to each port. [32]*

5.5.4 Regional Demand (D_{ik})

The total citrus volumes that need to be exported each week from each production region can be found in Appendix A. Table 5.1 and Table 5.8 show the annual volumes that must be exported from each region in the entire export season for the 2019 actual, 2019 forecasted and 2021 forecasted export years respectively. This data was obtained from the data supplied by Company X post data categorisation.

5.5.5 Maximum Seasonal Regional Supply (Q_{ij})

The adjusted allowable citrus throughput volume (R'_1) at the port of Durban is determined by subtracting the seasonal reallocation quantity (B_j) and seasonal priority demand (O_j) from the current throughput (A_j) according to Equation 4.28. Table 5.15 shows the the adjusted allowable citrus throughput (R'_1) that may be exported through the Port of Durban in each export season. Once the adjusted allowable citrus volume (R'_1) is determined, the allocation techniques are used to determine (Q_{ij}) the maximum volume each CGA production region can export through the Port of Durban in the export season. However, before the allocation techniques can be used, the regions must be ranked in a non-increasing order, based on pallet volume exported from each production region through the Port of Durban. The order of the regions per export year analysed is shown in Table 5.16. The ranking order for the 2019 and 2021 forecasted years is the same, because of the volumetric index used to disaggregate the annual citrus exports into the weekly exports from each production region to each port. Because the index from the 2017 and 2018 export years is applied to both the 2019 and 2021 forecasted export volumes, the same trends will be evident in both export years as a result. It is also very similar to the ranking order of the 2019 actual export season, with most rankings differing by ±1. The biggest difference was for Patensie which dropped three places in the rankings for the 2019 and 2021 forecasted export seasons. This order is also used as the lexicographic rank in the lexicographic allocation. The dummy nodes "Unknown-Coega/PE" and "Unkown-CPT" are excluded as they do not export through the Port of Durban and are assigned a maximum seasonal regional supply of zero pallets. The dummy node "Unknown-DBN" is also excluded as this volume is assigned priority capacity. Table B.1, Table B.2 and Table B.3 show the maximum seasonal regional supply per region per scenario for the 2019 actual, 2019 forecast and 2021 forecast export years respectively. The differences in total values between each allocation technique for each scenario and year analysed are due to rounding errors during the allocation process.

Scenario	2019 Actual	2019 Forecast	2021 Forecast
Scenario 1	-	-	-
Scenario 2	153,483	157,491	165,984
Scenario 3	307,994	316,646	333,721
Scenario 4	462,044	475,801	501,458
Scenario 5	616,145	634,956	669,195
Scenario 6	770,245	794,110	836,932

TABLE 5.15: *Adjusted allowable citrus export volume (R'_1), in pallets, that may be exported through the Port of Durban per scenario, for each year analysed, excluding that volume that has already been assigned priority capacity*

2019 Actual	2019 Forecast	2021 Forecast
Letsitele	Senwes	Senwes
Senwes	Letsitele	Letsitele
Hoedspruit	Hoedspruit	Hoedspruit
Limpopo River	Limpopo River	Limpopo River
Nelspruit	Onderberg	Onderberg
Onderberg	Nelspruit	Nelspruit
Burgersfort Ohrigstad	Burgersfort Ohrigstad	Burgersfort Ohrigstad
Sundays River Valley	Nkwalini	Nkwalini
Nkwalini	Sundays River Valley	Sundays River Valley
Western Cape	Southern KZN	Southern KZN
Southern KZN	Western Cape	Western Cape
Patensie	Pongola	Pongola
Eastern Cape Midlands	Eastern Cape Midlands	Eastern Cape Midlands
Pongola	Boland	Boland
Boland	Patensie	Patensie
VaalHarts	VaalHarts	VaalHarts
Orange River	Orange River	Orange River
Swaziland	Swaziland	Swaziland
*	Zimbabwe	Zimbabwe
*Zimbabwe was not included in the 2019 actual export dataset		

TABLE 5.16: *Rank of CGA production regions in each export year analysed, based on a non-increasing order of the citrus pallet volume to be exported through the Port of Durban*

5.5.6 Port Throughput Capacity Available Per Week (P_{jk})

The available port throughput capacity at the Port of Durban (P_{1k}) for each week is calculated by reducing the current port throughput at the Port of Durban (A_{1k}) by the contribution each week has to the total citrus that needs to be reallocated away from the Port of Durban ($V_{1k}B_1$) and adjusting it for those volumes that have already been assigned priority capacity using Equation 4.39, Equation 4.40 and Equation 4.41. The Port of Cape Town and Port of Coega/PE are assumed to have sufficient capacity each week. The contribution indices (V_{1k}) used for each week can be found in Appendix C. Appendix E shows the weekly available port throughput at the Port of Durban for each scenario and export season analysed. The calculated port throughput capacity follows the expected pattern of very low to zero supply in the off-season and maximum supply in the winter peak season. The Port of Cape Town and Port of Coega/PE are assigned an arbitrary large weekly available port throughput of $\mathcal{M}$ as per Equation 4.34. This arbitrary large value of $\mathcal{M}$ is 99,999 pallets. When the relaxation as per Equation 4.41 is applied, some weeks' adjusted allowable port throughput is set to zero ($P'_{1k} = 0$) as there was more volume requiring priority capacity in that week than allowable port throughput available. As a result, the new net sum of all the weeks' adjusted available port throughput may be greater than the allowable citrus throughput at the Port of Durban as listed in Table 5.15 such that:

$$\sum_{k \epsilon \mathcal{K}} P'_{1k} \geq R'_1. \tag{5.1}$$

This is a result of the negative allowable port throughput weeks no longer being included. However, this does not affect the reallocation model as the maximum volume that may flow between a CGA production region and the Port of Durban (Q_{i1}) in the export season still ensures that the total throughput exported through the Port of Durban is less than or equal to the adjusted allowable throughput listed in Table 5.15 as:

$$\sum_{i\epsilon\mathcal{Z}} Q_{i1} = R'_1, \tag{5.2}$$

and

$$\sum_{k\epsilon\mathcal{K}} x_{i1k} \leq Q_{i1} \quad \forall i\epsilon\mathcal{Z}. \tag{5.3}$$

Table 5.17 is an extract of the allowable port throughput at the Port of Durban for Scenario 2 in the 2019 forecasted year. It is clear that without the adjustment of setting the lower limit to zero, the total allowable port throughput will equal the actual adjusted allowable port throughput, however, as a result of the lower limit being set to zero when the priority capacity is greater than the adjusted allowable port throughput for the week, the new net total adjusted allowable port throughput will be overstated by 28 pallets.

	···	**Week 4**	···	**Week 50**	···	**Total**
(1)Adjusted Allowable Port Throughput (P_{ik})	···	19	···	6	···	**157,491**
(2)Priority Capacity	···	25	···	29	···	**1,664**
(3)Without Zero Lower Limit Adjustment	···	-6	···	-23	···	**157,491**
(4)With Zero Lower Limit Adjustment	···	0	···	0	···	**157,519**
Difference of (1) Versus (3)						**0**
Difference of (1) Versus (4)						**28**

Table 5.17: *Example showing the effect of setting the allowable port throughput lower limit to zero as a result of priority capacity being greater than allowable port throughout in a specific week for Scenario 2 of the 2019 forecasted export season*

5.5.7 Minimum (N_{ijk}) and Maximum (M_{ijk}) Weekly Throughput

No minimum weekly flow constraint is imposed in the model and so the minimum flow for all the network combinations is set at zero. The maximum flow imposed for CGA production regions to export through an alternate port and not the Port of Durban is set as an arbitrary large value $\mathcal{M}$, which is equal to 99,999 pallets as it is preferred that these alternate ports be used. The maximum flow imposed each week to export through the Port of Durban from a CGA production region M_{i1k} in each export season can be found in Appendix A.

5.6 Results Analysis

The results analysis (Step S6 of Figure 4.1) is split into multiple components. The first component involves analysing the results of the 2019 actual and 2019 forecasted export seasons to understand what is the change in the export flow dynamics between the actual and forecasted export season. This analysis is used to draw a conclusion as to whether or not there is a best suited allocation technique to use in all the scenarios for both an actual or a forecasted export year based on the incremental transport cost to the citrus export cold chain. The second component proposes an export plan for the 2021 export season based on the conclusion made in the first component. An analysis is also conducted on the 2021 season to compare against what the export flows would look like without the reallocation done. Again the incremental transport cost to the citrus export cold chain, as well as the change in export flows between the production regions and the ports is analysed.

2019 Actual versus 2019 Forecast

Figure 5.11 and Figure 5.12 are graphical representations of the transport costs for each scenario and allocation technique versus the transport cost without reallocation for the 2019 actual and forecasted export seasons respectively. Table F.1 and Table F.2 show the road transport cost from each production region to each port for the 2019 actual and forecasted export seasons respectively without reallocation, as well as the regional, port and overall totals. The 2019 actual export season transport cost is R6.5m higher than the 2019 forecasted export season. Transport costs to the Port of Durban and Port of Coega/PE from the production regions are lower by R900k and R4m respectively in the 2019 actual export season than in the 2019 forecasted export season. Transport costs to the Port of Cape Town from the production regions in the 2019 actual export season is R11.4m higher than the 2019 forecasted export season. This higher cost in the 2019 actual export season is driven by the Sundays River Valley, which had a cost that was R9.9m higher in the 2019 actual year due to it exporting 20,761 pallets via the Port of Cape Town versus the 4,760 pallets exported via the Port of Cape Town in the 2019 forecasted export year. This bigger export volume from the Sundays River Valley through the Port of Cape Town does not show in the 2019 forecasted export year due to the volumetric indexes used, which is based on the 2017 and 2018 export seasons, to disaggregate the annual forecasted citrus export volumes and so this trend in the 2019 actual export season is not shown in the 2019 forecasted export season.

There are only three instances for both the 2019 actual and forecasted export season in which the reallocation model resulted in transport cost to the citrus export cold chain that is less than the transport cost without reallocation as seen in Table 5.18, which shows the percentage difference in transport cost for each scenario and allocation technique versus the transport cost without the reallocation. These instances for both years occurred in Scenario 6 whereby the Port of Durban can export 50% of the total citrus exports from the production regions. The reason for this is because with the reallocation, the production regions use more of the "Corridor Concept" and export volumes through a port that is closest to them first, and then through an alternate port, which is further away.

Table 5.19 and Table 5.20 show the transport cost percentage difference for each region without reallocation versus the cost after the reallocation for the best suited allocation technique. It is evident that the biggest losers of the reallocation, based on the percentage increase in transport costs they will incur, are the Southern KZN, Nkwalini, Swaziland and Pongola production regions with transport cost increases ranging from +223.49% for Pongola in the 2019 forecasted year to +612.81% for Southern KZN in the 2019 actual year. It makes sense that these production regions will be worse off than others as they are the production regions in the Northern Corridor that primarily use the Port of Durban and are the closest production regions to the Port of Coega/PE, which is the next closest port to the Port of Durban. The production regions that gain the most as a result of their transport cost decreasing are the Eastern Cape Midlands, Sundays River Valley, Boland and the Western Cape, with cost decreases ranging from -20.81% for Patensie in the 2019 forcasted export season and -68.96% for the Eastern Cape Midlands in the 2019 actual export season. The decrease is a result of these production regions being allocated more volume to the Port of Coega/PE and Port of Cape Town, which are the closest ports to them. Figure 5.13 is a map showing which production regions are the biggest gainers (green), and which production regions are the biggest losers (red) as a result of the reallocations. The full transport costs for each scenario, allocation technique and year combination can be found in Appendix G.

Based on transport costs alone, it is evident that there is no best suited allocation technique for the reallocation of forecasted volumes. This is due to the fact that all techniques perform equally well in Scenario 1, and that between the 2019 actual and forecasted export years, different techniques performed better. In the 2019 actual export season, the lexicographic allocation technique performed best 80% of the time, however, in the 2019 forecasted export season, the proportional allocation technique performed best 80% of the time. The linear and uniform allocation techniques perform on average worse than the proportional and lexicographic allocation techniques. As such, the reallocation for each scenario will have to be done on a case-by-case basis using the best suited allocation technique for that specific scenario.

As the allowable volume that the Port of Durban can handle increases there is a noticeable decline in the transport cost to the citrus export cold chain, as seen in Figure 5.11 and Figure 5.12. This is due to the fact that the regions located in the "Northern Corridor", which primarily use the Port of Durban, as it is closer with the cheapest transport cost, are able to export more citrus volume through this port instead of an alternate port. The alternate port that these regions primarily use, as a result of the reallocation, is the Port of Coega/PE as it is the next closest port.

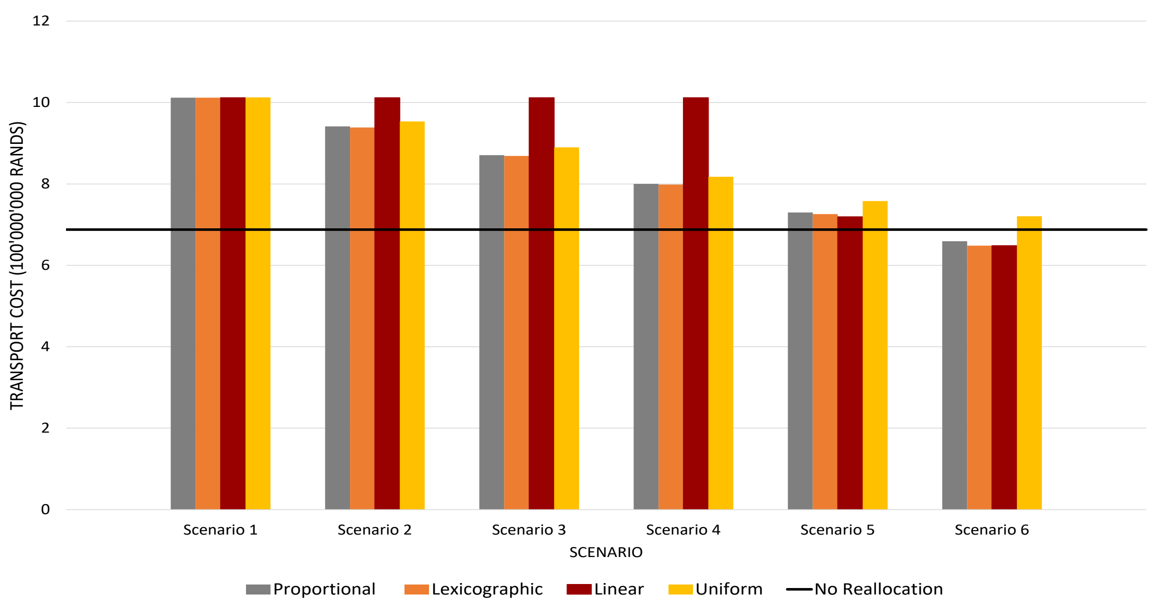

FIGURE 5.11: *Transport costs after the reallocation for each scenario and allocation technique versus the transport cost with no reallocation for the 2019 actual export season*

Analysis of the change in export flow dynamics between the regions and ports for each allocation technique used in each scenario yield some interesting results. In all instances, the total adjusted allowable throughput that may be handled at the Port of Durban (R'_1) is not fully utilised during the export season as seen in Table 5.21 and Table 5.22, which is the percentage difference between the adjusted allowable and allocated citrus throughput assigned to the Port of Durban for the 2019 actual and forecasted export seasons. The total allocated throughput that is exported through the Port of Durban is less than the adjusted allowable target throughput. The percentage differences in how much less the Port of Durban exported based on the allocation compared to its adjusted target allowable throughput ranges from 0.03% to 100%. The 100%

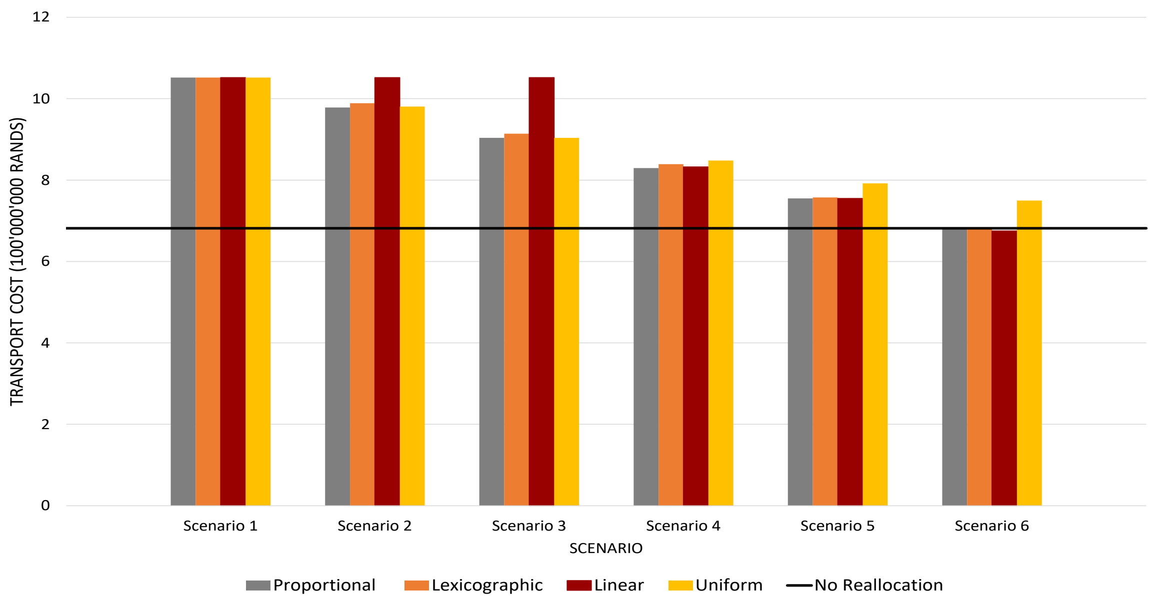

FIGURE 5.12: *Transport costs after the reallocation for each scenario and allocation technique versus the transport cost with no reallocation for the 2019 forecast export season*

