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Analysis of hinterland transport strategies when exporting perishable products

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ABSTRACT

Since a good hinterland connection is considered an important factor in port competitiveness, the objective of this paper is to analyse the impact of the development of hinterland transport strategies on the competitiveness of the port by taking the Port of Cape Town, the Republic of South Africa as an example. The development of transport strategies is reflected in terms of a lower cost and higher frequency of inland transport. To investigate the interplay among export products, transport, and access to a port for exporters, we use a linear programming model. The model considers both the choice of transport modes and the impacts of improved inland transport strategies. The model could easily be extended to deal with other modes or transport alternatives. It is assumed that, initially, two modes of transport – trucks and railway – are available for transportation of the export product from the farm to the port. The analysis is extended by including intermodal transportation as a combination of railway and road transport. The results of the analysis show that improving the rail services and offering more frequent rail services from the farm to the port, could lead to a better and more flexible transportation strategy.

1. Introduction

One of the critical determinants of a country's development is export. With the help of exports, a country can access a broader market to gain economies of scale, foster growth and employment, and generate foreign exchange required to finance imports (Pieterse, Farole, Odendaal, & Steenkamp, 2016). To gain international competitiveness, modern and efficient transport networks are considered necessary, and hinterland transport costs play a significant role in international trade costs (Albarran, Carrasco, & Holl, 2013; Behar & Venables, 2011). A hinterland is the inland area from where a port sources the majority of its businesses (Ferrari, Parola, & Gattorna, 2011). The cargo is moved to/from the seaport and the inland destination via the hinterland transportation system. The primary purpose of establishing a hinterland transportation system is to achieve overall cost-efficiency and the necessary logistics quality (Bergqvist, 2012). The hinterland transportation consists of the road (trucks), rail, intermodal (a combination of road and rail) and inland waterway (barges) (Ng & Talley, 2020; Zhen, Wang, Wang, Qu, & X., 2018).

Trade costs are higher in developing countries than in developed ones. In 2009, trade costs for emerging countries were, on average, 2.5 times higher than those in advanced economies (Arvis, Duval, Shepherd, & Utoktham, 2013). Investment in transport infrastructure mitigates the costs of doing international business and thus helps the firms gain a competitive advantage in the global markets. The international competitiveness of a firm indicates its ability to deliver goods to markets more cheaply compared to its competitors (Albarran et al., 2013). One of the well-established empirical findings in international economics is that there is a negative association between bilateral trade and distance (Disdier & Head, 2008; Leamer & Levinsohn, 1995; Overman, Redding, & Venables, 2003) and a positive relationship between the quality of transport infrastructure and international trade (Dusko & Bozica, 2016). However, one of the limitations of the existing literature on the relationship between trade and transport is that majority of the literature mainly focused on the international aspect of transport costs, while less articles have considered the domestic transportation within countries (Albarran et al., 2013; Anderson & Van Wincoop, 2004).

This paper analyses the impact of the development of a port's hinterland transport strategies on the export of perishable products via the Port of Cape Town in the Republic of South Africa (RSA). The

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development of transport strategies is in terms of improvements in infrastructure and superstructure, resulting in lower costs and a higher frequency of hinterland transport. Superstructures are mobile assets (like cranes, equipment) that usually have a shorter lifespan than infrastructure (Rodrigue, 2020). The analysis is shown with an example from The Republic of South Africa. Although the Republic of South Africa is better resourced than many other countries in sub-Saharan Africa when it comes to transport infrastructure, institutions, and logistics capabilities, it still faces significant challenges because of the many new forces and developments that currently shape the global economy (Steenkamp, Grater, & Viviers, 2015). Following Larsen (1992), the model is developed in such a way that simulates both the choice of transport modes by exporters and the impacts of improved transport strategies on export competitiveness of a port. Several factors impact port competitiveness, for instance, distance to port (both road and ocean distance), inland transport costs, maritime transport costs, geographical location, port efficiency (congestion, reputation, cargo damage, quick response to customers' need), port connectivity, port charges, and port infrastructure (Martínez Moya & Feo Valero, 2017). In this study, the focus is only on the impact of hinterland transport strategies on port competitiveness. Larsen (1992) presented a mathematical model for combining production volume and transportation decisions in rural farming. Following his ideas about solving such challenges as optimization problems, we have developed a model for choosing between different options for transportation of perishable products from the origin to one or more destination ports. We have considered only transportation cost from the farm to the port and deterioration cost and have not included port fees because these are independent of how the fruit (perishable product) is transported to the port. The rest of the paper proceeds as follows: the next section presents the literature review. The subsequent sections present the mathematical model, current situation and parameters values, analysis and results. Conclusion and discussion are presented in the final section.

