AN ALLOCATION MODEL FRAMEWORK FOR A CAPACITY-CONSTRAINED PORT: A CASE FOR CITRUS EXPORTS AT THE PORT OF DURBAN

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ABSTRACT

This article investigates the viability of using forced allocation as a mechanism to alleviate capacity challenges through scenarios of varying allowable citrus throughput at the Port of Durban. Rule-based resource allocation techniques are used to divide the allowable citrus throughput at the constrained port between production regions by setting quotas. The allocation model framework minimises the impact of the forced allocation on the citrus export cold chain by setting the quotas as constraints in an integer programming (IP) formulation of a minimum cost transportation problem (TP) for the system. The results show that forced allocation is feasible under at least one resource allocation technique for four of the scenarios tested.

OPSOMMING

Hierdie artikel ondersoek die lewensvatbaarheid van gedwonge toewysing as 'n meganisme om, deur scenario's van wisselende toelaatbare sitrusdeurvloei by die Durban hawe, kapasiteitsuitdagings te verlig. Reëlgebaseerde hulpbrontoekenningstegnieke word gebruik om die toelaatbare sitrusdeurvloei by die ingeperkte hawe tussen produksiestreke te verdeel deur kwotas vas te stel. Die toekenningsmodelraamwerk minimeer die impak van die gedwonge toekenning op die sitrusuitvoerkoelketting deur die kwotas te stel as beperkings in 'n heeltalligeprogrammering (HP) formulering van 'n minimum koste vervoerprobleem (VP) vir die stelsel. Die resultate toon dat gedwonge toekenning haalbaar is onder ten minste een van die hulpbrontoekenningstegnieke vir vier van die scenario's wat getoets is.

1. INTRODUCTION

The South African fresh fruit export cold chain is made up of numerous complex elements that are synchronised to deliver a final product that meets all regulatory and quality requirements and specifications in both the country of export and the country of import. South Africa is the largest fruit-exporting country in the southern hemisphere by volume [1], with an export volume of more than 3.6 million metric tons [2]. The main fruits exported by volume are citrus 63%, pome fruit (apples and pears) 20%, and table grapes 12% [1]. Currently fresh fruit exports account for about 35% of all agricultural exports from South Africa, with a value of R48.3 billion ($3.3 billion) to more than 100 countries [1]. The production season runs from March to November [2].

The South African fresh fruit export industry is an important contributor to the broader agricultural industry. Although agriculture, and consequently, fresh fruit exports are comparatively small relative to the South African GDP, their indirect role in and impact on the economy are noteworthy, as it is a significant generator of foreign revenue and a key employment provider, particularly in rural South Africa [3]. Therefore, it is crucial in South Africa's current economic climate that the fresh produce export industry and its associated components and processes be continually enhanced to improve efficiencies and remain competitive in the global export market.

This research stemmed from the fact that the peak in citrus exports occurs at a similar time to that of maize exports through the Port of Durban. Both occur during the winter months (June–August), corresponding with the period when high levels of congestion are experienced, and the Port of Durban faces the greatest demand for capacity. This article investigates an alternative solution to long-term infrastructure development that will help to immediately alleviate the congestion and strain placed on the citrus export cold chain at the Port of Durban. An allocation model framework is developed that utilises rule-based allocation techniques in conjunction with a minimum cost transportation problem to reallocate export volumes to alternative South African ports. Scenarios that limit the throughput at the Port of Durban to a certain percentage of the total citrus export volumes from all production regions in a season are examined.

The rest of the article is organised as follows. A brief review of the literature is given on the South African citrus industry, the Port of Durban, and the factors that cause congestion in it. A review of citrus export modelling and resource allocation techniques is also provided. The research methodology is presented in which the solution approach and the data used are discussed. The results and an interpretation of the analysis are provided. Finally, the feasibility of using forced allocation is discussed along with proposed recommendations for the South African citrus industry.

2. LITERATURE REVIEW

2.1. South Africa's citrus industry

The South African citrus industry is responsible for a significant volume of fruit exports from the southern hemisphere and is the second largest citrus exporter in the world [4;1]. In addition to being well-established, citrus production is also growing at a significant rate, which is not expected to change in the foreseeable future. The citrus industry expanded by 9,500 hectares of new citrus orchards (new hectares) planted in 2020 and 2021 [4]. This increase represented a 10% expansion in the total number of hectares of citrus planted in South Africa. The main citrus production regions in South Africa are Mpumalanga, Limpopo, the Eastern Cape, and the Western Cape [5]. Citrus moving through South Africa is split into three corridors: the northern corridor, the central corridor, and the southern corridor. Table 1 shows the production regions in each corridor and the preferred port of export for each region [6].

