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The proceeds derived from the effective selection of cargo parcels and routing of vessels to multiple destination ports

By

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Acknowledgements

The completion of this research paper and essentially my Masters in the Netherlands marks an important achievement in my life. The qualification signifies an accomplishment that I have always dreamt about. I have overcome both personal and academic challenges to conclude my Masters in Maritime Economics and Logistics. Although, this year has been difficult at times, I have thoroughly enjoyed expanding my knowledge of the maritime industry, a field I am extremely passionate about.

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Abstract

This research paper presents a novel approach for addressing both cargo parcel selection and ship routing problems concurrently, within the context of tramp shipping operations. In this problem, a set of spot market parcels of minor dry bulk commodities must be selected according to their offered freight rates and combined to achieve a full-shipment load. Moreover, the parcels are shipped on board a time-chartered handysize vessel from a single port of loading to multiple discharge ports.

The problem addressed is unique in a sense that it considers two key planning decisions underlying the transportation of spot minor bulk cargo. Firstly, the parcel selection of less-than-shipload quantities to be loaded in undedicated hold compartments of a dry bulk carrier and separated by separating sheets. Secondly, the optimal ship routing to ensure all parcel demand ports are included whilst sailing along the shortest path in an effort to minimize the consumption of bunker fuel oil.

The paper borrows from existing literature in both disciplines of cargo selection and ship routing. A theoretical model was created to represent both aspects of the problem with the objective of maximizing profit from the shipment. Furthermore, an investigated case including real-life data was employed to test the effectiveness of the model. The computational results from numerous instance testing of the case successfully achieved the model's objective whilst solving the optimal routing problem for ten demand ports with no occurrence of sub-cycles.

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List of Abbreviations

BHSI	Baltic Handysize Index
ECA	Emission Control Areas
EU	European Union
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
LSFO	Low Sulphur Fuel Oil
MARPOL	International Convention for the Prevention of Pollution from Ships
SA	South Africa
SECA	Sulphur Emission Control Areas
SRP	Ship Routing Problem
TNPA	Transnet National Port Authority
VRP	Vehicle Routing Problem

1. Introduction

Globalisation, through the reality of interconnected trade relations, has been facilitated by the services quintessential to the maritime industry. Shipping has played a significant role in transporting low value, high volume commodities between global networks. The UNCTAD report (2016), declared that in 2015, world seaborne trade accounted for approximately 80 per cent of the volume of total world trade. Furthermore, in the same year, dry cargo shipments with a volume of 4.8 billion tons, accounted for almost 71 per cent of total seaborne trade volumes; a first-time fall in traded dry bulk volume since 2009 (UNCTAD, 2016). The main cause for the decline was due to a drop in the volume of shipments of the five major bulk commodities, namely: iron ore, coal, grain, bauxite and alumina and phosphate rock. The leading reason behind the drop in trade stems from the three per cent decline in coal demand (Rex, 2016). In addition, the reduced demand of major bulks was accompanied by a constant yet comparatively low volume of minor bulk trades. Figure 1, illustrates a comparison between the traded volumes of iron ore and coal, both major bulks, with the quantity of globally traded minor dry bulk cargo between the years 2000 and 2017.