2. Review of literature on ports' hinterland transport

In this section, we review the previous studies on port hinterland transport to identify the research gap and explain this study's contribution. Wiegmans, Van Der Hoest, and Notteboom (2008) analysed the importance of port choice and container terminal selection for deep-sea container carriers. They addressed the question of why do deep-sea container lines prefer container ports and container terminals in the Hamburg–Le Havre range over others? Their results showed that one of the most critical criteria for port choice from a carrier's perspective is the availability of hinterland connections. An exploratory study conducted by De Langen (2008) recommended that landlord port authorities can play a significant role in improving hinterland access. This can be done by, for instance, adopting a number of policy measures such as investments in rail and barge terminals, setting infrastructure access rules, developing an effective port community system, setting conditions in concession contracts for improving the hinterland transportation system, and ensuring competition in transport chains.

Fremont and Franc (2010) studied the competitiveness of combined transport versus road transport, which serves the ports of the Northern European Range. Their study showed that, generally, combined transport is very competitive with road transport, and combined transport has a price advantage over the road for distant destinations. However, combined transport is not often competitive when the road distance between the port and the client is almost as short as the distance between the port and the inland terminal. The study also indicated that prices of combined transport must be 10–20% lower than road transport to convince users to switch to combined transport.

Ferrari et al. (2011) measured the quality of port hinterland accessibility by taking the Ligurian ports as a case study. They argued that the effects the competitiveness of inland connections played a fundamental role in reflecting the economic influence of a seaport on land and that a port has greater potential to enlarge its overall captive area if it has a better connection to the various inland markets. Their results showed that two main factors influence the hinterland shape: the first is the effectiveness of the infrastructural network (that is, highways and rail alpine crossings), since it defines the directions of the hinterland development, and the second is the location of inland terminals (that is, intermodal platforms). Iannone (2012) considered the seaports of Naples and Salerno as a case study and, with the help of a mathematical programming tool called the "interport model", investigated a range of options to achieve private and social cost efficiency in the inland multimodal distribution of maritime containers imported and exported in Italy. The empirical results demonstrated the advantages gained from improved rail connections and also from the practical implementation of the extended gateway concept. Their results also supported the role of internalization of transport external costs. For instance, they showed that the internalization of external diseconomies in transport prices could result in greater use of railway services between the regional interports and extra-regional locations, raising the option of investing in container shuttle trains based on these routes.

Acciaro and McKinnon (2013) reviewed the literature related to large container ports and their hinterland infrastructure. They concluded that it is necessary to expand the hinterland links, along with the development of container terminal capacity, to enhance supply chain value creation and reduce external costs associated with increasing container flows. They suggested that by better utilizing the road and rail transport facilities, such as by developing dry ports and empty container management, there would be substantial room for improvements in the interfaces between the container terminal and the inland transport modes.

Merk and Notteboom (2015) noted that one of the critical factors in competitiveness and development of the most ports around the world is the hinterland connections. They presented the review of various investments strategies adopted by national authorities of Canada, Europe, and China on inland hinterland connections, which showed the importance of inland hinterland connections realized by the national planners. Álvarez-Sanjaime, Cantos-Sanchez, Moner-Colonques, and Sempere-Monerris (2015) studied the integration of port activities with inland transport services and analysed the economic incentives and welfare implications to this integration under inter-port competition. The results indicated that engaging in such integration processes is favourable to ports because of the higher prices and higher profits achieved through such integration. However, it might lead to a total welfare decrease because higher prices will reduce users' benefits if they exceed the value of any service improvements. Meersman, Sys, Voorde, and Vanelslander (2016) mentioned road transport as the most prominent mode of hinterland transportation to and from seaports and analysed the impact of road pricing on the competitiveness of the ports in Hamburg-Le Havre range. The empirical results showed that the increase in road pricing would negatively affect Rotterdam's competitive position. However, the competitive position of Flemish ports will not be adversely affected.

On the basis of the literature review (see Table 1) the contribution of this study is as follows: to the best of our knowledge, this is the first study in which the competitiveness of inland hinterland transport of the RSA is analysed. We applied a linear programming model that simulates both the choice between transport alternatives and the impacts of improved inland transport strategies. The mathematical model is solved numerically, and it can be used in the strategic planning by analysing potential changes to the transportation modes, like increased fuel taxes, the imposition of road tolls on highways, increased reliability on the rail network, increased frequency of rail departures and the deployment of different options for reloading at dry ports.

3. A model for deciding transport strategies

The mathematical model we have applied in this study is general and describes how to solve transportation and mode choice problems in

Table 1
Literature review.