Table 1: Production regions in each citrus export corridor, and the preferred port of export [6] with the region numbers used in the article

Region number	Corridor	Production region	Preferred port
1	Northern	Senwes	Durban
2	Northern	Letsitele	Durban
3	Northern	Hoedspruit	Durban
4	Northern	Nelspruit	Durban
5	Northern	Limpopo River	Durban
6	Northern	Onderberg	Durban
7	Northern	Nkwaleni	Durban
8	Northern	Southern KZN	Durban
9	Northern	Pongola	Durban
10	Northern	Burgersfort Ohrigstad	Durban
20	Northern	Swaziland	Durban
21	Northern	Zimbabwe	Durban
11	Central	Eastern Cape Midlands	Port Elizabeth and Ngqura
12	Central	Patensie	Port Elizabeth and Ngqura
13	Central	Sundays River Valley	Port Elizabeth and Ngqura

Region number	Corridor	Production region	Preferred port
14	Southern	Western Cape	Cape Town
15	Southern	Boland	Cape Town
16	Southern	Orange River	Cape Town
17	Southern	Vaalharts	Cape Town

2.2. The Port of Durban

The Port of Durban is situated on the east coast of South Africa [7]. It is not only South Africa's premier multi-cargo port, but also the leading and busiest port in Africa. It plays an integral role in the country's economy, as it handles 60% of imports and exports as well as being geographically strategically positioned along the north-south trade route [8].

The Port of Durban comprises several business units managed by Transnet Port Terminals (TPT), including the Durban Container Terminal (DCT). The DCT was established in 1977, and operates as two terminals on Pier 1 and Pier 2. According to [9], the terminal has a combined capacity of 3.6 million twenty-foot equivalent units (TEU) per annum, with Pier 1 and Pier 2 handling 0.7 million TEUs and 2.9 million TEUs respectively.

2.2.1. Factors causing congestion at the Port of Durban

A key factor that supports the successful export of fresh fruit across the globe, including citrus from South Africa, is the availability of a sufficient number of reefer containers. Without enough of them the global fresh fruit supply chain would stop, as the capacity of conventional reefer vessels is insufficient to transport all the fruit that is traded internationally. Reefer containers are used for nearly 95% of all fruit exports from South Africa, while the remainder is transported by conventional reefer vessels or air freight [10]. It is therefore evident that reefer containers are key to the current distribution system.

The world currently faces a global shortage of containers, and their scarcity has affected South Africa [11], resulting in severe reefer container shortages in the fruit export industry. According to [12; 13], a "very high percentage" of reefer containers return to South Africa empty owing to an imbalance between the imports and exports of perishable products to and from South Africa. Repositioning empty reefer containers is commonplace in the container industry because of the demand for fast turnaround times [14]. However, in the present economic climate, in which shipping rates have risen steeply [15], repositioning empty containers to countries off the main East-West shipping route, such as South Africa, is disadvantageous for shipping lines. Therefore, the South African fruit export industry, including citrus, relies on shipping lines to supply sufficient reefer containers; and when they do not, it has a negative impact on congestion at the Durban Container Terminal.

Capacity analysis for the imports and exports of all commodities at the Ports of Durban and Richards Bay (classified as the eastern ports for this article) indicate that there is an anticipated shortage of container capacity during the berth deepening project at the Durban Container Terminal [16]. Even if the two eastern ports pool their capacities and the Port of Richards Bay uses 100% of its container capacity, equivalent to 0.5m TEUs per annum, there will still be a shortage of container capacity at the Port of Durban during this period.

In addition, the Port of Durban has faced two major global shocks in recent years that have also impacted the levels of congestion experienced. In July 2021, KwaZulu-Natal was hit by violent protests and socio-political unrest, exemplified by the widespread looting of businesses and the burning and destruction of public facilities and private properties [17]. During the unrest, operations at the Port of Durban were brought to a standstill [18]. They were halted again in April 2022 when the province was hit by floods, leading to a backlog of thousands of containers. The floods also caused extensive damage to the roads leading to the Port of Durban [19].