Scenario	Proportional	Lexicographic	Linear	Uniform	Average
		2019 Actual			
Scenario 1	32.00%	32.00%	32.00%	32.00%	**32.00%**
Scenario 2	26.92%	26.70%	32.00%	27.84%	**28.43%**
Scenario 3	21.00%	20.82%	32.00%	22.68%	**24.42%**
Scenario 4	14.03%	13.82%	32.00%	15.87%	**19.73%**
Scenario 5	5.72%	5.21%	4.36%	9.23%	**6.17%**
Scenario 6	-4.37%	-6.13%	-6.12%	4.53%	**-2.82%**
Average	**17.66%**	**17.31%**	**23.77%**	**19.87%**	**19.73%**
		2019 Forecast			
Scenario 1	35.20%	35.20%	35.20%	35.20%	**35.20%**
Scenario 2	30.33%	31.07%	35.20%	30.50%	**31.84%**
Scenario 3	24.60%	25.42%	35.20%	24.60%	**27.75%**
Scenario 4	17.84%	18.79%	18.13%	19.64%	**18.61%**
Scenario 5	9.75%	10.00%	9.75%	13.94%	**10.90%**
Scenario 6	-0.11%	-0.26%	-0.95%	9.12%	**2.13%**
Average	**21.35%**	**21.82%**	**24.53%**	**23.23%**	**22.75%**

TABLE 5.18: *Percentage difference in transport costs after reallocation for each scenario and allocation technique combination versus the transport cost without reallocation for the 2019 actual and forecast export season*

percentage difference refers to the instances where the condition of the linear allocation model is not met, and so no volume is assigned to the production regions to be exported through the Port of Durban. If one removes these instances, the biggest percentage difference from target to assigned is 27.76%. The same trend is observed on another level when analysing the flows between a production region and the Port of Durban. The production regions don't always use the full adjusted allowable throughput allocation assigned to them by the allocation technique in

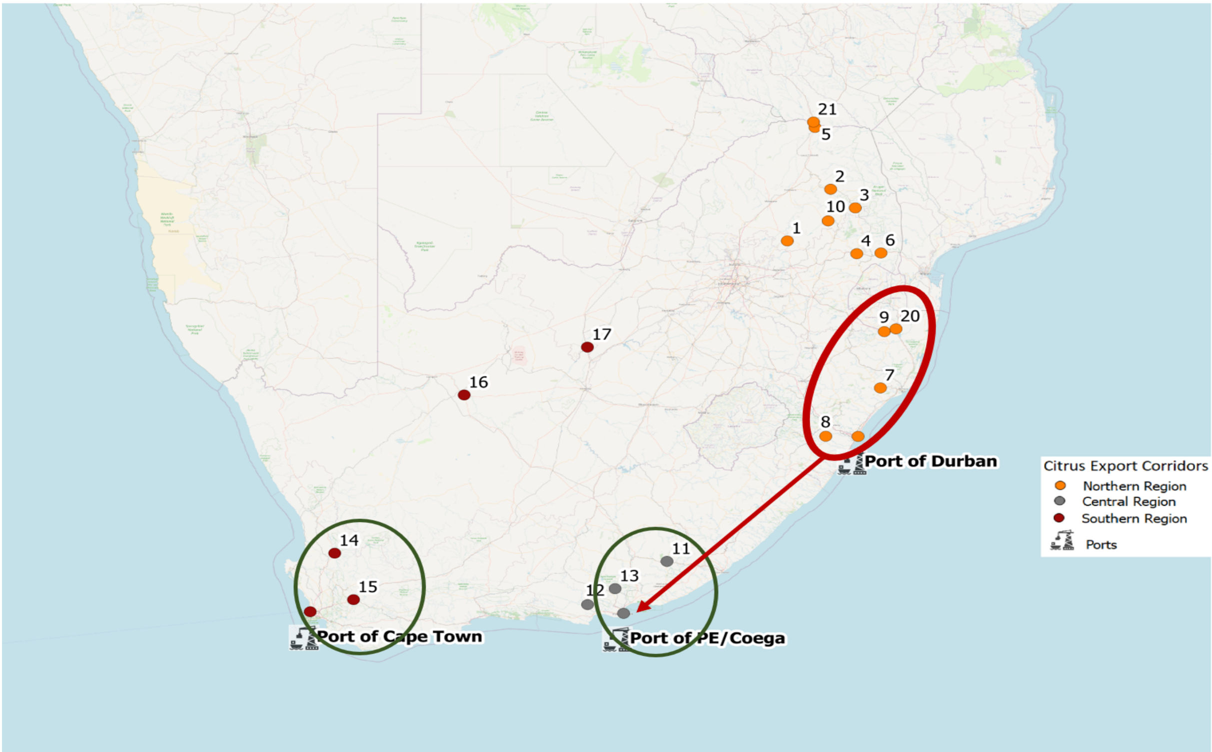

FIGURE 5.13: *Map showing which production regions are the biggest losers, and which production regions are the biggest winners as a result of the reallocation*

each scenario for the Port of Durban. This difference represents the amount of slack that exists in the capacity constraints used in the allocation model framework, namely the maximum seasonal regional supply (Q_{ij}) and the port throughput capacity available each week (P_{jk}). Therefore, the difference between the allocated citrus export volumes $\sum x_{ijk}$ and the upper limits set by the allocation techniques in Equation 4.8 and the upper limits set by Equation 4.9, ensure that:

$$\sum x_{i1k} \leq R_1' \qquad \forall i \epsilon \mathcal{I}, \forall k \epsilon \mathcal{K}. \tag{5.4}$$

The primary cause of this is that even if a region was granted allowable throughput at the Port of Durban, the LP model will still assign the volume to the Port of Cape Town or Port of Coega/PE if the region is located closer to these ports as it reduces the transport cost, and also because the capacity at these ports has not been constrained. A secondary cause to this is when the linear allocation technique is applied. With this technique, if a common deduction cannot be found that satisfies the condition of this rule, then all the production regions are assigned a maximum seasonal regional supply of zero and so no exports will go through the Port of Durban.

Region	Scenario 1 (All)	Scenario 2 (Lexicographic)	Scenario 3 (Lexicographic)	Scenario 4 (Lexicographic)	Scenario 5 (Linear)	Scenario 6 (Lexicographic)
Senwes	72.79%	72.79%	41.85%	1.94%	8.31%	-0.53%
Letsitele	70.79%	23.68%	1.66%	-0.38%	7.26%	-0.38%
Hoedspruit	80.32%	80.32%	80.32%	56.59%	13.93%	-0.22%
Nelspruit	91.78%	91.78%	91.78%	91.78%	32.73%	-0.86%
Limpopo River	39.23%	39.23%	39.23%	39.23%	11.93%	5.53%
Onderberg	90.94%	90.94%	90.94%	90.94%	41.12%	-0.42%
Nkwalini	486.53%	486.53%	486.53%	486.53%	486.53%	486.53%
Southern KZN	612.81%	612.81%	612.81%	612.81%	612.81%	612.81%
Pongola	223.55%	223.55%	223.55%	223.55%	223.55%	223.55%
Burgersfort Ohrigstad	69.18%	69.18%	69.18%	69.18%	69.18%	45.81%
Eastern Cape Midlands	-68.96%	-68.96%	-68.96%	-68.96%	-68.96%	-68.96%
Patensie	-51.90%	-51.90%	-51.90%	-51.90%	-51.90%	-51.90%
Sundays River Valley	-62.66%	-62.66%	-62.66%	-62.66%	-62.66%	-62.66%
Western Cape	-39.17%	-39.17%	-39.17%	-39.17%	-39.17%	-39.17%
Boland	-55.48%	-55.48%	-55.48%	-55.48%	-55.48%	-55.48%
Orange River	-0.26%	-0.26%	-0.26%	-0.26%	-0.26%	-0.26%
VaalHarts	-20.78%	-20.78%	-20.78%	-20.78%	-20.78%	-20.78%
Unknown-Coega/PE	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Unknown-CPT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Swaziland	249.49%	249.49%	249.49%	249.49%	249.49%	249.49%
Unknown-DBN	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

TABLE 5.19: *Percentage difference in transport cost after reallocation for each scenario using the best suited technique versus the transport cost without reallocation for the 2019 actual export season*

Region	Scenario 1 (All)	Scenario 2 (Proportional)	Scenario 3 (Proportional)	Scenario 4 (Proportional)	Scenario 5 (Proportional)	Scenario 6 (Linear)
Senwes	72.19%	59.10%	45.87%	32.64%	19.41%	1.18%
Letsitele	69.30%	56.74%	44.05%	31.36%	18.66%	1.24%
Hoedspruit	79.04%	64.77%	50.35%	35.93%	21.50%	3.57%
Nelspruit	90.38%	73.94%	57.34%	40.73%	24.12%	10.99%
Limpopo River	41.54%	34.03%	26.44%	18.85%	11.25%	2.66%
Onderberg	90.47%	74.11%	57.59%	41.06%	24.54%	9.78%
Nkwalini	490.45%	402.32%	313.26%	224.18%	135.12%	175.07%
Southern KZN	544.21%	445.24%	345.21%	245.10%	145.07%	544.21%
Pongola	223.49%	183.38%	142.80%	102.27%	61.73%	223.49%
Burgersfort Ohrigstad	67.77%	54.96%	42.01%	29.06%	16.11%	9.22%
Eastern Cape Midlands	-54.67%	-54.67%	-54.67%	-54.67%	-54.67%	-54.67%
Patensie	-20.81%	-20.81%	-20.81%	-20.81%	-20.81%	-20.81%
Sundays River Valley	-32.18%	-32.18%	-32.18%	-32.18%	-32.18%	-32.18%
Western Cape	-34.86%	-34.86%	-34.86%	-34.86%	-34.86%	-34.86%
Boland	-41.10%	-41.10%	-41.10%	-41.10%	-41.10%	-41.10%
Orange River	-0.23%	-0.23%	-0.23%	-0.23%	-0.23%	-0.23%
VaalHarts	-21.58%	-21.60%	-21.62%	-21.65%	-21.67%	-21.58%
Unknown-Coega/PE	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Unknown-CPT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Swaziland	243.56%	197.57%	151.59%	105.60%	59.62%	243.56%
Zimbabwe	49.01%	41.69%	34.36%	27.04%	19.71%	49.01%
Unknown-DBN	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

TABLE 5.20: *Percentage difference in transport cost after reallocation for each scenario using the best suited technique versus the transport cost without reallocation for the 2019 forecasted export season*

	Target (R'_1)	Allocated	Percentage Difference	Target (R'_1)	Allocated	Percentage Difference	Target (R'_1)	Allocated	Percentage Difference
	Scenario 1			**Scenario 2**			**Scenario 3**		
Proportional	-	-	0.00%	153,843	144,921	-5.80%	307,944	290,085	-5.80%
Lexicographic	-	-	0.00%	153,843	148,074	-3.75%	307,944	300,820	-2.31%
Linear	-	-	0.00%	153,843	-	-100.00%	307,944	-	-100.00%
Uniform	-	-	0.00%	153,843	111,133	-27.76%	307,944	238,555	-22.53%
	Scenario 4			**Scenario 5**			**Scenario 6**		
Proportional	462,044	435,250	-5.80%	616,145	580,413	-5.80%	770,245	725,579	-5.80%
Lexicographic	462,044	455,233	-1.47%	616,145	608,234	-1.28%	770,245	756,573	-1.78%
Linear	462,044	-	-100.00%	616,145	613,508	-0.43%	770,245	754,325	-2.07%
Uniform	462,044	386,773	-16.29%	616,145	515,574	-16.32%	770,245	592,709	-23.05%

TABLE 5.21: *Percentage difference between the adjusted allowable citrus throughput at the Port of Durban (R'_1) versus the assigned citrus throughput at the Port of Durban ($\sum_{i\epsilon\mathcal{Z}}\sum_{k\epsilon\mathcal{K}} x_{i1k}$) after the reallocation for each allocation technique and scenario for the 2019 actual export season*

	Target (R_1')	Allocated	Percentage Difference	Target (R_1')	Allocated	Percentage Difference	Target (R_1')	Allocated	Percentage Difference
	Scenario 1			**Scenario 2**			**Scenario 3**		
Proportional	-	-	0.00%	157,491	153,638	-2.45%	316,646	308,900	-2.45%
Lexicographic	-	-	0.00%	157,491	147,839	-6.13%	316,646	310,995	-1.78%
Linear	-	-	0.00%	157,491	-	-100.00%	316,646	-	-100.00%
Uniform	-	-	0.00%	157,491	136,023	-13.63%	316,646	292,016	-7.78%
	Scenario 4			**Scenario 5**			**Scenario 6**		
Proportional	475,801	464,161	-2.45%	634,956	619,423	-2.45%	794,110	774,683	-2.45%
Lexicographic	475,801	460,321	-3.25%	634,956	630,282	-0.74%	794,110	788,555	-0.70%
Linear	475,801	475,654	-0.03%	634,956	634,704	-0.04%	794,110	793,189	-0.12%
Uniform	475,801	408,885	-14.06%	634,956	532,253	-16.17%	794,110	621,329	-21.76%

TABLE 5.22: *Percentage difference between the adjusted allowable citrus throughput at the Port of Durban (R_1') versus the assigned citrus throughput at the Port of Durban ($\sum_{i\epsilon\mathcal{Z}}\sum_{k\epsilon\mathcal{K}} x_{i1k}$) after the reallocation for each allocation technique and scenario for the 2019 forecasted export season*

The export flow dynamics after reallocation follow a very similar pattern to that of the "corridor concept" as seen in Figure 5.14, which is the citrus export flows from each production region through each port after reallocation for Scenario 6 under proportional allocation for the 2019 forecasted export season. This flow is different to the flow dynamics without the reallocation whereby production regions export through multiple ports in South Africa in a criss-crossing flow network as seen in Figure 5.1. The current flow network used may be due to a number of factors such as last port of call for ships going to a specific destination, capacity availability at ports, exporter preference or shipping lines not calling a port, and instead calling the next port, which may force the exporter to change the port of export. After reallocation, all the "Central Corridor" production regions export through the Port of Coega/PE. All the "Southern Corridor" production regions except for Vaalharts, export through the Port of Cape Town. The Port of Cape Town also only exports the volumes from these regions, it does not handle any volumes from the other corridors. The reason Vaalharts, which is considered a "Southern Corridor" production region as it is based in the Northern Cape, does not export through the Port of Cape Town is because its closest port is the Port of Durban, followed by the Port of Coega/PE. As such, it will export through the Port of Durban when the throughput allows it to, otherwise it will export through the Port of Coega/PE. The "Northern Corridor" production regions, which are located closest to the Port of Durban, utilise the Port of Durban as their primary export port when the allowable port throughput allows it to do so. The volumes that need to be reallocated are redirected to the Port of Coega/PE, which is the next closest port. No volumes from the "Northern Corridor" production regions are assigned the Port of Cape Town. As such, the bulk of the reallocated volumes are assigned to the Port of Coega/PE. The volumes that must flow between each region and port combination for each scenario under each allocation rule for the 2019 actual and forecast export seasons can be found in Appendix A.