Authors	Research objective	Methodology	Main findings
Wiegmans et al. (2008)	To analyse the importance of port choice and container terminal selection for deep-sea container carriers.	A qualitative study (literature review and interviews)	Availability of hinterland connections is one of the most critical criteria for port choice from a carrier's perspective
De Langen (2008)	To analyse the role of landlord port authorities in improving hinterland access	Qualitative study	By adopting several policy measures, landlord port authorities can play a significant role to improve hinterland access.
Fremont and Franc (2010)	To investigate the competitiveness of combined transport versus road transport serving the ports of the Northern European Range.	A qualitative and quantitative study	Generally, combined transport is very competitive with road transport, and combined transport has a price advantage over the road for distant destinations.
Ferrari et al. (2011)	To measure the quality of port hinterland accessibility	Quantitative study (Gravity model)	The hinterland shape is influenced by the effectiveness of the infrastructural network and the location of inland terminals
Iannone (2012)	To investigate a range of options to achieve private and social cost efficiency in the inland multimodal distribution of maritime containers	Quantitative study (Mathematical model)	Advantages are gained from improved rail connections
Acciaro and McKinnon (2013)	To investigate the hinterland infrastructure of large container ports	Qualitative study	To improve supply chain value creation and reduce external costs it is necessary to expand the hinterland links along with the development of container terminal capacity
Merk and Notteboom (2015)	To identify main port-hinterland connectivity challenges and current and potential policy measures to tackle these challenges.	Qualitative study	A good hinterland connection is one of the critical factors in gaining competitiveness and development of most ports around the world.
Álvarez-Sanjaime et al. (2015)	To investigate the economic incentives and welfare implications related to the integration of port activities with inland transport services under inter-ports competition.	Quantitative study (Mathematical model)	Port-hinterland integration processes are favourable to ports, but it might lead to a total welfare decrease
Meersman et al. (2016)	To analyse the impact of road pricing on the competitiveness of the ports in Hamburg- Le Havre range.	Quantitative study	The increase in road pricing will have a negative effect on the port of Rotterdam's competitive position. However, the competitive position of Flemish ports will not be adversely affected.

general with a simplified example for transportation of fruit from Tzaneen to the Port of Cape Town. The Port of Cape Town was selected because it is the closest South African port to the export destinations. It takes 18 days to ship the cargo from the Port of Cape Town to markets in Europe, compared to 25 days from Durban (Freshplaza, 2015). After the USA, Europe is the second-biggest destination for export of South Africa's fresh fruits.[2]

We analysed the impact of the development of inland hinterland transport strategies on the export competitiveness of the Port of Cape Town. In the model, we have considered the following three transport modes (see Fig. 1) that connect fruit farms in Tzaneen in the northern part of the country to the Port of Cape Town for further transportation to the market. Tzaneen is a big tropical garden town in South Africa and is known for the production of fruits including citrus. Citrus fruits represented the largest share of exported fruits from South Africa.[3]

1. M1: Route1 – from the farm area by trucks to the port
2. M2: Route2 – from the farm area to the dry port first via truck and then from the dry port via rail to the port. A dry port is one of the critical locations in a sea-port hinterland. Talley and Ng (2017) defined a dry port as an inland node of a hinterland network, whereas the seaport is a sea node of the hinterland network. Roso et al. (2009, p. 341) also stated that a dry port is "an intermodal inland terminal directly connected to a seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport." Dry ports are given different names in different countries, such as "inland ports" or "inland terminals" in the United States and Canada, "strategic rail freight interchanges" in the United Kingdom, "dry ports" in Sweden and other European countries, and "interports" in Italy as an abbreviation of "interior ports" (Iannone, 2012).
3. M3: Route3 – from the farm area by rail to the port. Our model assumes that for M3, container feeder movements between farm and railway station are over short distances and made by truck.

The three routes (M1, M2 and M3) serve the hinterland area of the Port of Cape Town. Currently, only two routes – M1 and M3 – are available to deliver export products from the market to the Port of Cape Town. There is one large dry port – the "City Deep Terminal" in Johannesburg – that is connected to the Port of Durban, the Port of Ngqurha, the Port of Cape Town, as well as Southern Africa, by road and rail. However, as mentioned by Pieterse et al. (2016), the increased time and costs to collect and deliver containers to the "City Deep Terminal" in Johannesburg make it difficult to attract customers. Therefore, we considered the situation in which a new dry port was introduced in route M2 in Vanderbijlpark with improved services in terms of time and cost. The reasons we have selected Vanderbijlpark are that there is a big vacant area and it is only an hour drive from Johannesburg.

In order to investigate the interplay between export products, transport strategies and access to a port for exporters, we present a linear programming model in this paper. Linear programming has long been applied in agricultural economics for calculating optimal solutions, but its use has mainly been limited to the analysis of crop choice and technology of production. However, this methodology has also proved to be a powerful tool in the analysis of some problems relating to transport and location of activities (Larsen, 1992). In this research, we will use a linear programming model to determine the optimal combination of transportation modes. The mathematical model presented is general and can be used to determine the optimal combination among different options of transportation. It can easily be extended to include the transportation of several products. However, in this research we use a simple single product transportation problem with three different transportation alternatives.

The model allows for other options of transportation and other optional destinations. What we need will be the relative cost for each of them. This could be the transportation cost per unit and deterioration cost, which can be different between the alternatives. Suppose we choose to transport to Durban instead of Cape Town. In that case, the transportation costs can be smaller, but since the total transportation time to the end customers in Europe might increase by several days, the deterioration cost factor will be higher.

The solution will typically choose a limited number of options, and to keep the example simple, we have only showed the three alternatives we already have mentioned. Other options, not selected, are excluded from the example.

[2] See https://www.namc.co.za/wp-content/uploads/2018/07/NAMC-DAFF-TradeProbe-69-May-Issue.pdf accessed 06th June 2021.