2.3. Modelling South African fruit export

Previous studies in the South African fruit export industry that have focused on the infrastructure and commodity movements include a 2004 study by Fundira [20] on the transaction costs in the grape and citrus export supply chain to identify inefficiencies and reduce transaction costs. Van Dyk and Maspero [21] analysed the logistics infrastructure used by the South African fruit industry to identify opportunities to improve efficiency. Recommended opportunities included the viability of using Maputo as an alternative export port for the Port of Durban, and the investigation of a mechanism to alleviate port congestion at the Port of Durban by diverting volumes away from it. A study by Ortmann *et al*. in 2006 [22] modelled the South African fruit supply chain to find the maximum possible volume that could be handled by certain sections of the supply chain and to determine the minimum cost of transporting fruit from packhouses to ports. The results showed that bottlenecks observed in the export system were not fundamental to the infrastructure and its available capacities, but rather were because of sub-optimal use of the existing infrastructure. Sufficient export capacity existed to handle the 2003 export volumes that were modelled.

2.3.1. Allocation techniques

Most allocation techniques use either a mathematical model that optimally assigns resources to activities or follow a rule-based approach. Zografos and Martinez [23] developed an allocation method to improve port system performance by reallocating demand for services at the ports among the various ports in Ecuador. The allocation was executed using linear programming with the objective of minimising transportation costs in the system.

The types of rule-based approaches may vary depending on the logic applied to the problem. A few of the commonly used rule-based techniques include proportional, lexicographic, linear, and uniform allocation. These techniques assume that the resource requirements for each activity have been ordered in a non-increasing sequence [24]. Cachon and Lariviere [25; 26] and Li, Cai and Liu [27] studied the use of allocation methods to allocate a single supplier's limited capacity to multiple retailers in a supply chain. In these studies, the allocation techniques were compared using an allocation game to determine whether any of the rule-based techniques induced retailers to inflate their demand for capacity to ensure that they received a favourable outcome. The results showed that retailers would inflate their demand if linear or proportional allocation were used but not if uniform allocation were used [25].

3. RESEARCH DESIGN AND METHODOLOGY

An allocation model framework, illustrated in Figure 1, is developed that utilises rule-based allocation techniques to set quotas for the demand from each production region that may be serviced at the constrained port. These quotas are further used as constraints in a minimum cost transportation problem to reallocate the export volumes to alternative South African ports. The objective of the allocation model framework is to minimise the impact of additional transportation costs on the citrus export cold chain caused by the forced reallocation. This article examines scenarios in the citrus export cold chain in which the throughput at the Port of Durban is limited to a certain percentage of the total citrus export volume from all production regions in a season.

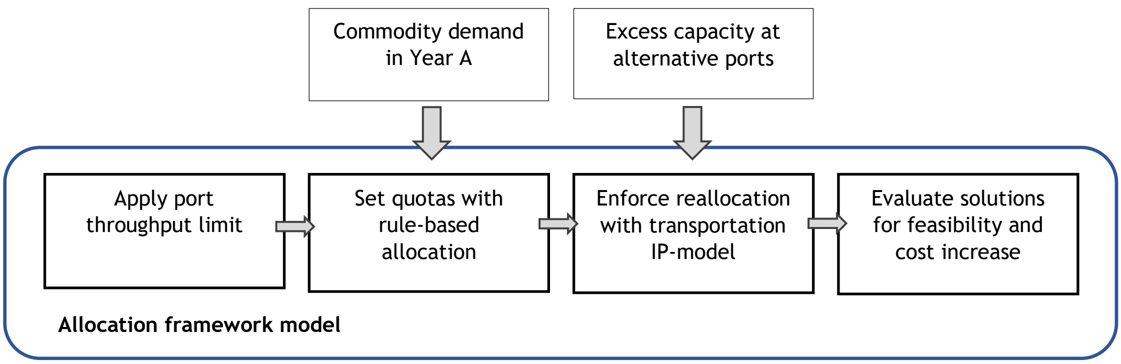

Figure 1: The allocation framework model with indicated data inputs

3.1. Allowable throughput scenario

The impact and feasibility of forced allocation is assessed by implementing an upper limit on the citrus export volume that may be exported through the Port of Durban in a given export season. Six throughput reduction scenarios are analysed, which range from the Port of Durban handling no citrus export volumes at 0% (Scenario 1) to the Port of Durban handling up to 50% of the total citrus export volume (Scenario 6). Scenario 1, at 0% throughput, corresponds to the worst-case scenario, in order to analyse whether and how the citrus export supply chain would cope in the event that the Port of Durban became completely unavailable, such as in the event of a natural disaster. Throughput limits closer to the actual use do not yield significant results to illustrate the application of the model; therefore, an upper limit of 50% – that is, a throughput of 770,502 pallets at the Port of Durban – is set as the maximum throughput scenario for Year A. Historically the Port of Durban has handled 50% to 60% of the total citrus export volumes, with the year in question exporting approximately 57% (873,483 pallets) of the citrus export volume. The 10% increments between scenarios are based on the premise that these six scenarios would be sufficient to gauge the impact on the citrus export cold chain and the swing in feasibility between scenarios.