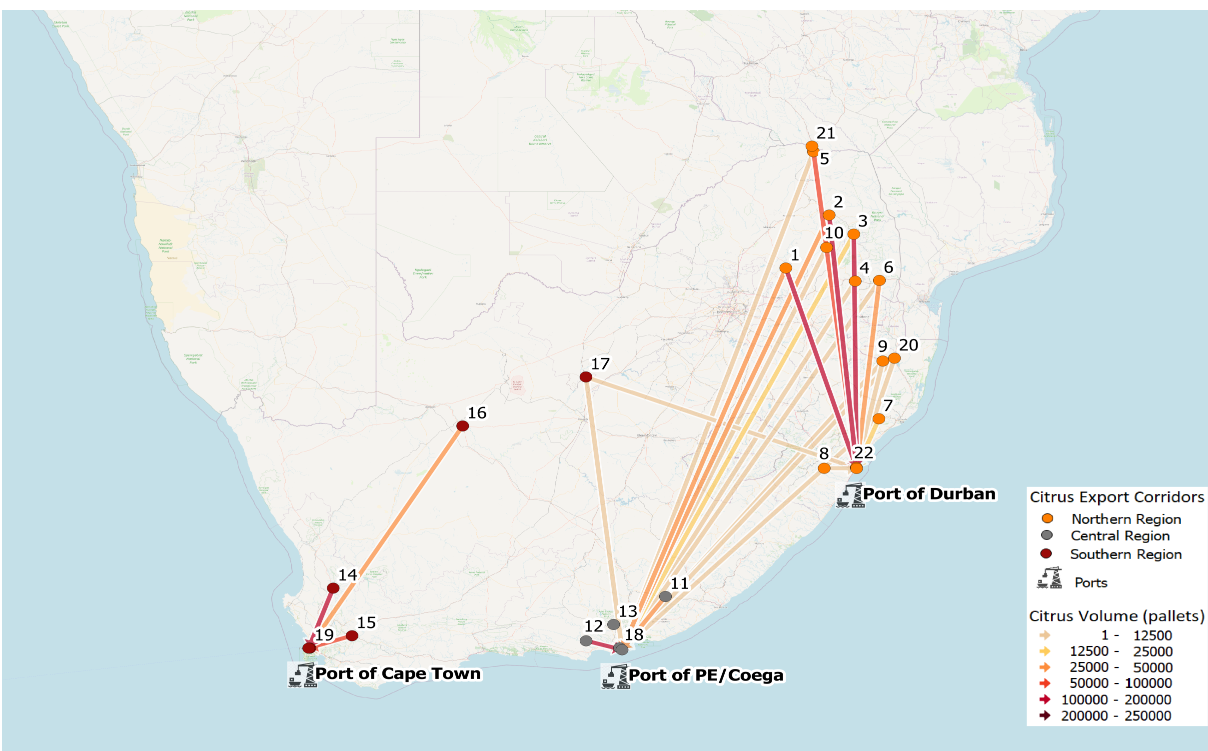

FIGURE 5.14: *A flow map showing the citrus exports after reallocation in Scenario 6 from each production through each port for the 2019 forecasted export season under proportional allocation*

An example of the flow analysis conducted is shown in Table 5.23 and Table 5.24, which are the results of Scenario 6 under proportional allocation in the 2019 actual and forecasted export season respectively. This specific scenario was selected for the comparison as it resulted in one of the lowest transport costs after reallocation when compared to the other techniques and scenarios, and showed the change in flow dynamics quite nicely. As one can see the "Southern Corridor" production regions, excluding Vaalharts, export through the Port of Cape Town and this is the only volume the Port of Cape Town handles. The dummy nodes all get allocated their respective preferred port, and all the "Central Corridor" production regions are exported through the Port of Coega/PE. The "Northern Corridor" production regions export through the Port of Durban as far as is possibly allowed, with the remaining volumes being exported through the Port of Coega/PE. Table 5.25 and Table 5.26 show what citrus volume is assigned to each port after the reallocation under each allocation rule for the 2019 actual and forecast export seasons respectively. Based on the results shown in Table 5.25 the Port of Durban saw a 147,904 (16.93%) pallet drop in the export volumes assigned to it (excluding volumes assigned priority capacity), the Port of Cape Town saw a 27,494 (9.07%) pallet volume decrease and the Port of Coega/PE saw a 175,141 (48.08%) pallet volume increase in the pallet volumes assigned for the 2019 actual export season. For the 2019 forecasted export season, the Port of Durban had a 104,391 (11.88%) pallet volume decrease, the Port of Cape Town pallet volume dropped by 10,141 (3.52%) pallets and the Port of Coega/PE had an increase in pallet volume of 112,867 (26.60%) pallets as seen in Table 5.26. The reduction in pallet volume assigned to the Port of Durban is significantly higher than the required citrus pallet throughput reduction of 102,981 pallets and 83,300 pallets for the 2019 actual and forecasted export seasons respectively.

	Pallets Exported Without Reallocation			Pallets Allocated			Percentage Difference		
Region	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**
Senwes	198,064	352	2,282	174,706	25,992	-	-11.79%	7,284.09%	-100.00%
Letsitele	223,700	191	1,997	197,319	28,569	-	-11.79%	14,857.59%	-100.00%
Hoedspruit	136,697	297	665	120,576	17,083	-	-11.79%	5,651.85%	-100.00%
Nelspruit	66,208	195	1,127	58,400	9,130	-	-11.79%	4,582.05%	-100.00%
Limpopo River	82,713	34	2,681	72,959	12,469	-	-11.79%	36,573.53%	-100.00%
Onderberg	52,795	239	455	46,569	6,920	-	-11.79%	2,795.40%	-100.00%
Nkwalini	17,732	-	45	15,641	2,136	-	-11.79%	0.00%	-100.00%
Southern KZN	8,246	-	36	7,274	1,008	-	-11.79%	0.00%	-100.00%
Pongola	4,962	-	-	4,377	585	-	-11.79%	0.00%	0.00%
Burgersfort Ohrigstad	31,208	166	2,388	27,528	6,234	-	-11.79%	3,655.42%	-100.00%
Eastern Cape Midlands	6,265	10,140	11,358	-	27,763	-	-100.00%	173.80%	-100.00%
Patensie	7,588	104,535	12,229	-	124,352	-	-100.00%	18.96%	-100.00%
Sundays River Valley	22,766	229,707	20,761	-	273,234	-	-100.00%	18.95%	-100.00%
Western Cape	9,583	9,911	157,504	-	-	176,998	-100.00%	-100.00%	12.38%
Boland	4,280	7,052	59,799	-	-	71,131	-100.00%	-100.00%	18.95%
Orange River	158	254	26,900	-	-	27,312	-100.00%	-100.00%	1.53%
VaalHarts	209	403	2,708	184	3,136	-	-11.96%	678.16%	-100.00%
Unknown-Coega/PE	-	797		-	797	-	0.00%	0.00%	0.00%
Unknown-CPT	-	-	313	-	-	313	0.00%	0.00%	0.00%
Swaziland	52	-	-	46	6	-	-11.54%	0.00%	0.00%
Unknown-DBN	257	-	-	257	-	-	0.00%	0.00%	0.00%
Total	**873,483**	**364,273**	**303,248**	**725,836**	**539,414**	**275,754**	**-16.90%**	**48.08%**	**-9.07%**

TABLE 5.23: *Flow of pallets between each region and port in Scenario 6 under proportional allocation for the 2019 actual export season*

Region	Pallets Exported Without Reallocation			Pallets Allocated			Percentage Difference		
	Durban	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**
Senwes	236,932	224	3,514	214,438	26,236	-	-9.49%	11,589.41%	-100.00%
Letsitele	228,722	442	3,682	207,008	25,838	-	-9.49%	5,745.28%	-100.00%
Hoedspruit	123,237	273	1,310	111,537	13,285	-	-9.49%	4,766.55%	-100.00%
Nelspruit	47,139	63	1,098	42,663	5,634	-	-9.49%	8,868.33%	-100.00%
Limpopo River	101,071	129	925	91,475	10,646	-	-9.49%	8,148.32%	-100.00%
Onderberg	54,764	42	702	49,565	5,939	-	-9.49%	14,145.51%	-100.00%
Nkwalini	17,505	11	24	15,843	1,695	-	-9.50%	15,520.81%	-100.00%
Southern KZN	6,798	11	79	6,153	739	-	-9.49%	6,369.96%	-100.00%
Pongola	4,710	-	-	4,263	446	-	-9.49%	0.00%	0.00%
Burgersfort Ohrigstad	34,830	62	3,014	31,524	6,381	-	-9.49%	10,150.61%	-100.00%
Eastern Cape Midlands	3,479	21,142	7,507	-	32,128	-	-100.00%	51.96%	-100.00%
Patensie	1,123	120,333	4,106	-	125,558	-	-100.00%	4.34%	-100.00%
Sundays River Valley	7,551	265,470	4,760	-	277,781	-	-100.00%	4.64%	-100.00%
Western Cape	6,790	11,057	160,211	-	-	178,056	-100.00%	-100.00%	11.14%
Boland	2,371	4,122	65,384	-	-	71,880	-100.00%	-100.00%	9.94%
Orange River	151	81	27,456	-	-	27,687	-100.00%	-100.00%	0.84%
VaalHarts	199	485	3,999	180	4,505	-	-9.43%	828.03%	-100.00%
Unknown-Coega/PE	-	444	-	-	444	-	0.00%	-0.07%	0.00%
Unknown-CPT	-	-	313	-	-	318	0.00%	0.00%	1.61%
Swaziland	33	-	-	29	3	-	-10.91%	0.00%	0.00%
Zimbabwe	6	-	-	5	1	-	-12.45%	0.00%	0.00%
Unknown-DBN	1,664	-	-	1,664	-	-	0.00%	0.00%	0.00%
Total	**879,074**	**424,392**	**288,082**	**776,347**	**537,259**	**277,941**	**-11.69%**	**26.60%**	**-3.52%**

TABLE 5.24: *Flow of pallets between each region and port in Scenario 6 under proportional allocation for the 2019 forecasted export season*

Further analysis of the results shown in Table 5.25 and Table 5.26 shows that in Scenario 1, the additional citrus throughput assigned to the Port of Coega/PE, in addition to the current throughput, is greater than the theoretical excess citrus capacity available for Scenario 1 in both the 2019 actual and forecast year. For the 2019 actual year, the total additional citrus assigned to both the Port of Coega/PE and Port of Cape Town is greater than their combined total theoretical excess citrus capacity. However, for the 2019 forecast export season, the contrary is observed and so if required, more volume can be reallocated to the Port of Cape Town, instead of to the Port of Coega/PE if no volume can be exported through the Port of Durban.

The results of Scenario 2 show that for the 2019 actual export season, the Port of Coega/PE cannot handle the additional throughput for all the allocation techniques, however, for the 2019 forecasted export season it can handle the additional citrus volume except when the reallocation is done under a linear allocation rule. The total additional citrus volume assigned to the Port of Cape Town and Port of Coega/PE combined is within the theoretical limits for both the 2019 actual and forecast export season except when the reallocation is done under a linear allocation rule. The reason behind the Port of Coega/PE not being able to handle the additional volume under linear allocation rule is because the condition of the linear allocation rule is not met and so no allowable throughput at the Port of Durban is assigned to the production regions.

The results of Scenario 3 and Scenario 4 are very similar. Additional citrus volumes can be handled except under linear allocation rule for Scenario 3 in the 2019 actual and forecast export seasons. In the Scenario 4, the Port of Coega/PE can handle the additional citrus volume except under linear allocation rule in the 2019 actual export season. For both Scenario 3 and 4 under linear allocation rule in the 2019 actual export season, the total theoretical citrus capacity between the Port of Cape Town and the Port of Coega/PE is too small for the additional citrus volumes. In the remaining instances, the combined theoretical excess capacity is sufficient if more volume was to be reallocated from the Port of Coega/PE. The Port of Coega/PE is able to handle the additional citrus volume across the allocation rules for both Scenario 5 and Scenario 6 in both the 2019 actual and forecasted export seasons. The Port of Cape Town is assigned a constant reduction of 27,494 pallets across all the scenarios and allocation techniques for the 2019 actual export season, and similarly a constant reduction of 10,141 pallets in the 2019 forecasted export season.

Port	Allocated Throughput (Pallets)				Additional Volume Handled (Pallets)				Percentage Difference to volume without reallocation			
	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform
Scenario 1												
Durban	-	-	-	-	- 873,483	- 873,483	- 873,483	- 873,483	-100.00%	-100.00%	-100.00%	-100.00%
Coega/PE	1,264,993	1,264,993	1,264,993	1,264,993	**900,720	**900,720	**900,720	**900,720	247.27%	247.27%	247.27%	247.27%
Cape Town	275,754	275,754	275,754	275,754	- 27,494	- 27,494	- 27,494	- 27,494	-9.07%	-9.07%	-9.07%	-9.07%
Scenario 2												
Durban	144,921	148,074	-	111,133	- 728,562	- 725,409	- 873,483	- 762,350	-83.41%	-83.05%	-100.00%	-87.28%
Coega/PE	1,120,072	1,116,919	1,264,993	1,153,860	*755,799	*752,646	**900,720	*789,587	207.48%	206.62%	247.27%	216.76%
Cape Town	275,754	275,754	275,754	275,754	- 27,494	- 27,494	- 27,494	- 27,494	-9.07%	-9.07%	-9.07%	-9.07%
Scenario 3												
Durban	290,085	300,820	-	238,555	- 583,398	- 572,663	- 873,483	- 634,928	-66.79%	-65.56%	-100.00%	-72.69%
Coega/PE	974,908	964,173	1,264,993	1,026,438	610,635	599,900	**900,720	662,165	167.63%	164.68%	247.27%	181.78%
Cape Town	275,754	275,754	275,754	275,754	- 27,494	- 27,494	- 27,494	- 27,494	-9.07%	-9.07%	-9.07%	-9.07%
Scenario 4												
Durban	435,250	455,233	-	386,773	- 438,233	- 418,250	- 873,483	- 486,710	-50.17%	-47.88%	-100.00%	-55.72%
Coega/PE	829,743	809,760	1,264,993	878,220	465,470	445,487	**900,720	513,947	127.78%	122.29%	247.27%	141.09%
Cape Town	275,754	275,754	275,754	275,754	- 27,494	- 27,494	- 27,494	- 27,494	-9.07%	-9.07%	-9.07%	-9.07%
Scenario 5												
Durban	580,413	608,234	613,508	515,574	- 293,070	- 265,249	- 259,975	- 357,909	-33.55%	-30.37%	-29.76%	-40.97%
Coega/PE	684,580	656,759	651,485	749,419	320,307	292,486	287,212	385,146	87.93%	80.29%	78.85%	105.73%
Cape Town	275,754	275,754	275,754	275,754	- 27,494	- 27,494	- 27,494	- 27,494	-9.07%	-9.07%	-9.07%	-9.07%
Scenario 6												
Durban	725,579	756,573	754,325	592,709	- 147,904	- 116,910	- 119,158	- 280,774	-16.93%	-13.38%	-13.64%	-32.14%
Coega/PE	539,414	508,420	510,668	672,284	175,141	144,147	146,395	308,011	48.08%	39.57%	40.19%	84.55%
Cape Town	275,754	275,754	275,754	275,754	- 27,494	- 27,494	- 27,494	- 27,494	-9.07%	-9.07%	-9.07%	-9.07%

*Additional citrus volume handled at the port exceeds the respective theoretical excess capacity for citrus at the alternative port

**Additional citrus volume handled at the port exceeds the total theoretical excess capacity for citrus at the alternative ports

TABLE 5.25: *Citrus throughput assigned to each South African port* ($\sum_{i\epsilon\mathcal{Z}}\sum_{j\epsilon\mathcal{J}}\sum_{k\epsilon\mathcal{K}} x_{ijk}$) *under each allocation technique for each scenario in the 2019 actual export season*

	Allocated Throughput (Pallets)				Additional Volume Handled (Pallets)				Percentage difference to volume without reallocation			
Port	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform
Scenario 1												
Durban	-	-	-	-	- 879,074	- 879,074	- 879,074	- 879,074	-100.00%	-100.00%	-100.00%	-100.00%
Coega/PE	1,311,942	1,311,942	1,311,942	1,311,942	*887,550	*887,550	*887,550	*887,550	209.13%	209.13%	209.13%	209.13%
Cape Town	277,941	277,941	277,941	277,941	- 10,141	- 10,141	- 10,141	- 10,141	-3.52%	-3.52%	-3.52%	-3.52%
Scenario 2												
Durban	153,638	147,839	-	136,023	- 725,436	- 731,235	- 879,074	- 743,051	-82.52%	-83.18%	-100.00%	-84.53%
Coega/PE	1,158,304	1,164,103	1,311,942	1,175,919	733,912	739,711	*887,550	751,527	172.93%	174.30%	209.13%	177.08%
Cape Town	277,941	277,941	277,941	277,941	- 10,141	- 10,141	- 10,141	- 10,141	-3.52%	-3.52%	-3.52%	-3.52%
Scenario 3												
Durban	308,900	310,995	-	292,016	- 570,174	- 568,079	- 879,074	- 587,058	-64.86%	-64.62%	-100.00%	-66.78%
Coega/PE	1,003,042	1,000,947	1,311,942	1,019,926	578,650	576,555	*887,550	595,534	136.35%	135.85%	209.13%	140.33%
Cape Town	277,941	277,941	277,941	277,941	- 10,141	- 10,141	- 10,141	- 10,141	-3.52%	-3.52%	-3.52%	-3.52%
Scenario 4												
Durban	464,161	460,321	475,654	408,885	- 414,913	- 418,753	- 403,420	- 470,189	-47.20%	-47.64%	-45.89%	-53.49%
Coega/PE	847,781	851,621	836,288	903,057	423,389	427,229	411,896	478,665	99.76%	100.67%	97.06%	112.79%
Cape Town	277,941	277,941	277,941	277,941	- 10,141	- 10,141	- 10,141	- 10,141	-3.52%	-3.52%	-3.52%	-3.52%
Scenario 5												
Durban	619,423	630,282	634,704	532,253	- 259,651	- 248,792	- 244,370	- 346,821	-29.54%	-28.30%	-27.80%	-39.45%
Coega/PE	692,519	681,660	677,238	779,689	268,127	257,268	252,846	355,297	63.18%	60.62%	59.58%	83.72%
Cape Town	277,941	277,941	277,941	277,941	- 10,141	- 10,141	- 10,141	- 10,141	-3.52%	-3.52%	-3.52%	-3.52%
Scenario 6												
Durban	774,683	788,555	793,189	621,329	- 104,391	- 90,519	- 85,885	- 257,745	-11.88%	-10.30%	-9.77%	-29.32%
Coega/PE	537,259	523,387	518,753	690,613	112,867	98,995	94,361	266,221	26.60%	23.33%	22.23%	62.73%
Cape Town	277,941	277,941	277,941	277,941	- 10,141	- 10,141	- 10,141	- 10,141	-3.52%	-3.52%	-3.52%	-3.52%