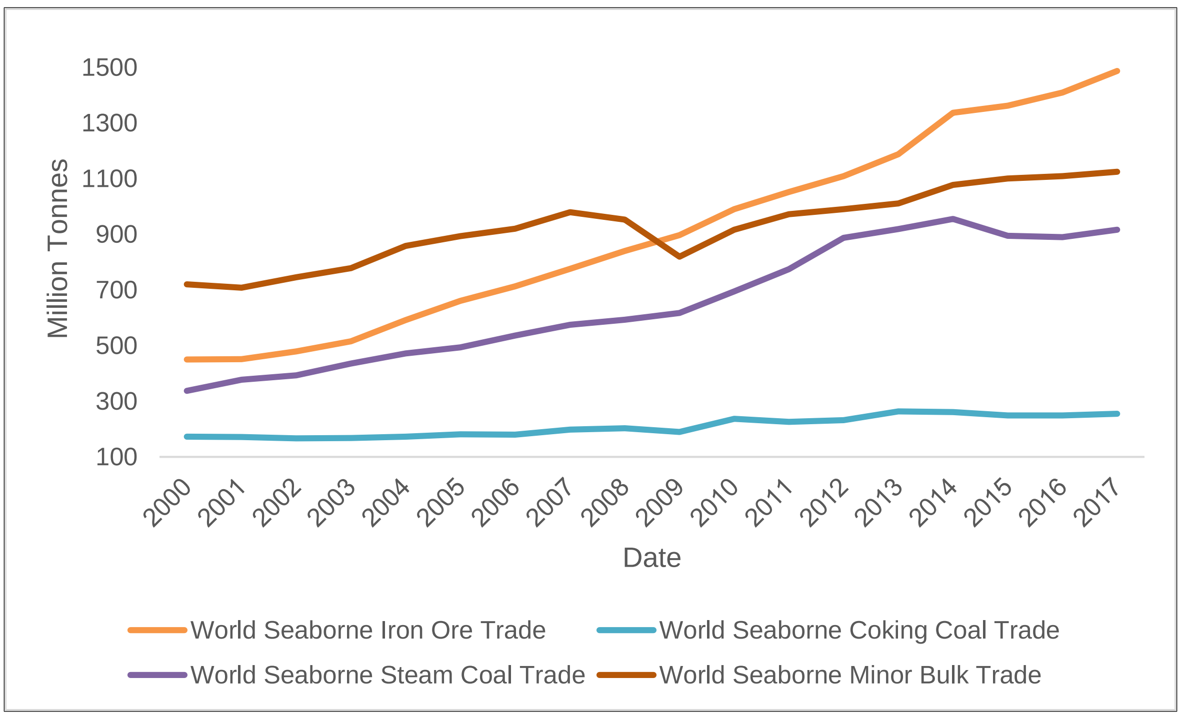

Figure 1: Worldwide seaborne dry bulk trade

Source: Author via Clarksons Research (2017e)

According to Clarksons Research (2017b), minor bulks can be categorized into agribulks and softs; metals and minerals; and manufacturers. Over the last decade, table 1 shows that 2009 experienced the largest year-on-year decline in minor bulk traded volumes with a drop of 12 per cent, which is also visible in the decline of the 'world seaborne minor bulk trade' graph in figure 1. Conversely, 2010 experienced the highest year-on-year percentage change in shipped minor bulk volume with a growth of 13 per cent. Moreover, the traded volume of minor bulks has remained relatively constant over the last three years with year-on-year percentage change of not more than one per cent. Clarksons Research (2017b) has forecasted a steady trade trend of 1,898 million tonnes for 2017, a two per cent year-on-year change. In brief, minor dry bulks are comprised of more commodity types and are traded in smaller quantities than major bulks; despite their comparatively low contribution to global dry bulk trades, they remain imperative in a dry bulk shipping context.

Table 1: Global minor bulk traded volumes

	Trade Volumes (million tonnes)										
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017(f)
Agribulks and Softs	306	298	279	309	331	347	347	366	374	374	388
Metals and Minerals	636	630	559	625	675	713	784	733	738	730	755
Manufactures	695	674	564	644	677	677	692	742	755	760	755
Total	1,637	1,602	1,402	1,578	1,682	1,736	1,823	1,841	1,867	1,864	1,898
Year-on-Year Percentage Change (%)	7	- 2	- 12	13	7	3	5	1	1	0	2

Source: Author via Clarksons Research (2017b)

The inherent disposition of both major and minor bulks require the commodities to be transported between continents in bulk carriers. The operation of dry bulk vessels employed for deep-sea shipping routes provides an opportunity to gain high returns; yet, undoubtedly considerable costs are incurred. For both company owned and chartered vessels, proper planning of shipping routes and the optimal utilisation of vessels can translate into small-scale improvements that can attain additional profits for a ship operator (Hvattum, *et al*., 2009). The increased interest in effective ship routing has contributed towards both reducing the negative environmental impacts of shipping as well as the survival of ship operators during the current times of depressed charter rates (Bronmo, *et al*., 2007). According to Gatica & Miranda (2011), the shipping industry can be characterised by major capital investments and high operating costs; thus, with proper fleet management, in the field of ship scheduling and routing, significant economic benefits are achievable.