[3] See https://www.namc.co.za/wp-content/uploads/2018/07/NAMC-DAFF-TradeProbe-69-May-Issue.pdf accessed 06th June 2021.

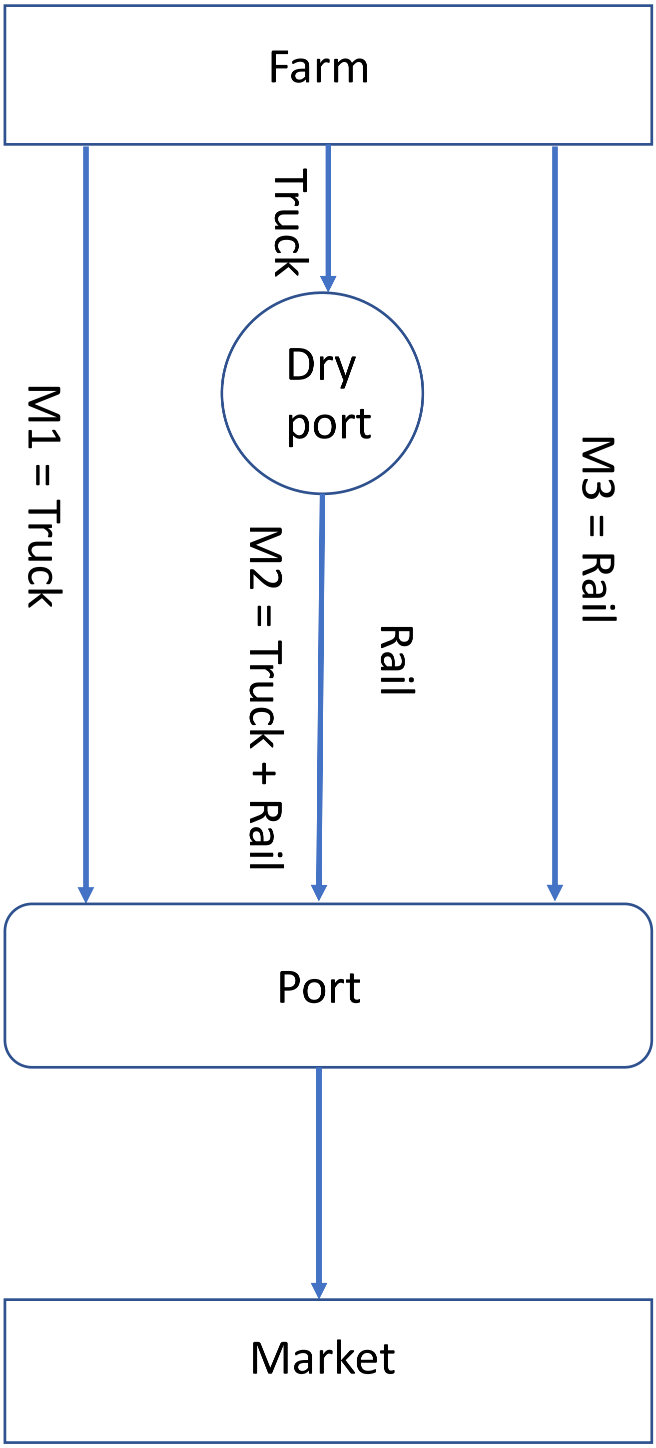

Fig. 1. Different transport modes to deliver cargo from farms to the port.

These could, for example, be:

- Reloading at other dry ports.
- Using different types of refrigerator technologies (both for trucks and for rail). Some could be more expensive to use but keep the product better, making the deterioration costs lower.
- Different destinations like Durban or Maputo.
- All combinations of technologies and reloading to the different destinations.

The model can be implemented and solved in any optimization software. The examples in this paper were modelled in Excel and solved using Frontline's Analytic Solver Platform.

We define M1 to be transportation by road from the production site in Tzaneen to the port in Cape Town for export. Then, option M2 is transportation by road to a dry port, in our example Vanderbijlpark (70 km south of Johannesburg), for reloading and transportation by rail to the destination in Cape Town. Johannesburg is around 50 km from Pretoria (see Fig. 2). Finally, we define option M3 as an existing rail transportation the whole distance from Tzaneen to Cape Town. When comparing the costs of the transportation alternatives, all relevant factors should be included, such as the transhipment costs at the dry ports. Still, while we know that transportation by rail is the cheapest option because of economies of scale,[4] its transportation time and limited departure frequency also makes it the alternative with the longest time from harvesting to loading at the export port. Hence, sorting the alternatives by cost gives the sequence M3, M2, M1, while sorting them by delivery time to the ports leads to M1, M2, M3.

We also know that the trains do not depart every day, so it is necessary to define a repeatable cycle time for each mode as the frequency between departures of the different modes. Here, we can assume that there is a higher frequency from the dry port in Vanderbijlpark than from the origin in Tzaneen.

In terms of the cost elements, we need to consider both the transportation costs, but also the deterioration costs of the product (fruits) during the transportation time or when waiting for the next train departure.