*Additional citrus volume handled at the port exceeds the respective theoretical excess capacity for citrus at the alternative port

**Additional citrus volume handled at the port exceeds the total theoretical excess capacity for citrus at the alternative ports

TABLE 5.26: *Citrus throughput assigned to each South African port ($\sum_{i\epsilon\mathcal{Z}}\sum_{j\epsilon\mathcal{J}}\sum_{k\epsilon\mathcal{K}} x_{ijk}$) under each allocation technique for each scenario in the 2019 forecasted export season*

Based on the analysis conducted on the reallocation results of the 2019 actual and forecasted export seasons, the following conclusions can be made:

- Four flow types are evident as a result of the reallocation:
    1. Southern Corridor production regions except Vaalharts export all volume through the Port of Cape Town and the Port of Cape Town handles only the volume from these production regions.
    2. Central Corridor production regions export through the Port of Coega/PE.
    3. Northern Corridor production regions and the Vaalharts production region use Durban as their preferred export port when the throughput capacity allows it.
    4. Northern Corridor production regions and the Vaalharts production region use the Port of Coega/PE as their preferred alternative port if they cannot export through the Port of Durban.
- Not all the scenarios are feasible, as the alternate ports may not be able to handle the additional citrus volume. This is also dependant on which allocation technique is used to allocate the allowable citrus throughput at the Port of Durban amongst the production regions, with the linear allocation technique failing the most. However, the reallocation of citrus export volumes is possible in those scenarios where the alternative ports are able to handle the reallocated citrus volume.
- The Port of Durban is assigned less volume than its allowable throughput limit.
- There is no one best suited allocation technique, however, the proportional and lexicographic allocation techniques perform on average better than the uniform and linear allocation techniques.
- Incremental transport cost to the citrus export cold chain is incurred, except in a small number of instances. Certain production regions are worse off and see a greater percentage increase in their transport costs, whilst some production regions are better off as they have a decrease in the transport costs as a result of the reallocations. The production areas that gain the most and those that lose the most are shown in Figure 5.13.
- Some of the solutions generated may not be practical as the solution may require a very small number of pallets to be reallocated away from the Port of Durban, which most likely won't happen in the real world as exporters or producers will try and transport a full truck load of pallets to a port as opposed to sending small amounts that are less than a truck load, unless the consignment is possibly going to be exported as break-bulk and so can be co-loaded with another commodity for transport to the port.

Proposed 2021 export plan

Based on the analysis of the 2019 actual versus 2019 forecasted results, there is no evident best suited allocation technique and so the allocation technique to use in the 2021 forecasted export season is done on a case-by-case basis for each scenario. The results of the 2021 export season are used to determine what the future exports should look like if it is required that the throughput at the Port of Durban be limited. The transport cost as per Figure 5.15 is used to determine which is the best suited allocation technique for reallocating citrus volume for the required level of capacity reduction at the Port of Durban. The full set of results per scenario and allocation technique for the 2021 forecasted export season can be found in Appendix H.

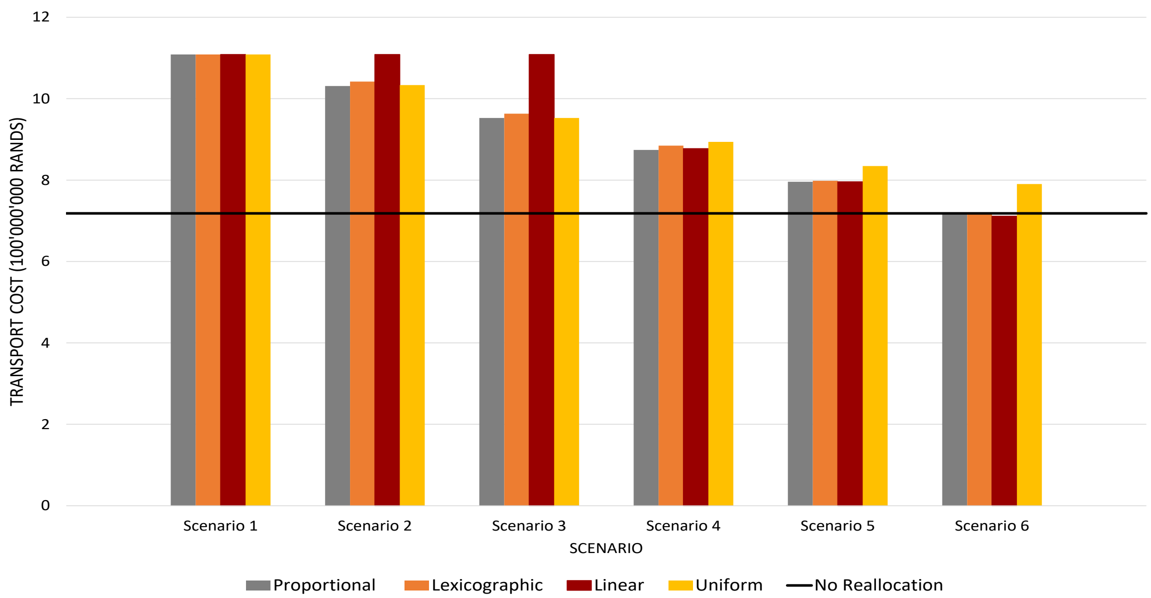

FIGURE 5.15: *Transport costs after the reallocation for each scenario and allocation technique versus the transport cost with no reallocation for the 2021 forecast export season*

If there is a requirement for the Port of Durban to handle no volume, except for the volume that requires priority capacity assignment, then either allocation technique will work as they perform equally well. What will happen to the flow of exports is that all the "Northern Corridor" production regions will export through the Port of Coega/PE, the "Central Corridor" production regions will also export through the Port of Coega/PE, the production region Vaalharts will export through the Port of Coega/PE and the remaining production regions, which are located in the "Southern Corridor" will export through the Port of Cape Town. The Port of Durban will handle zero pallets, the Port of Coega/PE 1,382,703 pallets (209.14% increase) and the Port of Cape Town will handle 292,925 pallets (3.52% decrease). The proposed exports that should flow from each region to each port for the 2021 forecasted export season for Scenario 1 can be found in Table H.1. This scenario, however, is not viable as the total combined theoretical excess citrus capacity between the Port of Cape Town and Port of Coega/PE is greater than the additional citrus volumes that need to be handled between these ports.

For the remaining scenarios, which are based on a proportional allocation technique for Scenarios 2-5 and a linear allocation technique for Scenario 6, the "Northern Corridor" production regions and the Vaalharts production region will start exporting more and more volume through the Port of Durban and less volume through the Port of Coega/PE as the allowable throughput limit at the Port of Durban is increased. The "Southern Corridor" production regions excluding Vaalharts will continue exporting all their volume through the Port of Cape Town and the "Central Corridor" production regions will continue exporting all their volume through the Port of Coega/PE. Table H.2 to Table H.6 shows the pallet flows between each region and port using the best suited technique for each scenario in the 2021 forecasted export season. All the scenarios are feasible or require no further adjustment to what volume is assigned to a port based on the respective best suited allocation technique except for Scenario 2, which would potentially require a reallocation of volume in real life away from the Port of Coega/PE to the Port of Cape Town as the additional volumes exceed its theoretical excess citrus capacity. The combined theoretical excess citrus capacity for the Port of Coega/PE and Port of Cape Town, however, is sufficient to handle the combined additional citrus throughput at the Port of Coega/PE and the Port of Cape Town. For all the scenarios the Port of Cape Town will handle

292,925 pallets, which is a decrease of 3.52% to the forecasted exports without reallocation. The Port of Durban will handle anywhere between 161,923 pallets (82.52% decrease) in Scenario 1 to 816,457 pallets (11.88% decrease) in Scenario 6 and the Port of Coega/PE will handle 1,220,780 pallets (172.94%) increase in Scenario 1 to 566,246 pallets (26.60%) increase in Scenario 6 as a result of the reallocations. The full set of results of what will be assigned to each port under each allocation technique per scenario for the 2021 forecasted export season can be found in Table H.7. Table H.8 shows the percentage difference between what is allowed to be allocated at the Port of Durban and what is potentially going to be assigned for the 2021 forecasted export season. The Port of Durban will potentially handle less due to the fact that certain production regions will still export through the Port of Coega/PE or Port of Cape Town if they are closer, even if it is assigned allowable port throughput at the Port of Durban.

Table 5.27 shows the change in transport cost using the best allocation technique for each scenario and Table 5.28 shows the percentage difference breakdown for each production region in the 2021 export season after the reallocation. Again, the same trend is observed as in the 2019 actual and forecasted export seasons in that the biggest losers are the Southern KZN, Nkwalini, Pongola and Swaziland production regions and the biggest winners are the Eastern Cape Midlands, Sundays River Valley, Boland and Western Cape production regions. Based on the results of this the incremental cost per pallet ranges from +R232.63 in Scenario 1 to -R4.03 in Scenario 6 based on the total number of pallets to be exported from the production regions in the 2021 forecasted export season. The reason Scenario 6 has a decrease in total transport cost is because with the reallocation the production regions use more of the “Corridor Concept” and export volumes through a port that is closest to them first, and then through an alternate port, which is further away. The full set of transport costs for all scenarios under each allocation technique for the 2021 forecasted export season can be found in Appendix G.

Scenario	Allocation Technique	Transport Cost Without Reallocation (ZAR)	Transport Cost With Reallocation (ZAR)	Percentage Difference	Increment Per Pallet (ZAR)
Scenario 1	All	718,252,494	1,108,462,600	35.20%	232.63
Scenario 2	Proportional	718,252,494	1,030,923,000	30.33%	186.40
Scenario 3	Proportional	718,252,494	952,563,930	24.60%	139.69
Scenario 4	Proportional	718,252,494	874,204,300	17.84%	92.97
Scenario 5	Proportional	718,252,494	795,845,810	9.75%	46.26
Scenario 6	Linear	718,252,494	711,493,410	-0.95%	- 4.03

TABLE 5.27: *Percentage difference in transport costs (ZAR) after reallocation for the best suited allocation technique for each scenario in the 2021 forecasted export year*

Region	Scenario 1 (All)	Scenario 2 (Proportional)	Scenario 3 (Proportional)	Scenario 4 (Proportional)	Scenario 5 (Proportional)	Scenario 6 (Linear)
Senwes	72.19%	59.10%	45.87%	32.63%	19.40%	1.17%
Letsitele	69.30%	56.74%	44.05%	31.36%	18.66%	1.24%
Hoedspruit	79.04%	64.77%	50.35%	35.93%	21.50%	3.57%
Nelspruit	90.39%	73.95%	57.35%	40.74%	24.13%	10.99%
Limpopo River	41.55%	34.04%	26.44%	18.85%	11.26%	2.67%
Onderberg	90.49%	74.14%	57.61%	41.09%	24.56%	9.80%
Nkwalini	490.52%	402.38%	313.33%	224.25%	135.20%	175.15%
Southern KZN	544.33%	445.34%	345.27%	245.28%	145.21%	544.33%
Pongola	223.56%	183.43%	142.90%	102.32%	61.79%	223.56%
Burgersfort Ohrigstad	67.78%	54.97%	42.02%	29.07%	16.12%	9.22%
Eastern Cape Midlands	-54.67%	-54.67%	-54.67%	-54.67%	-54.67%	-54.67%
Patensie	-20.81%	-20.81%	-20.81%	-20.81%	-20.81%	-20.81%
Sundays River Valley	-32.18%	-32.18%	-32.18%	-32.18%	-32.18%	-32.18%
Western Cape	-34.86%	-34.86%	-34.86%	-34.86%	-34.86%	-34.86%
Boland	-41.10%	-41.10%	-41.10%	-41.10%	-41.10%	-41.10%
Orange River	-0.23%	-0.23%	-0.23%	-0.23%	-0.23%	-0.23%
VaalHarts	-21.62%	-21.64%	-21.67%	-21.69%	-21.71%	-21.62%
Unknown-Coega/PE	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Unknown-CPT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Swaziland	246.36%	202.72%	159.09%	108.18%	64.55%	246.36%
Zimbabwe	41.39%	34.44%	27.49%	20.54%	13.59%	41.39%
Unknown-DBN	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

TABLE 5.28: *Percentage difference in transport cost after reallocation for each scenario using the best suited technique versus the transport cost without reallocation for the 2021 forecasted export season*

5.7 Validity

Validity refers to how well the model and data fulfils the required purpose for which it was developed and collected. In terms of the data used, unknown data points are handled in a manner such that the allocation model framework is executed on a worse case scenario and so overestimates the citrus volume that must be reallocated away from the Port of Durban. Table 4.6 and the discussion in §4.4 explain the assumption of why the break-bulk and reefer containers volumes for citrus exports are combined, and how this results in an overestimation of the citrus volume that needs to be reallocated, which is a worse case scenario. As mentioned, the data used is limited due to the historical record keeping of certain data, however, the latest data that was available to the researcher was used. This is indicated in §4.6 when a conversion factor is derived using data published in the CGA KIS for the latest available export season, namely the statistics for the 2018 export season.

In terms of the model validity, the best suited technique for the forecasting of predicted citrus export values is selected based on the accuracy tests of the forecasting model, and the applicability of the forecasting model based on the classification of the time series data (§4.6). The inclusion of policy and logistical constraints, such as CBS import regulations and last port of call, identified in the literature was explored during the model formulation process. These constraints were subsequently excluded as they were deemed to have no impact on the allocation process as the movement of the citrus to an alternate port was only within South Africa; the model did not change the final destination of the citrus exports as discussed in §4.9.7.

The calculated port throughput capacity available each week follows the expected pattern of very low to zero supply in the off-season and maximum supply in the winter peak season for citrus exports, which corresponds to the current export distribution of citrus exports each week through the South African ports (§5.5.6).

The allocation model framework had the purpose of optimally allocating the citrus export volumes in the export season, taking into account the limitation on the allowable port throughput for citrus at the Port of Durban. The results of the allocation model framework not only reallocated the citrus volume that could not be handled at the Port of Durban, but also optimally allocated all the volumes in the citrus export cold chain amongst the South African ports with the lowest transport cost. The results of the allocation model framework showed how the flow dynamics will change in the citrus export cold chain, which is discussed in §5.6. Thus, the allocation model framework is deemed to be a valid model for determining whether "forced" allocation can be used as a mechanism to free up throughput capacity at the Port of Durban.

Solving only the optimal reallocation of that citrus volume that could not be handled at the Port of Durban, and ensuring that the remaining export flows between the production regions to the alternative ports remains the same would require some adjustment to the allocation model framework. This adjustment would require that the current export volume between a production region and the Port of Coega/PE and Port of Cape Town for each export week in the export season be fixed and assigned in the preallocation step, and only reallocating the excess demand at the Port of Durban during the reallocation step.

5.8 Reliability and Sensitivity

Reliability and sensitivity refer to how sensitive the solution is to changes in parameters and input variables in the model to reproduce accurate results. Due to the limitation on the size of the dataset, it is expected that the forecasting and forecast disaggregation, and thus the accuracy of the allocation model framework, will only improve as data for more export years is received and the model is updated. This is especially expected on the calculation of the volumetric index to disaggregate the annual citrus forecasts as currently only the 2017 and 2018 export seasons are available to calculate this index as discussed in §4.6. An example of this is the production region Zimbabwe, which has exports in the 2017 export season but not in the 2018 export season. It was decided that during the forecasting process this region would still have to be included as it may just be an anomaly in the 2018 export dataset. Due to the historical record keeping limitation on the dataset no conclusive decision could be made that this region should be excluded or included. By including it, more exports are seen to be exported through the Port of Durban, which means that if in a real world scenario the region does not export through the Port of Durban, then a throughput buffer would be created, thus the worse case scenario would have been analysed.

The road transport distance calculation in §4.9.3 was estimated by identifying a single point of origin as the production regions encompass a large geographical area. The geographical position of this single point of origin can have an influence on the road transport cost, however, as the ports are not closely clustered together, but rather spread out, and because the regions are also not closely clustered near the ports, the influence on the road transport cost resulting from the geographical positioning of the single origin is negligible.

Various scenarios and allocation techniques were used to change the allowable citrus throughput input parameter, and the allocated allowable port throughput to the production regions in the allocation model framework. The results from each showed very similar and expected trends for each scenario, and also showed a flow dynamic change to the citrus export network that is similar to the one that has been proposed by the citrus industry to analyse the export of citrus from South Africa. This involves using the Northern, Central and Southern Corridors to analyse the flow of citrus exports from production regions through the South African ports. As the allocation model framework shows similar and expected results, the allocation model framework is deemed reliable in determining whether "forced" allocation can be used as a mechanism to free up throughput capacity at the Port of Durban.