Shipping companies are usually established within one of three general modes of operation, which are in accordance with their cargo interests, namely: liner, industrial or tramp shipping (Lawrence, 1972). The main difference between liner and industrial or tramp operations is the existence of prearranged schedules with specified shipping routes. Despite their differences, the persistent commonality in all three modes is the optimization of efficient operations. Currently, there is, to a large extent, more literature available on liner and industrial shipping than on tramp operations. However, this paper attempts to add to the present literature on tramp shipping. More specifically, the research conducted will obstruct the gap regarding tramp style ship routing problems (SRP) with the additional selection of spot market dry bulk cargo parcels. The SRP occurs between a single loading port and multiple discharge ports, whilst satisfying the overarching objective of profit maximization. Moreover, the remainder of this section will continue to lay the foundations for the research from a general shipping perspective. Gaining an overarching comprehension of minor bulks and ship chartering is imperative in the understanding of the research problem and the experimental case to follow.

The efficiency of the international maritime industry has an interconnected impact on the global economy. Hence, a great deal of research has been done into the optimization of shipping to make slight improvements, which can have a large impact on a company's bottom line. The accurate routing and scheduling of ships in a tramp operation is "more dynamic and an ongoing process compared to that of liner shipping (Vilhelmsen, *et al*., 2013)." Ship routing and scheduling is an extension of the well-known vehicle routing problem (VRP) with vital differences that generate industry and especially tramp specific methods. Tramp shipping is common in the transportation of dry bulk cargoes and these vessels can be bare boat, time or voyage chartered by ship operators.

Unregulated tramp ship operations are favourable to the transportation of spot market minor dry bulk cargoes. Shipments of minor bulks can comprise of a multiplicity of commodities. The main cargo types in the minor bulk category include both raw materials and semi-manufacturers and can be clustered into six groups, namely: agribulks; sugar; fertilizer; metals and minerals; steel products; and forest products (Stopford, 2009). These cargoes are mainly traded in smaller parcel quantities and shipped with the use of dry bulk carriers, such as handysize or handymax vessels. A cargo parcel can be defined as the size of an individual consignment, usually of less-than-shipload quantity, to be transported by a carrier on behalf of a consignee. Each cargo parcel bids a unique freight rate per ton, payable to the charterer for the transportation of the commodity. Freight rates are volatile due to the unstable demand and supply of each commodity. The uniting of minor cargo parcels to fill a vessel will ensure that scale economies are attained, whilst benefiting from assorted freight rate revenues. Combining cargo loads is a familiar case in the shipment of multiple heterogeneous chemicals and liquid bulk product parcels in multiple tanks onboard a bulk tanker vessel to various ports of discharge. This asset-free commercial function is possible to arrange in the transportation of minor dry bulk cargo; yet, full-shipload quantities of homogeneous cargoes are more common in the dry bulk domain.

Shipping parcels, each of less-than-shipload quantity can be a complex operation; yet, if organized effectively, large revenue gains can be realised. For shipping companies, with or without the possession of a company-owned vessel, it is possible to charter a vessel to perform the transportation of spot parcel cargoes. What is more, a ship operator can time charter a handysize vessel on the spot market at a rate lower than the daily cost of a company-owned ship (Lee & Kim, 2015). An operator can assess the possibility of saving money from chartering a vessel by comparing the trend of the Baltic Exchange Handysize Index (BHSI) with the actual cost of operating a company-owned vessel. The BHSI presents an indicative daily average charter rate for handysize vessels in the dry bulk shipping market and can be used as a litmus test for market performance (The Baltic Exchange, 2017). In February 2016, the global BHSI fell to a ten year low at a value of $2,916 per day, as indicated by the cross marked in figure 2 (Clarksons Research, 2017a). Since the drastic drop in charter rates, the handysize market has recovered somewhat with a declared average daily charter rate of $5,371 for the year 2016 and $6,526 for 2017 (Clarksons Research, 2017c). Moreover, according to the International Seaborne Market (2017a), the average time charter rate per day in week 31 of 2017, for a handysize vessel was between $7,000 and $8,000; more specifically, a vessel sailing via the Atlantic costs approximately $7,750 per day. A "decrease in rates seems to be inevitable" as the cargo flow in the Indian Ocean is expected to weaken in the near future (International Seaborne Market, 2017b). In summary, the weekly, if not daily variations in charter rates is notorious to the shipping industry due to the constantly changing demand and supply of cargo and vessels. This volatility provides shipping companies with a hedging opportunity to gain additional revenue by chartering vessels at a low daily rate..