We can create a general model for such a problem, defining the following parameters.

m	Number of modes/alternative transportation	
M	Set of modes/alternative transportation	$M = \{1, 2, \ldots, m\}$
h	Time horizon, typically least common multiple of the cycle time of the modes	
H	Set of time periods	$H = \{1, 2, \ldots, h\}$
T_i	Time for repeatable cycles of mode i	
c_i	Unit cost for transportation on mode i (including handling cost at dry port)	
d_{it}	Cost factor for deterioration when using mode i in period t	
p	Production amount per time period	
Q_i	Capacity of one transportation unit (truck, train, etc.) of mode i	

The variables are as follows:

X_{it}	Amount of product X transported by mode i in time period t.

We will also define the concept N_i as the number of cycles of mode i during the time horizon, $N_i = \frac{h}{T_i}$.

Hence, the mathematical model has the following form:

$$minimize\ costs = \sum_{i=1}^{m} \sum_{t=1}^{h} c_i X_{it} + \sum_{i=1}^{m} \sum_{t=1}^{h} d_{it} X_{it} \tag{1}$$

Such that

Fig. 2. Map showing a distance between Tzaneen and Port of Cape Town.

[4] See https://transportgeography.org/?page_id=5588

$$\sum_{i=1}^{m} X_{it} = p \forall t \in H \tag{2}$$

$$\sum_{t=a \bullet N_i+1}^{a \bullet N_i+N_i} X_{it} \leq Q_i \forall i \in M, a \in \{0, 1, \ldots, N_i\} \tag{3}$$

$$X_{it} \geq 0 \; and \; integer \forall i \in M, \forall t \in H \tag{4}$$

Eq. (1) is the objective function minimizing the total costs, defined as the sum of the transportation costs and the deterioration costs during transport on the different modes. Other cost factors could easily be added to the objective.

Constraint (2) states that the transportation amount for each time period should be equal to the production amount.

Constraints (3) specifies that the capacity of the transportation units of each mode is not exceeded.

Constraints (4) are the non-negativity constraints for the X-variables, also stating that only full containers should be used.

4. Current situation and parameter values

This analysis focuses on the production of citrus fruits and export to the main markets in Europe.

4.1. Volume

During 2016, it was predicted that approximately 1500 containers[5] of citrus would be transported from Tzaneen to the Ports of Durban and Cape Town (Freshplaza, 2015) and that 70% of the total amount of fruits from Tzaneen would be exported from Cape Town. The production takes place in the five-month period from May to September, and we can assume that it is constant during this period. Hence, we can expect a daily production of seven containers, which should be transported to the Port of Cape Town.

4.2. Time

The land distance between Tzaneen and Cape Town is 1222 miles (1967 km), so the driving time by road is approximately 22 h (Distantias, 2019). Considering resting time for the driver and other stops, we can estimate that a container transported by road will take approximately two days to travel from its origin to the port.

Currently, a cargo train takes 48 h to travel between Tzaneen and Cape Town (Freshplaza, 2015); considering that the train needs at least one day to load/unload the containers, the total transportation time is 72 h. The train leaves only once a week, which means a possible waiting time of up to six days in addition to the additional transportation time. Today, the possibility of reloading at a dry port in Vanderbijlpark is not an option. However, if considered, we would expect a higher frequency of departures from the dry port to Cape Town. This high frequency is possible because of cargo consolidation; as Khaslavskaya and Roso (2019) mentioned, a dry port has a freight terminal that can consolidate cargo from several sources. Hence, we assume a possible frequency of departure every fourth day in our analyses of this mode, making up to three days waiting time.

4.3. Capacity and frequency

Trains are currently able to transport 38 containers per departure (Freshplaza, 2015). Trucks can carry up to two containers, and we can assume that there are enough trucks available for the total transportation need. Thus, it is possible to set the upper limit for road transportation equal to the production amount, and we can assume that trucks leave daily. The train carrying fruit from Tzaneen to Cape Town leaves once a week during the production period (Lennane, 2014).

4.4. Cost

In South Africa, average rail tariffs are 46% lower than road tariffs across a range of cargo products (Transnet., 2008). Historically, freight transport in South Africa was railroad-driven; however, after transport liberalisation and eventual deregulation, the significant amount of freight shifted from rail to road. The reduction in market share decreases the income of railway that resulted in declining investment and expenditure on maintenance, inducing further freight losses (Havenga & Pienaar, 2012). In 2013, road accounted for approximately 90% of market share in volume (CSIR, 2014). Road transport provides flexible, reliable and door-to-door services compared to railways, which have a lower cost but at the expense of the loss of service flexibility. Moreover, the railway in RSA is characterized by a lack of reliability. Because of frequent train delays, customers prefer to use the road (Pieterse et al., 2016). Based on this information, we assume that the cost of transporting a product via roads (trucks) is 40% higher compared to the cost of rail transportation.