5.9 Conclusion

The results chapter analyses the results of the forecasting models to determine the best suited technique and make a forecast for the years 2019-2021 using said technique. Pegels classification (Figure 3.2) and Table 3.1 were used to classify the time series data and select potential forecasting models. The best suited forecasting model, the four period double moving average, was selected using the mean square error and Theil's U. It was used to execute the forecasts for the 2019 and 2021 forecasted export years using the export years 2003-2018 as the historical dataset. A pallet conversion factor, based on the 2018 export season, and volumetric indices, which were derived from the 2017 and 2018 export seasons, were used to disaggregate the annual citrus exports into the citrus exports each week from each production region to each port. The results of the estimated theoretical excess port capacity calculation are also shown.

The results of the 2019 actual and forecasted export years, after the reallocation model is applied, are compared to each other to determine if a best suited allocated technique exists, which can be used across all the export years and scenarios to allocate allowable port throughput to the production regions in the allocation model framework. It was concluded that no such technique exists and that the allocation techniques used to allocate the allowable port throughput to the production regions should be selected on a case-by-case basis.

The change in flow dynamics in the citrus export cold chain are also discussed, along with results of the allocation model in terms of transport cost changes and the availability of theoretical excess citrus capacity at alternate ports to handle the reallocated citrus volume.

A proposed export plan for the 2021 export season using the findings of the 2019 actual and 2019 forecasted export years is also provided for each allowable port throughput scenario.

CHAPTER 6

Conclusion

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6.1 Introduction

This chapter summarises the findings of the research and provides recommendations on the use of the results and findings. Some possible future work is also discussed.

6.2 Research Summary

The study set out to understand what impact "forced" allocation has on the citrus export cold chain if it is used as a mechanism to address capacity challenges at the Port of Durban. The aim of the study is to investigate whether the mechanism is feasible, measured in terms of the availability of port capacity at the alternate ports to handle the additional citrus volume that has been reallocated and the incremental transport cost to the citrus export cold chain. The aim of the study is supplemented by three research objectives, which were used to guide the research to understand the impact of "forced" allocation on the citrus export cold chain and the feasibility thereof.

The first objective was to understand the current and future citrus export cold chain throughput and port capacity availability. This was done by analysing the actual citrus exports for the 2019 export season (§5.2), as well as using forecasting models to predict citrus export volumes for the 2019 and 2021 export seasons (§5.3). The forecasts were executed using the four period double moving average forecasting model, which was selected based on the classification of the data set and accuracy of the forecasting models. A high level estimation of the theoretical excess port capacity for citrus exports at the alternate ports (Port of Coega/PE and Port of Cape Town) was also completed to serve as a benchmark to compare whether or not the citrus volumes reallocated could be handled at the alternate ports (§5.4). Analysis of the current citrus exports in the 2019 actual season show that the Sundays River Valley production region was the biggest single exporter of citrus, with a total of 273,234 pallets exported, whilst Swaziland was the smallest exporter, with only 52 pallets being exported (§5.2). During the 2019 actual export season, the Port of Durban handled the majority of the citrus exports at 56.68%, whilst the Port of Cape Town handled the least at 19.68% of total citrus exports after the data had been categorised and refined (§5.2). This answers research questions one and two, which respectively seek to understand the port and production region contributions of the citrus export volumes. Results of the forecasting yielded a projected increase of citrus exports in the coming years, with an estimated 1,677,372 pallets being exported in the 2021 forecasted export season (§5.3.3). Analysis of the export flows, used to answer research question three, which is to gain an understanding of the current flow network being used for citrus exports, shows that the production regions exported through numerous South African ports, results in a criss-crossing network of citrus export flows within South Africa as opposed to the "Corridor" approach suggested by the citrus industry for handling and analysing citrus exports (§5.2). The results of the available capacity calculation at the alternate ports show that the Port of Coega/PE has an estimated theoretical excess capacity of 688,090, 801,650 and 715,650 pallets for citrus in the 2019 actual, 2019 forecasted and 2021 forecasted citrus export seasons (§5.4). The Port of Cape Town has an estimated theoretical excess capacity of 110,280, 104,760 and 110,410 pallets for citrus exports in the 2019 actual, 2019 forecasted and 2021 forecasted export seasons (§5.4). Thus, the Port of Coega/PE has significantly more capacity to handle the reallocated citrus export volumes. This answers research question four regarding the existence and size of additional capacity at the alternative South African ports.

The second objective was to develop a model that optimally allocates the citrus export volume in the citrus export cold chain to the ports taking into account the allowable port throughput limit at the Port of Durban. To address this, an allocation model framework, which consisted of a preallocation and a reallocation model was developed and is solved using linear programming as a minimum cost transport problem (§4.8). The allocation model was formulated as a case specific problem for the Port of Durban, however, the formulation can be modified to be applicable to a different port or multiple ports at the same time. Six scenario's of allowable port throughput at the Port of Durban were used to limit the citrus volume that may be exported through the Port of Durban (§4.2), with the remaining volume being reallocated to alternate ports. The allowable citrus throughput at the Port of Durban for each of these scenario's is based on a percentage of the total citrus exports from the CGA production regions. Allocation techniques, namely proportional, lexicographic, linear and uniform allocation, were used to allocate the allowable port throughput to the competing production regions for each allowable port throughput scenario. This answers research question five, which is to identify allocation techniques for executing the allocations. The total allowable port throughput and the allowable port throughput assigned to each production region were used as capacity parameters in the allocation model framework to solve the LP for each scenario and allocation technique combination (§4.8). The average cost per pallet to export from a production region to a specific port for a one-way trip was calculated based on the road distance (§5.5.3) and used in the objective function of the LP to minimise the overall citrus export cold chain transport cost. The use of these parameters answers research question six regarding the constraint and parameters that need to be taken into consideration in the allocation model framework. This allocation model framework was applied to the citrus export volumes for the 2019 actual, 2019 forecasted and 2021 forecasted export season to provide the necessary results that could be used to achieve objective three of the study.

The third objective of the study is to analyse the results of the allocation model framework and understand the change in the flow dynamics and transport cost of the citrus export cold chain. The results of the allocation model framework show that production regions will export through the port that is closest to them first and then through another port (§5.6). As such, there is a greater flow of citrus through the Northern, Central and Southern citrus Corridors as opposed to citrus volumes flowing across South Africa in a crossing network of export paths (§5.6). It is recommended that the Vaalharts production region be classified as a Central Corridor region as its preferred port should be the Port of Coega/PE. Even though the Port of Durban is its closest port, by assigning the Port of Coega/PE as its preferred port as it is still closer than the Port of Cape Town, demand for capacity will be at the Port of Coega/PE and not the Port of Durban, which is facing capacity constraints. This answers research question eight, which is to determine if the flow network for citrus exports changes as a result of using the allocation model. Secondly, the majority of the reallocated citrus is allocated to the Port of Coega/PE as it is the next closest port for the majority of the production regions. There is an evident incremental increase in the transport costs, except in very few instances, with the transport cost changes ranging from a -6.13% drop, in Scenario 6 of the 2019 actual export season, to an increase of +35.20% in Scenario 1 of the 2019 and 2021 forecasted export seasons (§5.6). This answers research question seven regarding whether or not transport costs increase as a result of using the allocation model and by how much. The allowable port throughput for citrus at the Port of Durban is not fully utilised due to some production regions exporting through a port that is closer to them even though allowable port throughput is allocated to them at the Port of Durban (§5.6). This allowable port throughput for citrus at the Port of Durban can be used fully, however, this will result in further transport cost increases as the production regions would have to export more through a port that is not the closest port to them.

6.3 Feasibility of "Forced" Allocation

The feasibility of using "forced" allocation as a mechanism to address capacity challenges at the Port of Durban is assessed on two criteria, namely the availability of theoretical excess or free capacity at the alternate ports to handle the additional citrus volume and the increase in transport costs to the citrus export cold chain.

Based on the availability of the theoretical excess capacity for citrus at the alternate ports, "forced" allocation will only be feasible for Scenario 1 for the 2019 forecasted export season, and only if some volume is moved away from the Port of Coega/PE to another port. "Forced" allocation is a feasible mechanism for Scenario 2 to Scenario 6 for at least one of the allocation techniques used to allocate the allowable port throughput amongst the production regions for the 2019 actual, 2019 forecasted and 2021 forecasted export seasons. This may not be the same allocation technique for each scenario in the different export year, however, as determined there is no best suited allocation technique, and so the allocation technique to be used in each scenario must be selected on a case-by-case basis. The proportional and lexicographic allocation techniques, however, performed on average better than the linear and uniform allocation techniques. For Scenario 2 in the 2019 actual and 2021 forecasted export season, the Port of Coega/PE does not have enough theoretical excess capacity for citrus to handle the volume allocated to it and so some additional volume may need to be handled at the Port of Cape Town and/or Port of Durban as the system as a whole has enough theoretical excess capacity for citrus. This may, however, result in increased transport costs to what has been calculated.

The increase in transport costs is a relative measure as the impact will vary across the production regions and stakeholders, depending on the size of citrus exports from these regions/stakeholders, their geographical location, their preferred or current export port and their new assigned export

port after the reallocation of citrus. The incremental transport cost, which ranges from -6.13% to +35.20% must be weighed up against the cost of lost time or missed shipments as a result of congestion experienced at the Port of Durban, as well as against the change in total time used to reach the export market. Time is an important component of fresh fruit exports as it impacts the quality of the fruit as fruit quality starts to deteriorate as soon as it is harvested. The quality of the fruit is directly related to its commercial value. Fortunately citrus fruit is less sensitive than other soft fruit and may tolerate the additional travel time to an alternative Port better.

6.4 Recommendation

In summary, the "forced" allocation is feasible in terms of available capacity in the system, but the acceptance of the solution will depend on how the incremental transport cost increases are absorbed amongst the production regions and stakeholders in the citrus export cold chain. It is recommended that the "forced" allocation mechanism be used as a tool at the start of the citrus export season to provide a baseline plan for the volume each region may export through each port based on a target throughput at the Port of Durban. When implemented, this will aid in reducing congestion at the Port of Durban in the short to medium term, and extend the useful life of the current infrastructure at the Port of Durban by utilising infrastructure currently available at the alternative South African ports that can export citrus first.

6.5 Future Work

This study only touches on a small component of the citrus export cold chain and greater fresh fruit export cold chain as a whole. Thus, there is a wide array of potential work that can still be done that would aid in optimising both of these cold chains. The following is a list of suggested future work:

1. Do a brownfields analysis that preserves the current citrus flow to the Port of Cape Town and Port of Coega/PE and only reallocates the surplus citrus export volume away from the Port of Durban to compare to the semi-greenfields approach from this study.

2. Update the model with refreshed data each year, as more export seasons lapse, so that the forecasting process is refined and becomes more accurate, especially on the process of disaggregating the annual citrus export data into citrus export volume by week, production region and port.

3. Develop a mechanism to spread the incremental transport costs amongst the stakeholders in an manner that is fair, and incentivise them to use alternative ports. One potential avenue that could be explored is the use of the levies charged by CGA as a vehicle to spread these costs.

4. Updating the theoretical excess port capacity for citrus with data that is more accurate and that uses less assumptions.

5. Including more commodities or analysing a different commodity, such as maize, in the allocation model framework.

6. Updating the model with a split between break-bulk and containerised volumes. This would of course be dependant on the industry having and/or starting to collect the data in this detail.

7. Using additional allocation techniques to allocate allowable port throughput amongst production regions or using the transport cost between a production region and the Port of Durban as the ranking method in the lexicographic allocation technique instead of citrus export volume. By ranking the production regions on the transport cost lowest to highest, those regions closest to the Port of Durban will be assigned more allowable port throughput capacity first as opposed to a region that may be a big exporter but is located further away. It is envisioned that this ranking method will result in a lower incremental transport cost to the citrus export cold chain.

8. Including additional cost components in the modelling process, such as cold storage costs and port handling fees. The model could also be broken up to include exports transported via road and rail to the ports for export.

9. Analyse the impact of lead times in the citrus export cold chain as a result of the reallocations and the subsequent impact on fruit quality.

10. Execute the allocations and calculate the transport costs based on full containers or truck loads instead of using pallets to understand the change on the citrus export cold chain and the variance to executing the allocations based on pallets.

11. Investigate the use of the Port of Maputo as an alternative port for the Northern Corridor regions, as these regions are most negatively affected by limited capacity at the Port of Durban. Recent developments at the Port of Durban has attracted the attention of the CGA to use this port in the future [74].

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APPENDIX A

Electronic Appendix

The following appendices can be found on the electronic appendix:

1. **Volumetric Index (E_{ijkn})**: The index used to disaggregate the annual forecasted volumes for the 2019 and 2021 export seasons into a weekly-regional-port split. The index is based on the 2017 and 2018 export data.

2. **Regional Demand (D_{ik})**: Citrus pallet volume that must be exported from each production region i for each week k in each export season n.

3. **Maximum Weekly Throughput (M_{ijk})**: The maximum citrus pallet volume that may be exported from a production region i through port j in week k of export season n.

4. **Region Port Flows After Allocation ($\sum_{k \epsilon \mathcal{K}} x_{ijk}$)**: The citrus pallet volume that will be exported from each production region i through port j under each scenario and allocation technique after the allocation model framework has been executed.

5. **LINGO Code Example**: Example of the LINGO code used for solving the reallocation model. This example is specific for Scenario 1, under proportional allocation, in the 2019 actual export season.

    5.1. **LINGO Code Example_LINGO File**: Example of the LINGO code viewable in LINGO.

    5.2. **LINGO Code Example_Text File**: Example of the LINGO code viewable in a text file reader.

APPENDIX B

Maximum Seasonal Regional Supply

Table B.1, Table B.2 and Table B.3 shows the maximum citrus volume (Q_{i1}) that can be exported from a production region i through the Port of Durban for each scenario using the different allocation techniques for the 2019 actual and forecasted, and the 2021 forecasted export years.

	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform
Regions	**Scenario 1**				**Scenario 2**				**Scenario 3**			
Senwes	-	-	-	-	34,895	-	-	12,208	69,847	84,244	-	29,622
Letsitele	-	-	-	-	39,411	153,843	-	12,208	78,888	223,700	-	29,622
Hoedspruit	-	-	-	-	24,083	-	-	12,208	48,206	-	-	29,622
Nelspruit	-	-	-	-	11,664	-	-	12,208	23,348	-	-	29,622
Limpopo River	-	-	-	-	14,572	-	-	12,208	29,169	-	-	29,622
Onderberg	-	-	-	-	9,301	-	-	12,208	18,618	-	-	29,622
Nkwalini	-	-	-	-	3,124	-	-	12,208	6,253	-	-	29,622
Southern KZN	-	-	-	-	1,453	-	-	8,246	2,908	-	-	8,246
Pongola	-	-	-	-	874	-	-	4,962	1,750	-	-	4,962
Burgersfort Ohrigstad	-	-	-	-	5,498	-	-	12,208	11,006	-	-	29,622
Eastern Cape Midlands	-	-	-	-	1,104	-	-	6,265	2,209	-	-	6,265
Patensie	-	-	-	-	1,337	-	-	7,588	2,676	-	-	7,588
Sundays River Valley	-	-	-	-	4,011	-	-	12,208	8,028	-	-	29,622
Western Cape	-	-	-	-	1,688	-	-	12,208	3,379	-	-	9,583
Boland	-	-	-	-	754	-	-	4,280	1,509	-	-	4,280
Orange River	-	-	-	-	28	-	-	158	56	-	-	158
VaalHarts	-	-	-	-	37	-	-	209	74	-	-	209
Swaziland	-	-	-	-	9	-	-	52	18	-	-	52
Regions	**Scenario 4**				**Scenario 5**				**Scenario 6**			
Senwes	104,800	198,064	-	54,315	139,753	198,064	174,059	83,849	174,706	198,064	191,215	109,533
Letsitele	118,365	223,700	-	54,315	157,842	223,700	199,695	83,849	197,319	223,700	216,851	109,533
Hoedspruit	72,330	40,280	-	54,315	96,453	136,697	112,692	83,849	120,576	136,697	129,848	109,533
Nelspruit	35,032	-	-	54,315	46,716	-	42,203	83,849	58,400	66,208	59,359	109,533
Limpopo River	43,765	-	-	54,315	58,362	57,684	58,708	83,849	72,959	82,713	75,864	109,533
Onderberg	27,935	-	-	54,315	37,252	-	28,790	83,849	46,569	52,795	45,946	109,533
Nkwalini	9,382	-	-	17,732	12,512	-	-	17,732	15,641	-	10,883	17,732
Southern KZN	4,363	-	-	8,246	5,818	-	-	8,246	7,274	-	-	8,246
Pongola	2,626	-	-	4,962	3,501	-	-	4,962	4,377	-	-	4,962
Burgersfort Ohrigstad	16,513	-	-	54,315	22,020	-	-	31,208	27,528	10,068	24,359	31,208
Eastern Cape Midlands	3,315	-	-	6,265	4,421	-	-	6,265	5,526	-	-	6,265
Patensie	4,015	-	-	7,588	5,354	-	-	7,588	6,693	-	-	7,588
Sundays River Valley	12,046	-	-	22,766	16,064	-	-	22,766	20,081	-	15,917	22,766
Western Cape	5,071	-	-	9,583	6,762	-	-	9,583	8,453	-	-	9,583
Boland	2,265	-	-	4,280	3,020	-	-	4,280	3,775	-	-	4,280
Orange River	84	-	-	158	111	-	-	158	139	-	-	158
VaalHarts	111	-	-	209	147	-	-	209	184	-	-	209
Swaziland	28	-	-	52	37	-	-	52	46	-	-	52