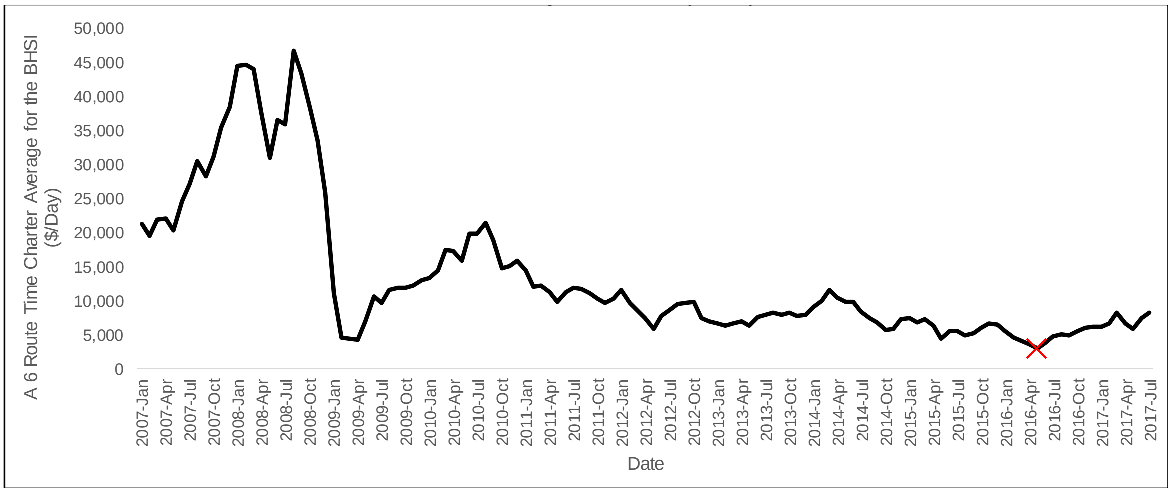

Figure 2: The BHSI for six shipping routes

Source: Author via Clarksons Research (2017a)

In relation to the aforementioned charter rate movements, there are two main reasons why the BHSI dropped to the decade's lowest point in February of 2016. Firstly, from an oversupply in the handysize vessel market and secondly, a suppressed demand from a decline in freight rate earnings for dry bulk cargoes (Hellenic Shipping News, 2016 and Rex, 2016). Figure 3, shows a one-year time charter rate specifically for handysize vessels as well as the development in the global handysize fleet between 2000 and 2017. Handysize vessels experienced a peak in time charter rates during the years 2007 and 2008, which promoted the ordering of handysize tonnage. Consequently, the arrival of orders placed during the years of booming charter rates caused a spike in the year-on-year fleet growth percentage during the year of 2010. The arrival of new tonnage resulted in too much supply with not enough cargo demand, which caused the downturn in BHSI between the years 2010 and 2012 with no reliable recovery since, as shown in figure 2. An overcapacity remains to exist in the handysize market; although Rex (2016), mentions that these smaller vessels are better positioned to achieve higher earnings in the future compared to larger vessel size categories.