3.2. Rule-based allocation quotas

The production regions are in direct competition with each other for the capacity available at the Port of Durban. Since a forced limit is imposed on the allowable citrus throughput, the ability of production regions to freely choose the port of export is negated. Thus the allowable citrus throughput that may flow through the Port of Durban is divided among the competing production regions to ensure that they receive their 'fair' allocation or quota of citrus export volume that may flow from their production region through the Port of Durban for the export season. This fair division is evaluated over four different rule-based allocation techniques: proportional, lexicographic, linear, and uniform allocation.

- **Proportional allocation:** A region's quota is calculated as a proportion of the region's demand at the Port of Durban to the total seasonal demand at the Port of Durban, multiplied by the allowable port capacity.
- **Lexicographical allocation:** Regions are ranked from highest to lowest volume of demand at the Port of Durban. In order of ranking, a region is allocated its full demand quota until the allowable port capacity is exhausted.
- **Linear allocation:** Regions are allocated a quota based on their demand at the Port of Durban, minus a common deduction. If the common deduction is greater than their demand, they are allocated a zero quota.
- **Uniform allocation:** The allowable port capacity is divided equally between the production regions. If a region requires less than the uniform quota, the surplus capacity is not redistributed to the other regions for the purposes of this research.

3.3. Minimum transportation cost forced allocation

The allocation model framework uses a minimum cost transportation problem, which is solved as an integer programming model (IP), to execute the forced allocation. The quotas determined by the respective rule-based allocation techniques are used as upper limits in the transportation problem model as constraints to assign citrus export volumes from each production region to each export port for each week of the citrus export season. The integer programming model is formulated as follows:

$$Min \quad \sum_{i \in Z} \sum_{j \in J} \sum_{k \in K} C_{ij} X_{ijk} \qquad (1)$$

$$s.t. \sum_{j \in J} X_{ijk} = D_{ik} \qquad \forall i \in Z, \forall k \in K, \qquad (2)$$

$$\sum_{k \in K} X_{ijk} \le Q_{ij} \qquad \forall i \in Z, \forall j \in J, \qquad (3)$$

$$\sum_{i \in Z} X_{ijk} \le P'_{jk} \qquad \forall j \in J, \forall k \in K, \qquad (4)$$

$$X_{ijk} \leq M_{ijk} \quad \forall i \in Z, \forall j \in J, \forall k \in K, (5)$$

$$X_{ijk} \geq N_{ijk} \quad \forall i \in Z, \forall j \in J, \forall k \in K, (6)$$

$$X_{ijk} \geq 0 \quad \forall i \in Z, \forall j \in J, \forall k \in K, (7)$$

$$X_{ijk} \in \mathbb{Z} \quad \forall i \in Z, \forall j \in J, \forall k \in K, (8)$$

where X_{ijk} is the is the quantity of citrus that has been allocated to be exported from production region i to port j in week k, and C_{ij} is the transportation cost from production region i to port j. D_{ik} is the citrus quantity (demand) that must be exported from production region i in week k. Q_{ij} is the maximum citrus quantity that may be exported between production region i and port j for the entire export season. P'_{jk} is the capacity available at port j in week k for citrus exports after accounting for citrus volumes that are assigned priority capacity at the port. M_{ijk} is the maximum citrus quantity that can be exported from production region i to port j in week k. N_{ijk} is the minimum citrus quantity that must be exported from production region i to port j in week k. Equation 2 ensures that the total citrus quantity demand D_{ik} at each production region, in each week, is allocated to available ports. Equation 3 ensures that the total citrus quantity allocated to a port from a specific region is no more than its allowable throughput Q_{ij} as determined by the rule-based quotas. Equation 4 ensures that the total quantity allocated to a port does not exceed its adjusted allowable throughput in the export season P'_{jk}. The allowable throughput is adjusted prior to the execution of the transportation problem to account for demand at the port that is given priority allocation. Equation 5 ensures that the quantity allocated to a region and port for a specific week is within the maximum allowable flow; and Equation 6 sets a minimum quantity to be exported from a region to a port in week k. Equations 7 and 8 are non-negative and integer constraints.

The forced allocation model framework is applied throughout a citrus export season, called Year A, based on actual export volumes. The combination of the export season being analysed with the six throughput scenarios at the Port of Durban and the four different rule-based allocation techniques to set quotas for the assignment in the transportation problem results in 24 test cases that are analysed. The increase in transportation cost and the availability of excess port capacity are used to determine the feasibility of forced allocation. The increase in transportation cost is calculated as the difference in transportation cost for the export year being analysed when there is forced allocation versus no forced allocation. The volume of citrus that is reallocated away from the Port of Durban must be met by available excess capacity at alternative citrus export ports.