However, looking only at the transportation costs will not give the full picture, since the cost advantage is often eroded or lost for time-sensitive products (Pieterse et al., 2016). A product like fruit is highly dependent on short delivery time. Every extra day of transportation will lead to a loss of value of the product and a higher degree of deterioration. Hence, we need to consider the reduced value for the longer transportation time in addition to the direct transportation costs. We have used a deterioration cost of 10% per extra day of transportation in our calculations; that is, the production for one day sent by rail the same day is considered with a 10% higher loss compared to if it was sent by road, and the costs will further increase by 10% for each day of waiting time. This leads to a deterioration factor of 1.10^t, where t is the number of days of waiting time for production on a given day. Since fruit is a perishable product that needs to be stored in a cool environment, it requires special refrigerator vans or wagons for transportation by truck or train. Using these vans/wagons will induce a cost, which is included in the transportation costs.

4.5. Optimal solution with current parameter values

We have solved the mathematical model described in Section 4 with the parameter values shown in Table 2. The values are assumed and estimated based on the real values as described in the previous sections. Note that the unit costs for the modes are relative values, i.e. stating that the costs for using mode M1 ($c_1 = 1.4$) is 40% higher than using mode M3 ($c_3 = 1.0$). Hence, the deterioration factor should also be set relative to this value.

Using the cost factor for M1, we can easily calculate the costs of only road transportation for comparison. This solution gives transportation costs of $1.4 \cdot 7 \cdot 28 = 274.4$, meaning seven containers to a cost of 1.4 in 28 days. The corresponding deterioration costs are $7 \cdot 1.1 \cdot 28 = 215.6$ (seven containers with a deterioration for one day over 28 days), making a total of 490.0 for this option. Table 3 shows the optimal solution for a 28-day period when including mode M3. This time frame is chosen as the least common multiple of the repeatable cycles for M1, M2, and M3,

Table 2
Parameter values for model.

Mode	c	T	N	Q	m	3
M1	1.40	1	28	7	h	28
M2	1.20	4	7	0	p	7
M3	1.00	7	4	38	d	1.10^t

[5] Containers refer to the twenty-foot equivalent unit (TEU)

Table 3
Optimal solution without considering Mode 2.

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
M1	7	7	7	0	0	0	0	7	7	7	0	0	0	0
M2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M3	0	0	0	7	7	7	7	0	0	0	7	7	7	7

Day	15	16	17	18	19	20	21	22	23	24	25	26	27	28
M1	7	7	7	0	0	0	0	7	7	7	0	0	0	0
M2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M3	0	0	0	7	7	7	7	0	0	0	7	7	7	7

which is convenient for comparing different strategies with different parameter values.

We can see that the cycle is repeated every seventh day, which is the frequency of the weekly rail transportation. The production of the first three days of the cycle should be sent by road, while the production of the four following days should be sent by rail. This makes a total of 28 containers on each rail departure, which is far from the maximum capacity of 38 containers per train. This solution has an objective value of 464.94 with the current parameter values. This number describes relative costs, meaning that the costs are calculated with cost factors relative to the other modes as shown in Table 2.

Assuming a base price for transporting one container by rail (mode M3) to be 10,000 ZAR (South African rand). Then if the corresponding price of one container sent by truck (M1) is assumed to be 14,000 and using the intermodal option (M2) costs 12,000 ZAR, this will give cost factors of 1.4 and 1.2, respectively.

Similarly, we need to set the deterioration costs relative to the base price. In our example, the deterioration cost is calculated relative to the base price of the transportation rather than the value of the product. The loss in product value is considered to be equivalent to an addition to the freight rate. A 10%[6] loss of value due to deterioration would increase a base transportation price of 10,000 ZAR by 1000 ZAR. We have used an exponential growth of the cost factor, although this can be calculated in any other way or eventually stated directly if one can estimate the value loss of the product.

To get the exact monetary cost from the objective value of the model, the value needs to be multiplied by the base price, in our example 10,000, making the combined road and rail solution cost 4,649,400 compared to 4,900,000 for the pure road-based solution.

5. Analysis and results

The value of the different cost parameters will decide what the optimal transportation solution looks like. In the following section, we will analyse how the solution is affected if the parameter values change because of improvements in transport strategies, and we will also introduce the intermodal alternative with transhipment in Vanderbijlpark. The most interesting parameters to analyse are the transportation costs and the departure frequency. These are dependent on man-made decisions, unlike the deterioration costs, which are more like a constant.

This section only includes some examples of improvements in this particular case, but it does show how the mathematical model can be used to analyse potential alternatives and provide useful information to decision makers.

5.1. Analysis with two modes of transportation: Trucks and rail

Solving the transportation problem, with only the two options of solely using either road or rail, is straightforward. We can easily find the limit value for the cost factor leading to maximum utilization of the train capacity. If the cost factor for the road is increased to 1.7, then only the production of seven containers the first day of the cycle and three containers the second day of the cycle should be sent by road, while the train should be fully loaded with the remaining 38 containers once a week. Likewise, we can find the limit value for the cost factor, leading to road transport being the most profitable transportation mode. If the cost factor for the road is reduced to 1.0, there is no difference in transportation costs between the modes, and all transportation should be performed by road. For all values between these limits, the optimal solution lies somewhere between pure road and maximum rail transportation.[7] The relative weight of the cost factors will depend on actual costs like fuel consumption and toll charges, but they will also be affected by the reliability of the transportation modes.