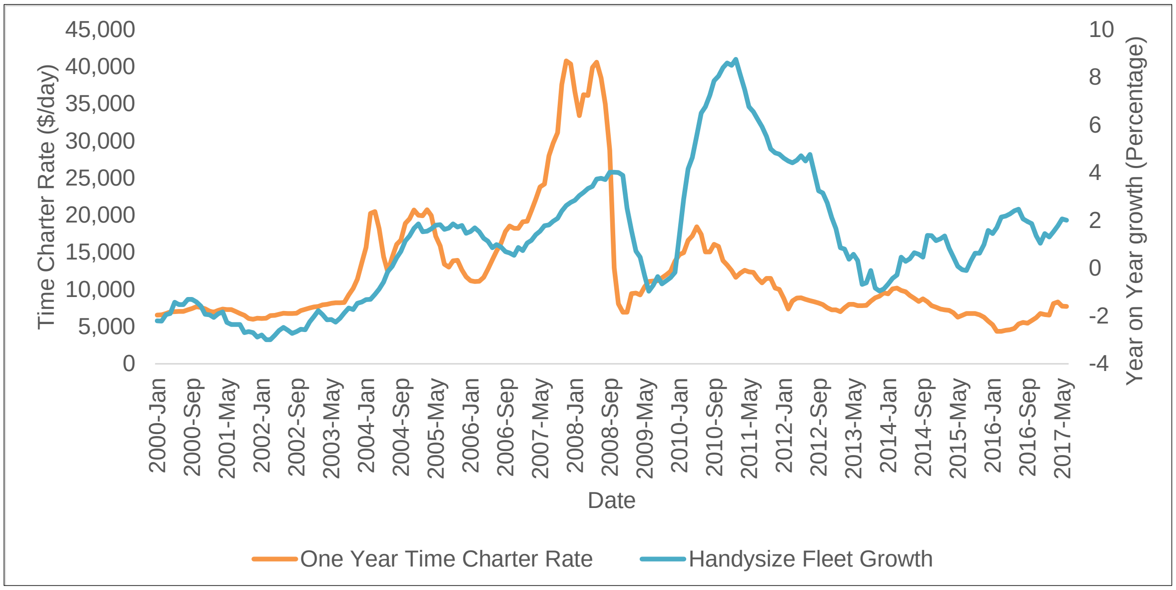

Figure 3: Handysize fleet development and one-year time charter rate

Source: Author via Clarksons Research (2017d)

Since the shipping market downturn in 2009, as indicated by the sudden drop of the Baltic Dry Index for all vessel size categories in figure 4; ship owners have often suffered from losses associated with chartering out company-owned vessels at depressed daily rates. From an industry wide perspective, the chain of repeatedly low daily charter rates can again be seen as the partial consequence of the existing overcapacity in the dry bulk shipping market. The recent trend of slow steaming has somewhat assisted in reducing the oversupply of available capacity in the market. Nonetheless, it has not been enough to recover the charter rates and ship owning companies have no option but to charter out their vessels at rates often below the operating cost of the vessel (Rex, 2016). Despite the daily losses incurred by company-owned carriers, a favourable situation has recently been induced; whereby, asset-free ship operators could charter a vessel at a low daily charter expense to ship spot cargo in pursuance of making a profit. The option presents, to ship optional cargo parcels with high freight rates, ensuring that the revenue earned from the shipment of cargo covers the absolute cost of chartering the vessel.