TABLE B.1: *Maximum seasonal regional supply (Q_{i1}) in pallets per CGA export region through the Port of Durban for each allocation technique for the 2019 actual export season*

Regions	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform
	Scenario 1				Scenario 2				Scenario 3			
Senwes	-	-	-	-	42,528	157,491	-	15,535	85,506	236,932	-	37,990
Letsitele	-	-	-	-	41,055	-	-	15,535	82,543	79,714	-	37,990
Hoedspruit	-	-	-	-	22,120	-	-	15,535	44,474	-	-	37,990
Nelspruit	-	-	-	-	8,461	-	-	15,535	17,012	-	-	37,990
Limpopo River	-	-	-	-	18,142	-	-	15,535	36,475	-	-	37,990
Onderberg	-	-	-	-	9,830	-	-	15,535	19,764	-	-	37,990
Nkwalini	-	-	-	-	3,142	-	-	15,535	6,317	-	-	17,505
Southern KZN	-	-	-	-	1,220	-	-	6,798	2,453	-	-	6,798
Pongola	-	-	-	-	845	-	-	4,710	1,700	-	-	4,710
Burgersfort Ohrigstad	-	-	-	-	6,252	-	-	15,535	12,570	-	-	37,990
Eastern Cape Midlands	-	-	-	-	624	-	-	3,479	1,256	-	-	3,479
Patensie	-	-	-	-	202	-	-	1,123	405	-	-	1,123
Sundays River Valley	-	-	-	-	1,355	-	-	7,551	2,725	-	-	7,551
Western Cape	-	-	-	-	1,219	-	-	6,790	2,451	-	-	6,790
Boland	-	-	-	-	426	-	-	2,371	856	-	-	2,371
Orange River	-	-	-	-	27	-	-	151	54	-	-	151
VaalHarts	-	-	-	-	36	-	-	199	72	-	-	199
Swaziland	-	-	-	-	6	-	-	33	12	-	-	33
Zimbabwe	-	-	-	-	1	-	-	6	2	-	-	6
Regions	**Scenario 4**				**Scenario 5**				**Scenario 6**			
Senwes	128,483	236,932	183,392	60,726	171,461	236,932	209,541	91,568	214,438	236,932	230,671	118,094
Letsitele	124,031	228,722	175,182	60,726	165,519	228,722	201,331	91,568	207,008	228,722	222,461	118,094
Hoedspruit	66,829	10,146	69,696	60,726	89,183	123,237	95,845	91,568	111,537	123,237	116,975	118,094
Nelspruit	25,562	-	-	60,726	34,113	-	19,747	91,568	42,663	47,139	40,877	118,094
Limpopo River	54,808	-	47,530	60,726	73,142	46,064	73,679	91,568	91,475	101,071	94,809	118,094
Onderberg	29,697	-	-	60,726	39,631	-	27,373	91,568	49,565	54,764	48,503	118,094
Nkwalini	9,493	-	-	17,505	12,668	-	-	17,505	15,843	-	11,244	17,505
Southern KZN	3,687	-	-	6,798	4,920	-	-	6,798	6,153	-	-	6,798
Pongola	2,554	-	-	4,710	3,408	-	-	4,710	4,263	-	-	4,710
Burgersfort Ohrigstad	18,888	-	-	60,726	25,206	-	7,439	34,830	31,524	2,246	28,569	34,830
Eastern Cape Midlands	1,887	-	-	3,479	2,518	-	-	3,479	3,149	-	-	3,479
Patensie	609	-	-	1,123	813	-	-	1,123	1,016	-	-	1,123
Sundays River Valley	4,095	-	-	7,551	5,464	-	-	7,551	6,834	-	-	7,551
Western Cape	3,682	-	-	6,790	4,914	-	-	6,790	6,146	-	-	6,790
Boland	1,286	-	-	2,371	1,716	-	-	2,371	2,146	-	-	2,371
Orange River	82	-	-	151	109	-	-	151	136	-	-	151
VaalHarts	108	-	-	199	144	-	-	199	180	-	-	199
Swaziland	18	-	-	33	24	-	-	33	29	-	-	33
Zimbabwe	3	-	-	6	4	-	-	6	5	-	-	6

TABLE B.2: *Maximum seasonal regional supply (Q_{i1}) in pallets per CGA export region through the Port of Durban for each allocation technique for the 2019 forecasted export season*

Regions	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform	Proportional	Lexicographic	Linear	Uniform
	Scenario 1				Scenario 2				Scenario 3			
Senwes	-	-	-	-	44,822	165,984	-	16,373	90,117	249,709	-	40,039
Letsitele	-	-	-	-	43,268	-	-	16,373	86,994	84,012	-	40,039
Hoedspruit	-	-	-	-	23,313	-	-	16,373	46,873	-	-	40,039
Nelspruit	-	-	-	-	8,917	-	-	16,373	17,929	-	-	40,039
Limpopo River	-	-	-	-	19,120	-	-	16,373	38,442	-	-	40,039
Onderberg	-	-	-	-	10,360	-	-	16,373	20,829	-	-	40,039
Nkwalini	-	-	-	-	3,312	-	-	16,373	6,658	-	-	18,449
Southern KZN	-	-	-	-	1,286	-	-	7,165	2,586	-	-	7,165
Pongola	-	-	-	-	891	-	-	4,964	1,791	-	-	4,964
Burgersfort Ohrigstad	-	-	-	-	6,589	-	-	16,373	13,248	-	-	40,039
Eastern Cape Midlands	-	-	-	-	658	-	-	3,667	1,323	-	-	3,667
Patensie	-	-	-	-	212	-	-	1,183	427	-	-	1,183
Sundays River Valley	-	-	-	-	1,428	-	-	7,958	2,872	-	-	7,958
Western Cape	-	-	-	-	1,285	-	-	7,157	2,583	-	-	7,157
Boland	-	-	-	-	449	-	-	2,499	902	-	-	2,499
Orange River	-	-	-	-	29	-	-	159	57	-	-	159
VaalHarts	-	-	-	-	38	-	-	209	76	-	-	209
Swaziland	-	-	-	-	6	-	-	34	12	-	-	34
Zimbabwe	-	-	-	-	1	-	-	6	2	-	-	6
Regions	Scenario 4				Scenario 5				Scenario 6			
Senwes	135,412	249,709	193,282	64,001	180,707	249,709	220,841	96,506	226,002	249,709	243,110	124,462
Letsitele	130,719	241,056	184,629	64,001	174,445	241,056	212,188	96,506	218,170	241,056	234,457	124,462
Hoedspruit	70,432	10,693	73,455	64,001	93,992	129,882	101,014	96,506	117,551	129,882	123,283	124,462
Nelspruit	26,941	-	-	64,001	35,952	-	20,812	96,506	44,964	49,681	43,082	124,462
Limpopo River	57,764	-	50,093	64,001	77,086	48,548	77,652	96,506	96,408	106,521	99,922	124,462
Onderberg	31,299	-	-	64,001	41,768	-	28,849	96,506	52,237	57,717	51,118	124,462
Nkwalini	10,005	-	-	18,449	13,351	-	-	18,449	16,698	-	11,850	18,449
Southern KZN	3,885	-	-	7,165	5,185	-	-	7,165	6,485	-	-	7,165
Pongola	2,692	-	-	4,964	3,592	-	-	4,964	4,493	-	-	4,964
Burgersfort Ohrigstad	19,906	-	-	64,001	26,565	-	7,840	36,708	33,223	2,367	30,110	36,708
Eastern Cape Midlands	1,988	-	-	3,667	2,654	-	-	3,667	3,319	-	-	3,667
Patensie	642	-	-	1,183	856	-	-	1,183	1,071	-	-	1,183
Sundays River Valley	4,316	-	-	7,958	5,759	-	-	7,958	7,203	-	-	7,958
Western Cape	3,881	-	-	7,157	5,179	-	-	7,157	6,477	-	-	7,157
Boland	1,355	-	-	2,499	1,809	-	-	2,499	2,262	-	-	2,499
Orange River	86	-	-	159	115	-	-	159	144	-	-	159
VaalHarts	114	-	-	209	152	-	-	209	190	-	-	209
Swaziland	19	-	-	34	25	-	-	34	31	-	-	34
Zimbabwe	3	-	-	6	4	-	-	6	5	-	-	6

TABLE B.3: *Maximum seasonal regional supply (Q_{i1}) in pallets per CGA export region through the Port of Durban for each allocation technique for the 2021 forecasted export season*

APPENDIX C

Weekly Port Contribution Indices

Table C.1 shows the contribution index (V_{jk}) used for the 2019 actual, and for the 2019 and 2021 forecasted export seasons to split the seasonal reallocation volume amongst each of the weeks in the export season.

Week	2019 Actual	2019 Forecast	2021 Forecast
1	-	-	-
2	-	-	-
3	-	-	-
4	-	0.0001	0.0001
5	-	0.0003	0.0003
6	0.0001	0.0002	0.0002
7	-	0.0004	0.0004
8	0.0005	0.001	0.001
9	0.0005	0.0012	0.0012
10	0.0008	0.0009	0.0009
11	0.0018	0.0025	0.0025
12	0.004	0.0058	0.0058
13	0.0045	0.004	0.004
14	0.0061	0.0055	0.0055
15	0.0074	0.0065	0.0065
16	0.0068	0.009	0.009
17	0.006	0.0086	0.0086
18	0.0096	0.022	0.022
19	0.0214	0.0226	0.0226
20	0.0388	0.0276	0.0276
21	0.0399	0.0325	0.0325
22	0.0375	0.0405	0.0405
23	0.0403	0.0447	0.0447
24	0.0329	0.0431	0.0431
25	0.0532	0.0364	0.0364
26	0.0528	0.0393	0.0393
27	0.0503	0.0488	0.0488
28	0.034	0.0468	0.0468
29	0.0475	0.0577	0.0577
30	0.0611	0.0453	0.0453
31	0.0562	0.0586	0.0586
32	0.0515	0.0391	0.0391
33	0.0574	0.0514	0.0514
34	0.0549	0.0496	0.0496
35	0.0617	0.0518	0.0518
36	0.0431	0.0554	0.0554
37	0.0397	0.0365	0.0365
38	0.0269	0.0362	0.0362
39	0.0302	0.0241	0.0241
40	0.0117	0.0126	0.0126
41	0.0036	0.0141	0.0141
42	0.0012	0.0084	0.0084
43	0.0023	0.0046	0.0046
44	0.0008	0.0019	0.0019
45	0.0003	0.0017	0.0017
46	0.0003	0.0004	0.0004
47	0.0002	0.0002	0.0002
48	-	-	-
49	-	-	-
50	-	-	-
51	-	-	-
52	-	-	-

TABLE C.1: *Weekly index (V_{jk}) representing a certain weeks citrus export volume in relation to total citrus export volumes at the Port of Durban*

APPENDIX D

Weekly Priority Capacity Demand at the Port of Durban

Table D.1 show the citrus volumes requiring priority capacity allocation each week at the Port of Durban (O_{1k}) for the 2019 actual, and for the 2019 and 2021 forecasted export seasons.

Week	2019 Actual	2019 Forecast	2021 Forecast
1	-	-	-
2	-	-	-
3	-	-	-
4	-	25	26
5	-	24	25
6	4	-	-
7	-	-	-
8	-	34	36
9	1	-	-
10	-	-	-
11	-	11	12
12	-	-	-
13	-	2	2
14	6	-	-
15	7	-	-
16	2	17	18
17	-	10	10
18	6	6	7
19	18	17	18
20	11	51	54
21	6	41	43
22	32	120	126
23	-	88	93
24	40	10	10
25	11	103	109
26	5	30	31
27	5	43	45
28	22	13	13
29	22	83	87
30	26	11	12
31	7	174	184
32	-	207	218
33	-	103	109
34	-	57	60
35	1	52	55
36	17	75	79
37	6	21	22
38	-	80	84
39	1	102	107
40	-	8	8
41	-	-	-
42	-	2	2
43	-	5	5
44	1	2	2
45	-	-	-
46	-	-	-
47	-	2	2
48	-	-	-
49	-	6	6
50	-	29	30
51	-	-	-
52	-	-	-

Table D.1: *Weekly citrus export volumes (pallets) requiring priority capacity allocation at the Port of Durban (O_{1k}) for each export season*

APPENDIX E

Weekly Allowable Port Throughput

Table E.1, Table E.2 and Table E.3 show the weekly available throughput for citrus at the Port of Durban (P_{1k}) per scenario for the 2019 actual, 2019 forecasted and 2021 forecasted export seasons respectively.

Week	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	4	7	11	14	18
6	-	18	40	62	84	105
7	-	7	14	21	28	35
8	-	85	169	254	339	423
9	-	73	147	221	295	369
10	-	116	233	349	466	582
11	-	271	542	813	1,085	1,356
12	-	624	1,248	1,872	2,496	3,120
13	-	691	1,382	2,073	2,763	3,454
14	-	933	1,873	2,812	3,751	4,690
15	-	1,133	2,272	3,412	4,552	5,691
16	-	1,045	2,092	3,140	4,187	5,234
17	-	927	1,854	2,781	3,708	4,635
18	-	1,468	2,942	4,417	5,891	7,365
19	-	3,281	6,581	9,880	13,180	16,479
20	-	5,969	11,950	17,930	23,910	29,891
21	-	6,136	12,277	18,419	24,560	30,702
22	-	5,749	11,530	17,310	23,091	28,872
23	-	6,215	12,431	18,646	24,861	31,076
24	-	5,035	10,109	15,184	20,258	25,333
25	-	8,182	16,375	24,568	32,762	40,955
26	-	8,125	16,255	24,385	32,515	40,645
27	-	7,750	15,506	23,261	31,017	38,772
28	-	5,216	10,453	15,691	20,928	26,166
29	-	7,298	14,618	21,938	29,257	36,577
30	-	9,386	18,798	28,210	37,622	47,034
31	-	8,648	17,304	25,959	34,614	43,270
32	-	7,941	15,882	23,823	31,764	39,705
33	-	8,849	17,699	26,548	35,398	44,247
34	-	8,464	16,928	25,392	33,857	42,321
35	-	9,513	19,027	28,541	38,054	47,568
36	-	6,619	13,254	19,890	26,526	33,162
37	-	6,107	12,220	18,332	24,445	30,558
38	-	4,150	8,300	12,450	16,600	20,751
39	-	4,656	9,313	13,969	18,626	23,283
40	-	1,807	3,613	5,420	7,227	9,034
41	-	554	1,108	1,662	2,216	2,770
42	-	178	355	533	711	888
43	-	354	708	1,062	1,416	1,769
44	-	116	233	349	466	583
45	-	49	97	146	195	243
46	-	53	105	158	210	263
47	-	32	64	96	128	161
48	-	4	7	11	14	18
49	-	4	7	11	14	18
50	-	6	12	18	24	30
51	-	5	10	14	19	24
52	-	-	-	-	-	-

TABLE E.1: *Weekly citrus throughput capacity available in pallets for the 2019 actual export season at the Port of Durban* (P_{1k})

Week	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	5	9	14	18	23
4	-	-	13	33	52	71
5	-	21	65	110	154	199
6	-	37	75	112	150	187
7	-	71	141	212	282	353
8	-	121	277	432	587	743
9	-	191	382	574	765	956
10	-	137	275	412	549	687
11	-	392	794	1,197	1,600	2,003
12	-	923	1,847	2,770	3,693	4,617
13	-	635	1,272	1,909	2,546	3,183
14	-	875	1,750	2,625	3,501	4,376
15	-	1,037	2,075	3,112	4,150	5,187
16	-	1,411	2,840	4,269	5,697	7,126
17	-	1,356	2,721	4,086	5,452	6,817
18	-	3,489	6,984	10,479	13,974	17,469
19	-	3,575	7,166	10,758	14,350	17,941
20	-	4,343	8,737	13,131	17,525	21,919
21	-	5,133	10,307	15,480	20,654	25,828
22	-	6,323	12,767	19,210	25,653	32,096
23	-	7,022	14,132	21,242	28,352	35,462
24	-	6,851	13,712	20,573	27,433	34,294
25	-	5,691	11,485	17,280	23,074	28,868
26	-	6,231	12,493	18,754	25,015	31,276
27	-	7,718	15,478	23,239	31,000	38,760
28	-	7,440	14,894	22,347	29,800	37,253
29	-	9,105	18,293	27,480	36,668	45,856
30	-	7,206	14,423	21,640	28,857	36,074
31	-	9,158	18,490	27,822	37,154	46,486
32	-	6,016	12,239	18,462	24,685	30,908
33	-	8,076	16,256	24,436	32,616	40,796
34	-	7,832	15,721	23,610	31,499	39,388
35	-	8,195	16,441	24,688	32,934	41,181
36	-	8,739	17,554	26,369	35,184	43,999
37	-	5,784	11,589	17,394	23,199	29,003
38	-	5,684	11,448	17,212	22,976	28,740
39	-	3,729	7,559	11,389	15,220	19,050
40	-	2,003	4,014	6,025	8,036	10,047
41	-	2,241	4,482	6,723	8,964	11,205
42	-	1,330	2,662	3,994	5,325	6,657
43	-	726	1,457	2,188	2,919	3,649
44	-	299	600	901	1,202	1,503
45	-	276	552	828	1,104	1,380
46	-	59	117	176	235	294
47	-	25	53	80	108	135
48	-	4	8	12	17	21
49	-	2	10	18	25	33
50	-	-	-	-	-	-
51	-	-	-	-	-	-
52	-	2	5	7	10	12