5.2. Analysis with an additional mode of transportation: Trucks, intermodal and rail

If we include Mode 2 with reloading at the dry port in Vanderbijlpark, the problem becomes more complex. Using the same parameter values as in Table 2 but including a positive value for the capacity parameter for Mode 2 (for example, 38), would lead to the solution shown in Table 4. Now, we need the total time frame of 28 to get repeatable cycles. We can see that, for two to four periods ahead of the rail departure from the origin, the production should be sent by rail. For instance, the departure on day 7 includes production from days 5, 6 and 7 (three days). The departure on day 14 includes production from days 13 and 14 (two days); similarly, departure on day 21 (four days) and day 28 (four days). We can also see that the more frequent departures from the dry port will lead to some days of production being sent there for reloading. This is evident for the days in accordance with the departure from the dry port, which is every fourth day. However, we can see that this is not the case for the production in day 20 since it is cheaper to wait one day for the departure from the origin than to send it to the dry port for reloading on the same day. Similarly, on day 28 there is no need to send the production to the dry port since the train from the origin departs the same day. The relative cost of this solution is 457.11, which is directly comparable with the current solution of 464.94 from Section 4.5. The difference will show the savings when introducing the new intermodal alternative and can be calculated to real figures when the actual cost values are known.

As shown in Section 5.1, it is easy to analyse the effect on the optimal solution when the cost factors are changed. Increasing the road factor to 1.6 will lead to no transport at all by road since the two other modes have sufficient capacity for the full production. Then, the relative difference between mode M2 and M3 will decide the distribution between transportation on these modes. Again, we can see that if the road factor

[6] The value of 10% is chosen as an example of the loss of value for the product in this study. Another relative value can exchange this percentage if this is more appropriate.

[7] We have used the word “pure” to describe the strategy that is selecting only road transport. Maximum is used when a mode is utilized up to its capacity level.

Table 4
Optimal solution when considering Mode 2.

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
M1	7	7	0	0	0	0	0	0	7	7	0	0	0	0
M2	0	0	7	7	0	0	0	7	0	0	7	7	0	0
M3	0	0	0	0	7	7	7	0	0	0	0	0	7	7

Day	15	16	17	18	19	20	21	22	23	24	25	26	27	28
M1	0	0	7	0	0	0	0	7	0	0	0	0	0	0
M2	07	7	0	0	0	0	0	0	7	7	0	0	0	0
M3	0	0	0	7	7	7	7	0	0	0	7	7	7	7

is reduced to 1.0, there will be no transportation by rail, but possibly some intermodal transportation depending on the relative cost difference between modes M1 and M2.

5.3. Analysis with improvements in the inland transportation

In this section, we analyse a potential improvement of the rail connections that is reflected in the form of an increase in frequency. If the frequency trains from the origin were increased from every seventh day to every sixth day, how would that affect the optimal solution? We kept the parameter values constant and solve the model with the new deterioration costs due to the lower waiting time when using mode M3. In this case, we can use only a 12-day repeatable cycle as the planning period, since 12 is the least common multiplier of the M2 cycle time of 4 and the M3 cycle time of 6. The 28-day costs to use for comparison will then be equal to the 12-day result multiplied by 2.33. Table 5 shows the results for this option.

This solution shows that, in the first three days of the cycle, transportation should be performed by road. On the fourth day, the intermodal option should be used, while the production on the two next days should be sent by the train leaving on day 6. On day 7, the road should be used again, while on day 8 it is preferable to use the intermodal option to meet the departure of the train from the reloading point. Next, day 9's production should be sent by road, while the three following days' production should wait for the departure of the train from the origin. The relative 28-day cost for this option is 450.00, showing a saving from the previous examples due to the more frequent use of mode M3. The limit for not using road transportation is a road cost factor of 2.0; similarly, a road cost factor of less than 1.0 leads to a solution where all transport should be performed by road. Here, we assume that the M2 factor is midway between the values for M1 and M3.

Finally, we analyse the option of increasing the frequency of intermodal transport, assuming that the train leaves every third day instead of every fourth day. We kept the parameter values at the same level and continue with a seven-day frequency on mode 3. Now, we can use repeatable cycles of 21 days and calculate the 28-day cost by multiplying the objective value with 1.33. Table 6 shows the optimal solution for this alternative.

We can see that, with a higher frequency of departure on mode M2, this is the most convenient mode to use for the production days corresponding to the departure of this mode. The exceptions are when this departure is either on the same day or the day before the departure of mode M3 when the production should use this mode instead. This is the situation on day 6 and day 21 in this plan. The relative cost for a 28-day period with this transportation plan is 454.50, which is slightly higher than the previous option of increasing the M3 frequency instead. In this situation, the limit for not using road transportation is lower at 1.5 since the more frequent departures from the dry port makes it more favourable to reload there compared to driving the full distance with the truck.

Table 5
Optimal solution with a higher frequency on Mode 3.