3.4. Data

The data used in the forced allocation model is categorised into three categories: citrus export volume, port capacity, and cost.

The citrus export volumes used are the total pallets exported each week from each production region through each export port in South Africa. The citrus export volume datasets used were derived from a combination of the Citrus Growers Association key industry statistics [29] and data provided by Company X [30]. Table 2 provides a breakdown of the citrus export volumes from each production region to each export port for Year A. In the dataset are smaller amounts of citrus volume of unknown regional origin that are handled at an indicated port. This is dealt with by assigning these volumes to dummy nodes in the system – for example, 'Unknown-DBN', which is indicated as node 22 – and given priority allocation at the export port.

Table 2: Citrus pallets exported from each production region through each South African port for Year A with no forced allocation [28]

Production region	Port of Cape Town	Port of Ngqura/PE	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-Ngqura/ PE (18)		797		797
Unknown-CPT (19)	313			313
Unknown-DBN (22)			257	257
Swaziland			52	52
Total	**303,248**	**364,273**	**873,483**	**1,541,004**

One key assumption of the data used is that reefer and break-bulk export volumes are aggregated into one figure to represent reefer volumes. This is because the datasets used do not distinguish between reefer and break-bulk. Based on the capacity analysis of container capacity available and the shortage related to it, the aggregation would cause more volume to be allocated away from the Port of Durban than required when the break-bulk volumes were removed, thus creating an artificial buffer in the system.

Because port capacity is finite, is shared between commodities, and is used for both imports and exports, volume cannot be specifically attributed to one commodity and/or international trade function. Therefore, for the purpose of the research, the port capacity available at the Port of Durban (j=1) is assumed to be insufficient for citrus exports, as it requires a reduction in volume throughput. The excess capacity available at the alternative ports is assumed to be sufficient to handle any additional citrus export volumes; therefore, the alternative ports are modelled as having big **M** capacity in the integer model:

$$Q_{ij} = \mathbf{M} \qquad j \neq 1, \qquad (9)$$

$$P'_{jk} = \mathbf{M} \qquad j \neq 1, \qquad (10).$$

However, a high-level validation is also performed to determine whether the additional citrus throughput could be handled within the ports design capacity (theoretical maximum throughput) at the alternative ports. The estimated theoretical excess port capacity available for citrus exports at the alternative exports ports is derived from the National Ports Plan 2019 Update [16], and is calculated based on the share that citrus has in relation to total exports and imports through a port, and multiplying it by the excess capacity available at that port.

The transportation cost used in the study is the transportation cost per pallet from each production region to each export port. The cost per pallet is calculated by multiplying the average cost per kilometre by the distance for a one-way trip between the designated origin of each production region and each export port, and then dividing the total cost by the average number of pallets on a one-way trip. The average cost per kilometre for trips within the borders of South Africa was provided by Company A [31].

4. RESULTS

4.1. Citrus export volumes

Analysis of the citrus exports in Year A, without forced allocation, shows that the Sundays River Valley production region is the biggest contributor of citrus export volumes both in respect of total exports from South Africa and exports through the Port of Ngqura/PE. The Western Cape production region is the biggest exporter of citrus through the Port of Cape Town, and the Letsitele production region is the biggest exporter of citrus through the Port of Durban. A network flow analysis, which is shown in Figure 2, depicts an export supply chain of criss-crossing flows, with each production region using multiple ports for export. This is in contrast to the industry-preferred notion of using export corridors. The flow analysis shows that the Port of Durban handles most of the export volumes (56.68%) with a significant amount originating from production regions in the north, while the Port of Ngqura/PE is the second largest exporter of citrus (23.64%), and the Port of Cape Town is the smallest exporter of citrus (19.68%).

4.2. Estimated excess port capacity

An analysis of the theoretical excess capacity for citrus exports at the alternative ports shows that the Port of Ngqura/PE has more excess capacity (688,090 pallets) than the Port of Cape Town (110,280 pallets) for Year A [28]. This is ideal, since volumes allocated away from the Port of Durban will likely be allocated to the Port of Ngqura/PE, which is closer to the Port of Durban, rather than to the Port of Cape Town. The total theoretical excess capacity at the alternative ports (798,370), however, is less than the total citrus volume assigned to the Port of Durban with no forced allocation in Year A.

4.3. Transportation costs

The average cost per kilometre used in the calculation of the transportation cost was based on R16 per kilometre. The average number of pallets per trip was based on 20 pallets, which is the total number of pallets that can fit into a forty-foot container, the container type used for most citrus exports. The kilometres used from each production region to each port and the designated origin for each production region are listed in Table 3.