TABLE E.2: *Weekly citrus throughput capacity available in pallets for the 2019 forecasted export season at the Port of Durban (P_{1k})*

Week	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	-	5	10	14	19	24
4	-	-	14	34	54	74
5	-	22	69	116	163	210
6	-	39	79	118	158	197
7	-	74	149	223	297	372
8	-	128	291	455	619	783
9	-	201	403	604	806	1,007
10	-	145	289	434	579	724
11	-	413	837	1,262	1,687	2,111
12	-	973	1,946	2,919	3,892	4,866
13	-	669	1,340	2,012	2,683	3,354
14	-	922	1,845	2,767	3,689	4,612
15	-	1,093	2,187	3,280	4,373	5,467
16	-	1,488	2,993	4,499	6,005	7,510
17	-	1,429	2,868	4,307	5,746	7,185
18	-	3,677	7,361	11,044	14,728	18,411
19	-	3,767	7,553	11,338	15,123	18,909
20	-	4,577	9,208	13,839	18,470	23,101
21	-	5,410	10,862	16,315	21,768	27,221
22	-	6,664	13,455	20,246	27,036	33,827
23	-	7,401	14,894	22,388	29,881	37,375
24	-	7,221	14,451	21,682	28,913	36,144
25	-	5,998	12,105	18,211	24,318	30,425
26	-	6,568	13,166	19,765	26,364	32,963
27	-	8,134	16,313	24,492	32,671	40,851
28	-	7,842	15,697	23,552	31,407	39,261
29	-	9,596	19,279	28,962	38,645	48,329
30	-	7,594	15,200	22,807	30,413	38,019
31	-	9,652	19,487	29,322	39,158	48,993
32	-	6,341	12,899	19,458	26,017	32,575
33	-	8,512	17,133	25,754	34,375	42,996
34	-	8,254	16,569	24,883	33,197	41,512
35	-	8,637	17,328	26,019	34,710	43,402
36	-	9,211	18,501	27,791	37,081	46,372
37	-	6,096	12,214	18,332	24,450	30,567
38	-	5,991	12,065	18,140	24,215	30,290
39	-	3,930	7,967	12,004	16,040	20,077
40	-	2,111	4,230	6,350	8,469	10,589
41	-	2,362	4,724	7,085	9,447	11,809
42	-	1,402	2,805	4,209	5,612	7,016
43	-	765	1,535	2,306	3,076	3,846
44	-	315	632	950	1,267	1,584
45	-	291	582	873	1,163	1,454
46	-	62	124	186	248	309
47	-	27	56	85	114	143
48	-	4	9	13	17	22
49	-	2	10	18	27	35
50	-	-	-	-	-	-
51	-	-	-	-	-	-
52	-	3	5	8	10	13

TABLE E.3: *Weekly citrus throughput capacity available in pallets for the 2021 forecasted export season at the Port of Durban* (P_{1k})

APPENDIX F

Transport Costs Without Reallocation

Table F.1, Table F.2 and Table F.3 show the total road transport cost without reallocation from each production region to each port for the 2019 actual, 2019 forecasted and 2021 forecasted export seasons respectively.

Region Number	Production Region	Port of Durban	Port of Coega/PE	Port of Cape Town	Total
1	Senwes	111,708,096	348,480	2,934,652	**114,991,228**
2	Letsitele	152,116,000	224,234	2,935,590	**155,275,824**
3	Hoedspruit	89,126,444	351,945	984,865	**90,463,254**
4	Nelspruit	36,877,856	214,110	1,571,038	**38,663,004**
5	Limpopo River	71,629,458	41,990	4,104,611	**75,776,059**
6	Onderberg	31,254,640	274,611	657,930	**32,187,181**
7	Nkwalini	2,482,480	-	60,435	**2,542,915**
8	Southern KZN	692,664	-	46,296	**738,960**
9	Pongola	1,538,220	-	-	**1,538,220**
10	Burgersfort Ohrigstad	18,381,512	182,102	3,328,872	**21,892,486**
11	Eastern Cape Midlands	3,852,975	1,541,280	8,200,476	**13,594,731**
12	Patensie	6,024,872	8,780,940	6,909,385	**21,715,197**
13	Sundays River Valley	16,710,244	13,552,713	12,913,342	**43,176,299**
14	Western Cape	12,467,483	6,481,794	22,365,568	**41,314,845**
15	Boland	5,260,120	3,737,560	5,381,910	**14,379,590**
16	Orange River	137,776	163,068	16,731,800	**17,032,644**
17	VaalHarts	129,998	260,741	2,320,756	**2,711,495**
18	Unknown-Coega/PE	-	-	-	**-**
19	Unknown-CPT	-	-	-	**-**
20	Swaziland	15,444	-	-	**15,444**
22	Unknown-DBN	-	-	-	**-**
	Total	**560,406,282**	**36,155,568**	**91,447,526**	**688,009,376**

Table F.1: *Total road transport cost (ZAR) without reallocation from each production region through each port for the 2019 actual export season*

Region Number	Production Region	Port of Durban	Port of Coega/PE	Port of Cape Town	Total
1	Senwes	133,629,905	222,198	4,518,980	**138,371,083**
2	Letsitele	155,531,174	518,945	5,412,371	**161,462,490**
3	Hoedspruit	80,350,283	323,488	1,940,265	**82,614,036**
4	Nelspruit	26,256,219	68,978	1,530,131	**27,855,328**
5	Limpopo River	87,527,059	159,400	1,415,580	**89,102,040**
6	Onderberg	32,420,269	47,902	1,014,922	**33,483,093**
7	Nkwalini	2,450,752	9,104	32,213	**2,492,069**
8	Southern KZN	571,064	7,264	102,086	**680,415**
9	Pongola	1,460,058	-	-	**1,460,058**
10	Burgersfort Ohrigstad	20,515,033	68,288	4,201,094	**24,784,415**
11	Eastern Cape Midlands	2,139,674	3,213,605	5,419,725	**10,773,004**
12	Patensie	891,490	10,107,937	2,319,687	**13,319,115**
13	Sundays River Valley	5,542,500	15,662,717	2,960,441	**24,165,658**
14	Western Cape	8,834,290	7,231,328	22,749,936	**38,815,555**
15	Boland	2,914,216	2,184,768	5,884,522	**10,983,506**
16	Orange River	131,472	51,697	17,077,773	**17,260,942**
17	VaalHarts	123,618	314,077	3,427,500	**3,865,195**
18	Unknown-Coega/PE	-	-	-	**-**
19	Unknown-CPT	-	-	-	**-**
20	Swaziland	9,668	-	-	**9,668**
21	Zimbabwe	5,037	-	-	**5,037**
22	Unknown-DBN	-	-	-	**-**
	Total	**561,303,7826**	**40,191,696**	**80,007,228**	**681,502,707**

TABLE F.2: *Total road transport cost (ZAR) without reallocation from each production region through each port for the 2019 forecasted export season*

Region Number	Production Region	Port of Durban	Port of Coega/PE	Port of Cape Town	Total
1	Senwes	140,835,849	234,180	4,762,664	**145,832,694**
2	Letsitele	163,918,137	546,929	5,704,231	**170,169,297**
3	Hoedspruit	84,683,143	340,932	2,044,893	**87,068,968**
4	Nelspruit	27,672,076	72,697	1,612,643	**29,357,416**
5	Limpopo River	92,246,924	167,995	1,491,915	**93,906,835**
6	Onderberg	34,168,520	50,485	1,069,651	**35,288,656**
7	Nkwalini	2,582,908	9,595	33,951	**2,626,453**
8	Southern KZN	601,858	7,656	107,591	**717,106**
9	Pongola	1,538,791	-	-	**1,538,791**
10	Burgersfort Ohrigstad	21,621,298	71,971	4,427,636	**26,120,905**
11	Eastern Cape Midlands	2,255,055	3,386,898	5,711,982	**11,353,934**
12	Patensie	939,563	10,653,004	2,444,776	**14,037,343**
13	Sundays River Valley	5,841,378	16,507,323	3,120,082	**25,468,783**
14	Western Cape	9,310,676	7,621,275	23,976,718	**40,908,669**
15	Boland	3,071,364	2,302,581	6,201,843	**11,575,788**
16	Orange River	138,561	54,485	17,998,686	**18,191,732**
17	VaalHarts	130,284	331,013	3,612,327	**4,073,624**
18	Unknown-Coega/PE	-	-	-	**-**
19	Unknown-CPT	-	-	-	**-**
20	Swaziland	10,190	-	-	**10,190**
21	Zimbabwe	5,309	-	-	**5,309**
22	Unknown-DBN	-	-	-	**-**
	Total	**591,571,886**	**42,359,019**	**84,321,589**	**718,252,494**

TABLE F.3: *Total road transport cost (ZAR) without reallocation from each production region through each port for the 2021 forecasted export season*

APPENDIX G

Transport Costs After Reallocation

Table G.1 shows the total transport cost for each scenario in the different export seasons after the allocation model framework has been executed using the different allocation techniques to assign allowable port throughput to the production regions.

Scenario	Proportional	Lexicographic	Linear	Uniform	Average
			2019 Actual		
Scenario 1	1,011,827,800	1,011,827,800	1,011,827,800	1,011,827,800	**1,011,827,800**
Scenario 2	941,397,340	938,679,260	1,011,827,800	953,411,190	**961,328,898**
Scenario 3	870,848,620	868,902,300	1,011,827,800	889,854,720	**910,358,360**
Scenario 4	800,299,090	798,377,000	1,011,827,800	817,795,160	**857,074,763**
Scenario 5	729,750,480	725,853,020	719,407,210	758,002,540	**733,253,313**
Scenario 6	659,200,790	648,278,360	648,356,310	720,652,920	**669,122,095**
Average	**835,554,020**	**831,986,290**	**902,512,453**	**858,590,722**	857,160,871
			2019 Forecast		
Scenario 1	1,051,734,600	1,051,734,600	1,051,734,600	1,051,734,600	**1,051,734,600**
Scenario 2	978,162,390	988,755,150	1,051,734,600	980,574,910	**999,806,763**
Scenario 3	903,812,080	913,830,150	1,051,734,600	903,828,630	**943,301,365**
Scenario 4	829,462,210	839,235,470	832,437,000	848,109,830	**837,311,128**
Scenario 5	755,112,230	757,200,940	755,123,370	791,915,710	**764,838,063**
Scenario 6	680,763,150	679,735,970	675,077,040	749,868,670	**696,361,208**
Average	**866,507,777**	**871,748,713**	**902,973,535**	**887,672,058**	882,225,521
			2021 Forecast		
Scenario 1	1,108,462,600	1,108,462,600	1,108,462,600	1,108,462,600	**1,108,462,600**
Scenario 2	1,030,923,000	1,042,085,500	1,108,462,600	1,033,463,500	**1,053,733,650**
Scenario 3	952,563,930	963,122,370	1,108,462,600	952,575,990	**994,181,223**
Scenario 4	874,204,300	884,503,710	877,339,890	893,853,160	**882,475,265**
Scenario 5	795,845,810	798,046,970	795,857,810	834,630,570	**806,095,290**
Scenario 6	717,486,920	716,402,200	711,493,410	790,315,340	**733,924,468**
textbfAverage	**913,247,760**	**918,770,558**	**951,679,818**	**935,550,193**	929,812,083

TABLE G.1: *Total transport cost (ZAR) for each scenario and allocation technique combination after reallocation for the 2019 actual and forecasted export years, and the 2021 forecasted export year*

APPENDIX H

2021 Forecasted Export Season Results

Table H.2 to Table H.6 shows the flow of pallets between each production region to each port for the best suited allocation technique for each scenario in the 2021 forecasted export season. Table H.7 shows the citrus pallet volume assigned to each port ($\sum_{i\epsilon\mathcal{Z}}\sum_{j\epsilon\mathcal{J}}\sum_{k\epsilon\mathcal{K}} x_{ijk}$) after the reallocations for the 2021 forecasted export seasons and Table H.8 shows the difference between what citrus volume is assigned to the Port of Durban ($\sum_{i\epsilon\mathcal{Z}}\sum_{k\epsilon\mathcal{K}} x_{i1k}$) versus the adjusted allowable throughput (R'_1) after the allocation model framework was executed for the different scenarios and allocation techniques in the 2021 export season.

	Pallets Exported Without Reallocation			Pallets Allocated			Percentage Difference		
Region	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**
Senwes	249,709	237	3,703	-	253,646	-	-100.00%	107129.28%	-100.00%
Letsitele	241,056	466	3,880	-	245,402	-	-100.00%	52576.27%	-100.00%
Hoedspruit	129,882	288	1,381	-	131,552	-	-100.00%	45624.34%	-100.00%
Nelspruit	49,681	66	1,157	-	50,904	-	-100.00%	76784.21%	-100.00%
Limpopo River	106,521	136	974	-	107,632	-	-100.00%	79024.48%	-100.00%
Onderberg	57,717	44	740	-	58,504	-	-100.00%	133049.83%	-100.00%
Nkwalini	18,449	11	25	-	18,486	-	-100.00%	161546.86%	-100.00%
Southern KZN	7,165	12	84	-	7,265	-	-100.00%	60250.87%	-100.00%
Pongola	4,964	-	-	-	4,964	-	-100.00%	0.00%	0.00%
Burgersfort Ohrigstad	36,708	66	3,176	-	39,951	-	-100.00%	60794.64%	-100.00%
Eastern Cape Midlands	3,667	22,282	7,911	-	33,861	-	-100.00%	51.96%	-100.00%
Patensie	1,183	126,821	4,327	-	132,334	-	-100.00%	4.35%	-100.00%
Sundays River Valley	7,958	279,785	5,016	-	292,761	-	-100.00%	4.64%	-100.00%
Western Cape	7,157	11,653	168,850	-	-	187,657	-100.00%	-100.00%	11.14%
Boland	2,499	4,344	68,909	-	-	75,755	-100.00%	-100.00%	9.93%
Orange River	159	85	28,937	-	-	29,181	-100.00%	-100.00%	0.84%
VaalHarts	209	512	4,215	-	4,935	-	-100.00%	864.60%	-100.00%
Unknown-Coega/PE	-	468	-	-	466	-	0.00%	-0.49%	0.00%
Unknown-CPT	-	-	330	-	-	332	0.00%	0.00%	0.66%
Swaziland	34	-	-	-	34	-	-100.00%	0.00%	0.00%
Zimbabwe	6	-	-	-	6	-	-100.00%	0.00%	0.00%
Unknown-DBN	1,753	-	-	1,753	-	-	0.00%	0.00%	0.00%
Total	**926,478**	**447,277**	**303,617**	**1,753**	**1,382,703**	**292,925**	**-99.81%**	**209.14%**	**-3.52%**

TABLE H.1: *Flow of pallets between each region and port in Scenario 1 under proportional allocation (best suited allocation technique) for the 2021 forecasted export season*

Region	Pallets Exported Without Reallocation			Pallets Allocated			Percentage Difference		
	Durban	Coega/PE	Cape Town	Durban	Coega/PE	Cape Town	Durban	Coega/PE	Cape Town
Senwes	249,709	237	3,703	44,822	208,824	-	-82.05%	88180.70%	-100.00%
Letsitele	241,056	466	3,880	43,268	202,134	-	-82.05%	43288.67%	-100.00%
Hoedspruit	129,882	288	1,381	23,313	108,239	-	-82.05%	37521.30%	-100.00%
Nelspruit	49,681	66	1,157	8,917	41,987	-	-82.05%	63316.18%	-100.00%
Limpopo River	106,521	136	974	19,120	88,512	-	-82.05%	64968.63%	-100.00%
Onderberg	57,717	44	740	10,360	48,144	-	-82.05%	109471.40%	-100.00%
Nkwalini	18,449	11	25	3,312	15,174	-	-82.05%	132585.78%	-100.00%
Southern KZN	7,165	12	84	1,286	5,979	-	-82.05%	49567.98%	-100.00%
Pongola	4,964	-	-	891	4,073	-	-82.05%	0.00%	0.00%
Burgersfort Ohrigstad	36,708	66	3,176	6,589	33,362	-	-82.05%	50751.47%	-100.00%
Eastern Cape Midlands	3,667	22,282	7,911	-	33,861	-	-100.00%	51.96%	-100.00%
Patensie	1,183	126,821	4,327	-	132,334	-	-100.00%	4.35%	-100.00%
Sundays River Valley	7,958	279,785	5,016	-	292,761	-	-100.00%	4.64%	-100.00%
Western Cape	7,157	11,653	168,850	-	-	187,657	-100.00%	-100.00%	11.14%
Boland	2,499	4,344	68,909	-	-	75,755	-100.00%	-100.00%	9.93%
Orange River	159	85	28,937	-	-	29,181	-100.00%	-100.00%	0.84%
VaalHarts	209	512	4,215	38	4,897	-	-81.86%	857.17%	-100.00%
Unknown-Coega/PE	-	468	-	-	466	-	0.00%	-0.49%	0.00%
Unknown-CPT	-	-	330	-	-	332	0.00%	0.00%	0.66%
Swaziland	34	-	-	6	28	-	-82.51%	0.00%	0.00%
Zimbabwe	6	-	-	1	5	-	-83.39%	0.00%	0.00%
Unknown-DBN	1,753	-	-	1,753	-	-	0.00%	0.00%	0.00%
Total	**926,478**	**447,277**	**303,617**	**163,676**	**1,220,780**	**292,925**	**-82.33%**	**172.94%**	**-3.52%**