Day	1	2	3	4	5	6	7	8	9	10	11	12
M1	7	7	7	0	0	0	7	0	7	0	0	0
M2	0	0	0	7	0	0	0	7	0	0	0	0
M3	0	0	0	0	7	7	0	0	0	7	7	7

Table 6
Optimal solution with a higher frequency on Mode 2.

Day	1	2	3	4	5	6	7	8	9	10	11
M1	7	0	0	7	0	0	0	0	0	7	0
M2	0	7	7	0	0	0	0	7	7	0	7
M3	0	0	0	0	7	7	7	0	0	0	0

Day	12	13	14	15	16	17	18	19	20	21
M1	0	0	0	0	7	0	0	0	0	0
M2	7	0	0	7	0	7	7	0	0	0
M3	0	7	7	0	0	0	0	7	7	7

Table 7
Objective value with different alternatives.

Alternative	Objective value
M1	490.00
M1, M3	464.94
M1, M2, M3	457.11
6 days M3	450.00
3 days M2	454.50

Table 7 shows an overview of the relative objective values with the four alternatives shown in Tables 3, 4, 5 and 6, compared with the option of only road transportation. These values show the effect of introducing new modes and changing frequency for them when keeping the parameter values constant.

We can see that including new modes would lead to considerable savings in the objective function. We can also see that increasing the frequency for M3 would have a better effect than increasing the frequency for M2 if these were two alternative options. In this way, it is possible to analyse possible changes in the transportation modes and compare the relative efficiency between the different options.

6. Conclusion and policy implications

In this study, we have discussed the impact of developing the strategies of hinterland transport when exporting perishable products and used an example from the Port of Cape Town in the Republic of South Africa. A good hinterland connection is acknowledged as one of the crucial factors in port competitiveness because any delay caused by poor inland hinterland connection will result in a higher logistics cost for cargo owners and a delay in delivery of the product to the final customers. Consequently, cargo owners can switch to another port that has efficient hinterland connections. The inland hinterland connection can be improved in the following ways: introducing a dry port; improving the railway (including infrastructure and superstructure) such that the frequency, reliability, and capacity of the railway will increase; and improving the roads. The present study has discussed the first two options because the roads in the RSA are already handling about the 90% of freight transport and there is a need to switch traffic from the roads to railway and intermodal transportation to reduce the congestions on roads and environmental pollutions caused by the road traffic.

We have developed a simple optimization model that is used to consider both planning transportation with different inland hinterland transport modes and to analyse the impact of improvement in inland transport strategies when exporting perishable products. The model is general and can be used in various situations with different options for transportation. We have used an example from South African fruit export and shown how the model can be used to find the optimal transportation strategy based on the relative difference between the cost parameters and the frequency of the departure on the different modes. The policymakers can use the proposed model to analyse the alternative transportation strategies.

We have applied the model to analyse whether the introduction of intermodal transport and improvement in railway services will affect the cost for exporting the perishable products (citrus in this case) from the Port of Cape Town. We have only considered the transportation cost from the farms to the port, the cost of transloading at a dry port, and the deterioration cost. We have not included port fees because these are independent of how the fruit is transported to the port. The values for the input parameters are assumed based on the facts and figures collected from the different sources.

The results recommend that introducing a dry port could reduce the cost compared to the present situation when road and railway are used to deliver the fruits from the farm to the port. These results support the previous findings obtained by Wiegmans and Konings (2015), which showed that intermodal transport had a cost advantage over road transport in a long-distance (more than 600 km). We also extended the analysis by considering improving the railway service. The results revealed that the best strategy that reduces the relative cost is to increase the frequency of trains from the origin. These results support the findings obtained by Iannone (2012) and explain the benefits achieved with improved railway connections. Based on these results, it is recommended to reconsider the rail reform strategies and invest in improving rail service, resulting in economic and environmental benefits for the users.

This study has the following limitations. Firstly, perishable products are temperature-sensitive products, and their transportation along the cold supply chain requires special thermal and refrigerated packaging techniques. To ensure a temperature-controlled surrounding during transportation, several cold chain technologies could be adopted, such as dry ice, gel packs, eutectic plates, liquid nitrogen, quilts, and finally, a temperature-controlled transport unit e.g., a van, small truck, a semi-trailer, or a container (Rodrigue & Notteboom, 2014). This study does not explicitly consider the refrigeration cost and the difference in the cost among different modes due to refrigeration in the model. The future study could include refrigeration costs as different alternatives in the model. For instance, the cost of different cooling options such as the cost of nitrogen compared to the cost of the dry ice could be incorporated in the model. Costs for refrigeration can also be included in the cost factor used when storing the product. This study has used the term deterioration to show the reduced value of the product when stored. But this cost factor could also include costs for refrigeration in the storage period. Hence, the cost factor can be defined as the extra cost for storage of the product when using mode i in period t. This factor could include the loss of value of the product, the cost for refrigeration of the product, and any other cost related to storing the product for the extra number of days when using the selected transport strategy or alternative.

Secondly, we have included the reliability issue of the railway by putting the higher cost of railway compared to the situation when railway service is reliable. Future research can use a more complex model of a complex stochastic problem with an uncertainty that explicitly includes reliability.

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