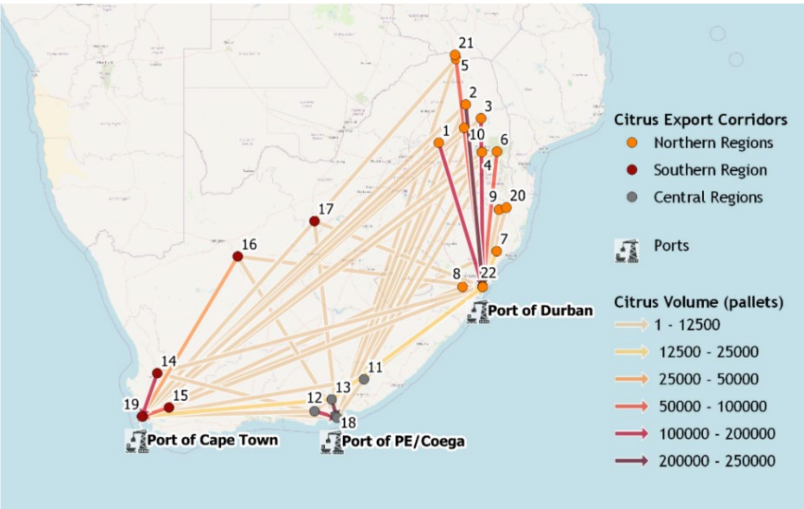

Figure 2: A flow map representing the citrus export flows from each production region through each port for Year A with no forced allocation [28]

Table 3: Road transport distance (kilometres) from the designated origin of the production region to each port [28]

Production region	*Region origin*	*Port of Durban*	*Port of Ngqura/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 border (DBN) Oshoek border (CPT and PE)	371	1,297	1,665
Vaalharts	Hartswater	777	809	1,071
Western Cape	Citrusdal	1,626	817	177
Zimbabwe	Beitbridge border	1,103	1,564	1,934

4.4. Export flow changes resulting from the forced allocation

Table 4 shows the change in transportation cost for each scenario and allocation technique when forced allocation is applied versus when there is no forced allocation. In Scenario 1, for example, no capacity is available at the Port of Durban, and therefore the model will forcefully divide the entire demand of 873,483 to be allocated to either the Port of Cape Town or the central Ports of Ngqura/PE, whichever is nearest. For the purpose of this study, and to compare the rule-base allocation techniques, no capacity limits were set on the alternative ports in the IP model. This enabled the calculation of the transportation cost under forced allocation, based on the volume and distance of the forced allocation, versus the transportation cost without forced allocation in Year A. The change in transportation cost is reported in Table 4.

Table 4: Change in transportation cost, shown as a percentage, for each scenario (% of total citrus exports, # pallets allowed at Port of Durban) and allocation technique when forced allocation is applied to Year A data versus when there is no forced allocation; '!' indicates scenarios that are not feasible because reallocated volumes exceed theoretical excess capacity at alternative ports [28]

Scenario (% citrus, #pallets allowed)	Proportional	Lexicographic	Linear	Uniform	Average
1 (0%, 0)	! 32.00%	! 32.00%	! 32.00%	! 32.00%	**32.00%**
2 (10%, 154 100)	! 26.92%	! 26.70%	! 32.00%	! 27.84%	**28.43%**
3 (20%, 308 201)	21.00%	20.82%	! 32.00%	22.68%	**24.42%**
4 (30%, 461 301)	14.03%	13.82%	! 32.00%	15.87%	**19.73%**
5 (40%, 616 402)	5.72%	5.21%	4.36%	9.23%	**6.17%**
6 (50%, 770 502)	-4.37%	-6.13%	-6.12%	4.53%	**-2.82%**
Average	**17.66%**	**17.31%**	**23.77%**	**19.87%**	**19.73%**

A high-level analysis of the utilised port capacity shows that, in certain cases, the alternative port cannot handle the additional citrus volume allocated to it for specific scenarios and under the specific allocation techniques, as indicated in Table 4 with an exclamation mark (!). Some scenarios are not feasible, such as Scenarios 1 and 2 for Year A data across all the allocation techniques. For Scenarios 3 and 4, only three of the four allocation techniques are feasible. The scenarios under linear allocation are not feasible, as the total citrus allocated to the Port grouping of Ngqura/PE is greater than their combined total theoretical citrus capacity. Scenarios 5 and 6 are the only ones that are feasible in respect of available theoretical excess capacity at Durban and the alternative ports across all the rule-based techniques for Year A. In most of the scenarios, the lexicographic rule-based technique is preferred for delivering feasible results with the lowest increase in transportation cost.