TABLE H.2: *Flow of pallets between each region and port in Scenario 2 under proportional allocation (best suited allocation technique) for the 2021 forecasted export season*

	Pallets Exported Without Reallocation			Pallets Allocated			Percentage Difference		
Region	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**
Senwes	249,709	237	3,703	90,117	163,529	-	-63.91%	69032.16%	-100.00%
Letsitele	241,056	466	3,880	86,994	158,408	-	-63.91%	33902.75%	-100.00%
Hoedspruit	129,882	288	1,381	46,873	84,679	-	-63.91%	29332.40%	-100.00%
Nelspruit	49,681	66	1,157	17,929	32,975	-	-63.91%	49704.67%	-100.00%
Limpopo River	106,521	136	974	38,442	69,190	-	-63.91%	50764.27%	-100.00%
Onderberg	57,717	44	740	20,829	37,675	-	-63.91%	85644.90%	-100.00%
Nkwalini	18,449	11	25	6,658	11,828	-	-63.91%	103327.41%	-100.00%
Southern KZN	7,165	12	84	2,586	4,679	-	-63.91%	38768.79%	-100.00%
Pongola	4,964	-	-	1,791	3,173	-	-63.92%	0.00%	0.00%
Burgersfort Ohrigstad	36,708	66	3,176	13,248	26,703	-	-63.91%	40601.60%	-100.00%
Eastern Cape Midlands	3,667	22,282	7,911	-	33,861	-	-100.00%	51.96%	-100.00%
Patensie	1,183	126,821	4,327	-	132,334	-	-100.00%	4.35%	-100.00%
Sundays River Valley	7,958	279,785	5,016	-	292,761	-	-100.00%	4.64%	-100.00%
Western Cape	7,157	11,653	168,850	-	-	187,657	-100.00%	-100.00%	11.14%
Boland	2,499	4,344	68,909	-	-	75,755	-100.00%	-100.00%	9.93%
Orange River	159	85	28,937	-	-	29,181	-100.00%	-100.00%	0.84%
VaalHarts	209	512	4,215	76	4,859	-	-63.72%	849.74%	-100.00%
Unknown-Coega/PE	-	468	-	-	466	-	0.00%	-0.49%	0.00%
Unknown-CPT	-	-	330	-	-	332	0.00%	0.00%	0.66%
Swaziland	34	-	-	12	22	-	-65.02%	0.00%	0.00%
Zimbabwe	6	-	-	2	4	-	-66.77%	0.00%	0.00%
Unknown-DBN	1,753	-	-	1,753	-	-	0.00%	0.00%	0.00%
Total	**926,478**	**447,277**	**303,617**	**327,310**	**1,057,146**	**292,925**	**-64.67%**	**136.35%**	**-3.52%**

TABLE H.3: *Flow of pallets between each region and port in Scenario 3 under proportional allocation (best suited allocation technique) for the 2021 forecasted export season*

	Pallets Exported Without Reallocation			Pallets Allocated			Percentage Difference		
Region	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**	**Durban**	**Coega/PE**	**Cape Town**
Senwes	249,709	237	3,703	135,412	118,234	-	-45.77%	49883.63%	-100.00%
Letsitele	241,056	466	3,880	130,719	114,683	-	-45.77%	24517.05%	-100.00%
Hoedspruit	129,882	288	1,381	70,432	61,120	-	-45.77%	21143.86%	-100.00%
Nelspruit	49,681	66	1,157	26,941	23,963	-	-45.77%	36093.15%	-100.00%
Limpopo River	106,521	136	974	57,764	49,868	-	-45.77%	36559.91%	-100.00%
Onderberg	57,717	44	740	31,299	27,205	-	-45.77%	61816.13%	-100.00%
Nkwalini	18,449	11	25	10,005	8,481	-	-45.77%	74060.28%	-100.00%
Southern KZN	7,165	12	84	3,885	3,380	-	-45.78%	27977.90%	-100.00%
Pongola	4,964	-	-	2,692	2,272	-	-45.77%	0.00%	0.00%
Burgersfort Ohrigstad	36,708	66	3,176	19,906	20,045	-	-45.77%	30453.25%	-100.00%
Eastern Cape Midlands	3,667	22,282	7,911	-	33,861	-	-100.00%	51.96%	-100.00%
Patensie	1,183	126,821	4,327	-	132,334	-	-100.00%	4.35%	-100.00%
Sundays River Valley	7,958	279,785	5,016	-	292,761	-	-100.00%	4.64%	-100.00%
Western Cape	7,157	11,653	168,850	-	-	187,657	-100.00%	-100.00%	11.14%
Boland	2,499	4,344	68,909	-	-	75,755	-100.00%	-100.00%	9.93%
Orange River	159	85	28,937	-	-	29,181	-100.00%	-100.00%	0.84%
VaalHarts	209	512	4,215	114	4,821	-	-45.57%	842.32%	-100.00%
Unknown-Coega/PE	-	468	-	-	466	-	0.00%	-0.49%	0.00%
Unknown-CPT	-	-	330	-	-	332	0.00%	0.00%	0.66%
Swaziland	34	-	-	19	15	-	-44.62%	0.00%	0.00%
Zimbabwe	6	-	-	3	3	-	-50.16%	0.00%	0.00%
Unknown-DBN	1,753	-	-	1,753	-	-	0.00%	0.00%	0.00%
Total	**926,478**	**447,277**	**303,617**	**490,944**	**893,512**	**292,925**	**-47.01%**	**99.77%**	**-3.52%**

TABLE H.4: *Flow of pallets between each region and port in Scenario 4 under proportional allocation (best suited allocation technique) for the 2021 forecasted export season*

	Pallets Exported Without Reallocation			Pallets Allocated			Percentage Difference		
Region	Durban	Coega/PE	Cape Town	Durban	Coega/PE	Cape Town	Durban	Coega/PE	Cape Town
Senwes	249,709	237	3,703	180,707	72,939	-	-27.63%	30735.09%	-100.00%
Letsitele	241,056	466	3,880	174,445	70,957	-	-27.63%	15131.13%	-100.00%
Hoedspruit	129,882	288	1,381	93,992	37,560	-	-27.63%	12954.96%	-100.00%
Nelspruit	49,681	66	1,157	35,952	14,952	-	-27.63%	22483.15%	-100.00%
Limpopo River	106,521	136	974	77,086	30,546	-	-27.63%	22355.56%	-100.00%
Onderberg	57,717	44	740	41,768	16,736	-	-27.63%	37989.63%	-100.00%
Nkwalini	18,449	11	25	13,351	5,135	-	-27.63%	44801.90%	-100.00%
Southern KZN	7,165	12	84	5,185	2,080	-	-27.63%	17178.71%	-100.00%
Pongola	4,964	-	-	3,592	1,372	-	-27.64%	0.00%	0.00%
Burgersfort Ohrigstad	36,708	66	3,176	26,565	13,386	-	-27.63%	20303.39%	-100.00%
Eastern Cape Midlands	3,667	22,282	7,911	-	33,861	-	-100.00%	51.96%	-100.00%
Patensie	1,183	126,821	4,327	-	132,334	-	-100.00%	4.35%	-100.00%
Sundays River Valley	7,958	279,785	5,016	-	292,761	-	-100.00%	4.64%	-100.00%
Western Cape	7,157	11,653	168,850	-	-	187,657	-100.00%	-100.00%	11.14%
Boland	2,499	4,344	68,909	-	-	75,755	-100.00%	-100.00%	9.93%
Orange River	159	85	28,937	-	-	29,181	-100.00%	-100.00%	0.84%
VaalHarts	209	512	4,215	152	4,783	-	-27.43%	834.89%	-100.00%
Unknown-Coega/PE	-	468	-	-	466	-	0.00%	-0.49%	0.00%
Unknown-CPT	-	-	330	-	-	332	0.00%	0.00%	0.66%
Swaziland	34	-	-	25	9	-	-27.13%	0.00%	0.00%
Zimbabwe	6	-	-	4	2	-	-33.54%	0.00%	0.00%
Unknown-DBN	1,753	-	-	1,753	-	-	0.00%	0.00%	0.00%
Total	**926,478**	**447,277**	**303,617**	**654,577**	**729,879**	**292,925**	**-29.35%**	**63.18%**	**-3.52%**

TABLE H.5: *Flow of pallets between each region and port in Scenario 5 under proportional allocation (best suited allocation technique) for the 2021 forecasted export season*

Region	Pallets Exported Without Reallocation			Pallets Allocated			Percentage Difference		
	Durban	Coega/PE	Cape Town	Durban	Coega/PE	Cape Town	Durban	Coega/PE	Cape Town
Senwes	249,709	237	3,703	243,110	10,536	-	-2.64%	4354.11%	-100.00%
Letsitele	241,056	466	3,880	234,457	10,945	-	-2.74%	2249.38%	-100.00%
Hoedspruit	129,882	288	1,381	123,283	8,269	-	-5.08%	2774.11%	-100.00%
Nelspruit	49,681	66	1,157	43,082	7,822	-	-13.28%	11714.17%	-100.00%
Limpopo River	106,521	136	974	98,953	8,679	-	-7.10%	6280.27%	-100.00%
Onderberg	57,717	44	740	51,118	7,386	-	-11.43%	16709.87%	-100.00%
Nkwalini	18,449	11	25	11,850	6,636	-	-35.77%	57927.08%	-100.00%
Southern KZN	7,165	12	84	-	7,265	-	-100.00%	60250.87%	-100.00%
Pongola	4,964	-	-	-	4,964	-	-100.00%	0.00%	0.00%
Burgersfort Ohrigstad	36,708	66	3,176	30,110	9,841	-	-17.98%	14899.98%	-100.00%
Eastern Cape Midlands	3,667	22,282	7,911	-	33,861	-	-100.00%	51.96%	-100.00%
Patensie	1,183	126,821	4,327	-	132,334	-	-100.00%	4.35%	-100.00%
Sundays River Valley	7,958	279,785	5,016	-	292,761	-	-100.00%	4.64%	-100.00%
Western Cape	7,157	11,653	168,850	-	-	187,657	-100.00%	-100.00%	11.14%
Boland	2,499	4,344	68,909	-	-	75,755	-100.00%	-100.00%	9.93%
Orange River	159	85	28,937	-	-	29,181	-100.00%	-100.00%	0.84%
VaalHarts	209	512	4,215	-	4,935	-	-100.00%	864.60%	-100.00%
Unknown-Coega/PE	-	468	-	-	466	-	0.00%	-0.49%	0.00%
Unknown-CPT	-	-	330	-	-	332	0.00%	0.00%	0.66%
Swaziland	34	-	-	-	34	-	-100.00%	0.00%	0.00%
Zimbabwe	6	-	-	-	6	-	-100.00%	0.00%	0.00%
Unknown-DBN	1,753	-	-	1,753	-	-	0.00%	0.00%	0.00%
Total	**926,478**	**447,277**	**303,617**	**837,716**	**546,740**	**292,925**	**-9.58%**	**22.24%**	**-3.52%**

TABLE H.6: *Flow of pallets between each region and port in Scenario 6 under linear allocation (best suited allocation technique) for the 2021 forecasted export season*

	Allocated Throughput (Pallets)				Additional Volume Handled (Pallets)				Percentage Difference to Volume Without Reallocation			
Port	**Proportional**	**Lexicographic**	**Linear**	**Uniform**	**Proportional**	**Lexicographic**	**Linear**	**Uniform**	**Proportional**	**Lexicographic**	**Linear**	**Uniform**
					Scenario 1							
Durban	-	-	-	-	- 926,478	- 926,478	- 926,478	- 926,478	-100.00%	-100.00%	-100.00%	-100.00%
Coega/PE	1,382,703	1,382,703	1,382,703	1,382,703	**935,426	**935,426	**935,426	**935,426	209.14%	209.14%	209.14%	209.14%
Cape Town	292,925	292,925	292,925	292,925	- 10,692	- 10,692	- 10,692	- 10,692	-3.52%	-3.52%	-3.52%	-3.52%
					Scenario 2							
Durban	161,923	155,815	-	143,361	- 764,555	- 770,663	- 926,478	- 783,117	-82.52%	-83.18%	-100.00%	-84.53%
Coega/PE	1,220,780	1,226,888	1,382,703	1,239,342	*773,503	*779,611	**935,426	*792,065	172.94%	174.30%	209.14%	177.09%
Cape Town	292,925	292,925	292,925	292,925	- 10,692	- 10,692	- 10,692	- 10,692	-3.52%	-3.52%	-3.52%	-3.52%
					Scenario 3							
Durban	325,557	327,764	-	307,771	- 600,921	- 598,714	- 926,478	- 618,707	-64.86%	-64.62%	-100.00%	-66.78%
Coega/PE	1,057,146	1,054,939	1,382,703	1,074,932	609,869	607,662	*935,426	627,655	136.35%	135.86%	209.14%	140.33%
Cape Town	292,925	292,925	292,925	292,925	- 10,692	- 10,692	- 10,692	- 10,692	-3.52%	-3.52%	-3.52%	-3.52%
					Scenario 4							
Durban	489,191	485,146	501,302	430,941	- 437,287	- 441,332	- 425,176	- 495,537	-47.20%	-47.64%	-45.89%	-53.49%
Coega/PE	893,512	897,557	881,401	951,762	446,235	450,280	434,124	504,485	99.77%	100.67%	97.06%	112.79%
Cape Town	292,925	292,925	292,925	292,925	- 10,692	- 10,692	- 10,692	- 10,692	-3.52%	-3.52%	-3.52%	-3.52%
					Scenario 5							
Durban	652,824	664,269	668,927	560,958	- 273,654	- 262,209	- 257,551	- 365,520	-29.54%	-28.30%	-27.80%	-39.45%
Coega/PE	729,879	718,434	713,776	821,745	282,602	271,157	266,499	374,468	63.18%	60.62%	59.58%	83.72%
Cape Town	292,925	292,925	292,925	292,925	- 10,692	- 10,692	- 10,692	- 10,692	-3.52%	-3.52%	-3.52%	-3.52%
					Scenario 6							
Durban	816,457	831,083	835,963	654,840	- 110,021	- 95,395	- 90,515	- 271,638	-11.88%	-10.30%	-9.77%	-29.32%
Coega/PE	566,246	551,620	546,740	727,863	118,969	104,343	99,463	280,586	26.60%	23.33%	22.24%	62.73%
Cape Town	292,925	292,925	292,925	292,925	- 10,692	- 10,692	- 10,692	- 10,692	-3.52%	-3.52%	-3.52%	-3.52%

*Additional citrus volume handled at the port exceeds the respective theoretical excess capacity for citrus at the alternative port

**Additional citrus volume handled at the port exceeds the total theoretical excess capacity for citrus at the alternative ports

TABLE H.7: *Citrus throughput assigned to each South African port ($\sum_{i\epsilon\mathcal{Z}}\sum_{j\epsilon\mathcal{J}}\sum_{k\epsilon\mathcal{K}} x_{ijk}$) under each allocation technique for each scenario in the 2021 forecast export season*

	Target (R'_1)	Allocated	Percentage Difference	Target (R'_1)	Allocated	Percentage Difference	Target (R'_1)	Allocated	Percentage Difference
		Scenario 1			**Scenario 2**			**Scenario 3**	
Proportional	-	-	0.00%	165,984	161,923	-2.45%	333,721	325,557	-2.45%
Lexicographic	-	-	0.00%	165,984	155,815	-6.13%	333,721	327,764	-1.79%
Linear	-	-	0.00%	165,984	-	-100.00%	333,721	-	-100.00%
Uniform	-	-	0.00%	165,984	143,361	-13.63%	333,721	307,771	-7.78%
		Scenario 4			**Scenario 5**			**Scenario 6**	
Proportional	501,458	489,191	-2.45%	669,195	652,824	-2.45%	836,932	816,457	-2.45%
Lexicographic	501,458	485,146	-3.25%	669,195	664,269	-0.74%	836,932	831,083	-0.70%
Linear	501,458	501,302	-0.03%	669,195	668,927	-0.04%	836,932	835,963	-0.12%
Uniform	501,458	430,941	-14.06%	669,195	560,958	-16.17%	836,932	654,840	-21.76%

TABLE H.8: *Percentage difference between the adjusted allowable citrus throughput at the Port of Durban (R'_1) versus the assigned citrus throughput at the Port of Durban ($\sum_{i\epsilon\mathcal{Z}}\sum_{k\epsilon\mathcal{K}} x_{i1k}$) after the reallocation for each allocation technique and scenario for the 2021 forecasted export season*