There were only three instances when the forced allocation resulted in a reduction of total transportation costs. These occurred in Scenario 6, in which the Port of Durban could handle up to 50% of the citrus export volumes for the season. This is because the 'transportation problem' part of the allocation framework forces exporters to use more of the corridor concept and to export volumes through a nearer port first, and only then through a more distant alternative port.

An analysis of the cost changes for each production region shows that, based on percentage increase in transportation costs, Southern KZN, Nkwalini, Swaziland, and Pongola will be the biggest losers, as their transportation costs will increase. This is to be expected, as these production regions are based in the Northern Corridor, with the Port of Durban being their primary port of export, and they are also located closest to the next alternative port, which is the Port of Ngqura/PE. The Eastern Cape Midlands, Sundays River Valley, Boland, and the Western Cape are the biggest winners, as they will see a decrease in transportation costs. The decrease results from the production regions being allocated volume to their closest ports first, which are the Port of Ngqura/PE and the Port of Cape Town, and then only to the Port of Durban should the capacity available allow it. Figure 3 shows the production regions that are the biggest winners (encircled in green) and the biggest losers (encircled in red).

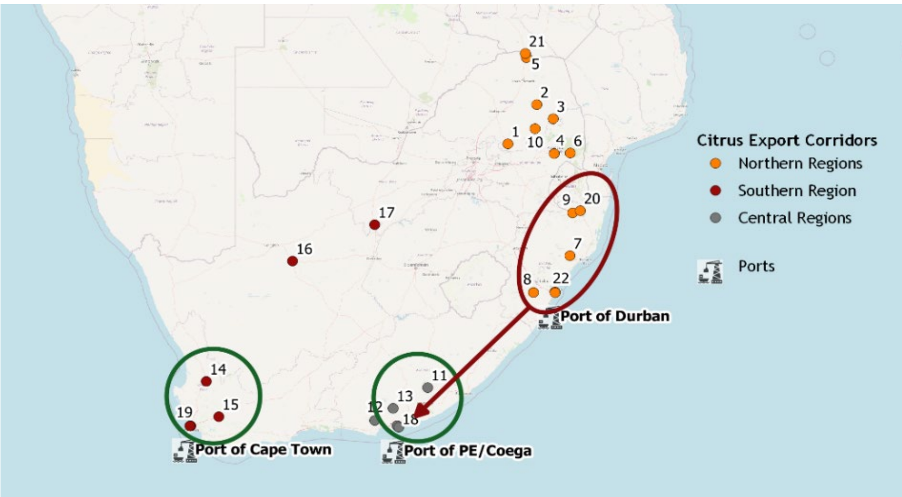

Figure 3: Map indicating which production regions are the biggest winners (encircled in green) and which are the biggest losers (encircled in red) because of forced allocation [28]

An analysis of the changes in the export flow dynamics between each production region and each export port show that, in all cases, the allowable port throughput that the Port of Durban may handle in an export season is not fully used. The same trend is observed in the volume quota assigned to each production region for citrus exports through the Port of Durban. The difference between what is actually allocated for export in the transportation problem and the quotas set by the rule-based techniques represents the existing slack in the capacity constraints. This is caused by the fact that, although a production region is granted a volume quota to export citrus through the Port of Durban, its volumes will still be allocated to the Port of Ngqura/PE or to the Port of Cape Town if these ports are closer to the production region than the Port of Durban. This is because the goal of the transportation problem allocation model is to reduce transportation costs and because the available capacity at the alternative ports has not been constrained. Thus, the export flow dynamics change from a more criss-crossed network to a pattern that is more like the corridor concept. However, the current export flow network for citrus exports is driven by multiple factors, which include preference for the port of export, the available capacity at the export port, and the last port of call for a shipping line en route to a specific destination to which the exporter is exporting.

5. INTERPRETATION OF RESULTS

The analysis of the forced allocation results for Year A enables the following conclusions to be drawn:

- The allocation model framework supports the notion of export corridors to assign citrus volumes to the nearest port while still being flexible enough to take other preferences into account in the different levels of allowable capacity at the Port of Durban.
- Citrus export flows can be categorised into four flow types:
  1. The Port of Cape Town only handles volumes from the Southern Corridor production regions, except for Vaalharts, which follows the Northern Corridor flows.
  2. The Northern Corridor production regions, along with Vaalharts, will export through the Port of Durban as their preferred port if the capacity allows them to do so.
  3. If the Northern Corridor production regions and Vaalharts cannot export though the Port of Durban, they will export through the Port of Ngqura/PE.
  4. The Central Corridor production regions export through the Port of Ngqura/PE only.
- The Port of Durban will not fully utilise its allowable throughput as less volume is allocated to it because of the location and proximity of production regions to ports. This slack in the system would allow for some leeway to handle unexpected changes in citrus demand volume when real-world impacting factors that cannot be accommodated in the model, play out.
- Not all scenarios are feasible. This is driven by the availability of theoretical excess capacity at the alternative ports to handle the additional volume allocated to them.

- The citrus export cold chain will incur an increase in transportation costs under forced allocation, except in a few instances where the alternative port is located closer than the Port of Durban.
- No rule-based technique is best suited for setting the quotas in allocating allowable citrus throughput at the Port of Durban across all the scenarios. However, the lexicographic and proportional allocation techniques perform on average better than the other techniques, and should therefore be preferred when drawing up a forced allocation plan.

6. THE FEASIBILITY OF FORCED ALLOCATION

The feasibility of forced allocation to address the capacity challenges experienced at the Port of Durban is assessed on the increase in transportation cost to the citrus export cold chain, as well as the availability of excess capacity at the alternative ports to handle additional citrus export volumes.

Based on excess capacity available at the alternative ports, forced allocation is feasible under at least one allocation technique for Scenarios 3 to 6. Scenarios 1 and 2 are not feasible, as the citrus volume allocated to the alternative ports is greater than the theoretical excess capacity available to handle the additional citrus volumes. The detailed week-by-week assignment of demand to ports per region that the model results provide can be of great use to planners to use capacity in the system to the best, even as a partial solution for scenarios in which all of the demand cannot be accommodated.

Increases in transportation cost is a relative measure that will have a varying impact across the production regions and its stakeholders, as is evident from the map of winners and losers in Figure 3. This relative impact is a result of the varying volumes of exports from these regions and individual stakeholders and the port preferred for citrus exports versus the new assigned port for citrus exports after the forced allocation. The increase in transportation cost that will be incurred must be compared against the cost associated with lost time or missed shipments resulting from port congestion, as well as changes in the total journey time to reach an export market. The time component is relevant to the citrus export cold chain, as it impacts the quality of fresh fruit. The quality of fresh fruit starts to deteriorate as soon as it is harvested, and its quality is also directly linked to its commercial value. Fortunately, because citrus is less sensitive than other soft fruit, this additional travel time to an alternative port may be tolerable.

A forced allocation solution may not always be practical, as the volume allocated away from the Port of Durban to an alternative port may be less than a full truck load. Exporters and producers may opt to deviate from the proposed citrus export plan and consolidate loads for export via another port when the model is put into practice.

7. CONTRIBUTION OF RESEARCH AND RECOMMENDATION

By linking the anticipated lack of capacity in reefer containers with the rising demand for reefer containers for citrus exports, it is evident that the citrus export cold chain faces a growing challenge to meet export demands, especially at the Port of Durban during the peak export season. The problem of long waiting and turn-around times because of high congestion levels at the Port of Durban is exacerbated by the disruption caused by unforeseen socio-political shocks.

This study developed an allocation model framework to set quotas on demand at a capacity constrained port and to reallocate the excess export volume to alternative ports. The model makes a contribution to the theory in the way in which it has combined rule-based allocation techniques to account for exporters' preferences with a transportation problem that minimises the impact of the additional transportation cost of the forced allocation to alternative ports. The combination of the two modelling techniques into one framework has provided results that would be better suited to the citrus export industry than if only the rule-based or only the transportation problem were applied. The study was also able to show that not all rule-based techniques perform equally to solve the problem at hand within the proposed allocation framework. The lexicographical allocation rule provided the best results in the allocation framework, whereas the uniform allocation rule performed the worst.

The results are acceptable on a macro level, since they support the corridor principle, but also on a micro level, as planners can utilise the week-by-week demand allocation obtained from the results that divide the limited capacity fairly between the competing citrus regions. This allocation module framework can be generalised to apply to other commodities or ports and to set additional port constraints.

The acceptance and use of forced allocation as a mechanism to address capacity challenges will depend on how the stakeholders absorb the increase in transportation costs. It is recommended that the forced allocation mechanism be implemented prior to the start of the citrus export season for a set throughput limit at the Port of Durban in order to provide a baseline plan for the citrus export industry. Implementing the mechanism will help to prolong the useful life of the current infrastructure at the Port of Durban by utilising infrastructure that is available to the citrus export cold chain at other ports to reduce congestion at the Port of Durban.

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