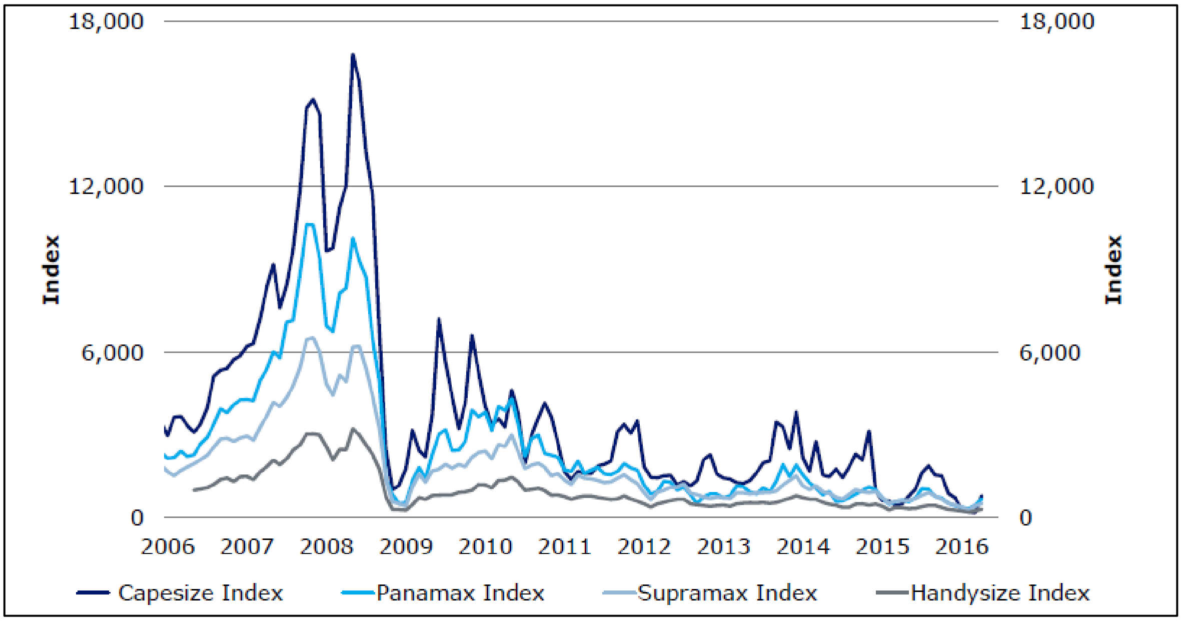

Figure 4: The Baltic Dry Index

Source: Rex (2016)

The chartering of vessels in a tramp style operation for the shipment of dry bulk cargo is not a new phenomenon and occurs worldwide. The common shipping occurrence will be analysed further in the remainder of this research paper. The analysis is particularly related to a ship operators decisions of selecting minor bulk cargo parcels to maximize revenue and effective routing of chartered ships. The foundation established in the first section of the introduction provides an insight into the identified problem. The problem specifics will follow in section 1.1. In this research, a specific case will be considered and computational tests will be conducted to test the model's validity. Furthermore, section 1.2 will conclude chapter 1 by mentioning the investigative questions answered by the research conducted.

1.1 *Problem Identification*

To hone in from the aforementioned global background perspective of minor bulk cargo and chartering; the problem addressed in this research paper originates from an opportunity present in the dry bulk shipping industry. For ship operators or otherwise referred to as charterers, who have the desire to operate a vessel but remain asset free; an opportunity prevails to charter a handysize vessel with a low daily charter cost and to fill the ship with an assortment of minor bulks available on the spot market. The revenue generated from shipping minor bulks is volatile in nature and the selection of high freight rate cargo can generate profits for charterers. Moreover, Jing, *et al*. (2008), affirm that unstable freight rates propose revenue generating opportunities to ship operators. The combination of smaller parcels with high freight rates provides an opportunity to earn a total revenue that will sufficiently cover the cost of a time chartered vessel. A profit can be made by fully utilising a vessels' available capacity to load parcels and to efficiently route the vessel along the most cost minimizing course.

This research investigates the a method to derive the possible proceeds acquired from a two part problem of accurately selecting the correct minor bulk parcels from the spot market to loading on board a handysize vessel and at the same time, solving the ship's routing problem. The objective for charterers is to select the cargo parcels with the highest freight rate so to maximize the revenue proceeds from the shipment. Subsequent to the selection of cargo parcels, the chartered vessel needs to be routed effectively. The optimal solution to the existent vessel routing problem, would be for the chartered vessel to visit all demand ports, whilst minimizing the sailing distance.

Many tramp shipping companies that may have long-term contracted cargo face the issue of ship routing particularly when including spot cargo to fill their ship's capacity. The shipment of additional cargo realises further revenue for shipping companies; however, the vessel is required to be routed to more destination ports. The basic routing of a single vessel from one loading port to multiple discharge ports is illustrated in figure 5. Effective routing can be a multiplex decision, especially when one needs to consider a large fleet of ships. Nevertheless, notable monetary gains regarding bunker fuel oil costs, an additional expense to the charterer over and above the vessel charter rate, can be realised by minimizing the sailing distance of a time chartered vessel. Figure 5 is a simplified schematic representation of the underlying routing problem, which is further assessed and modelled in section 2.4 and 3.2.2, respectively.

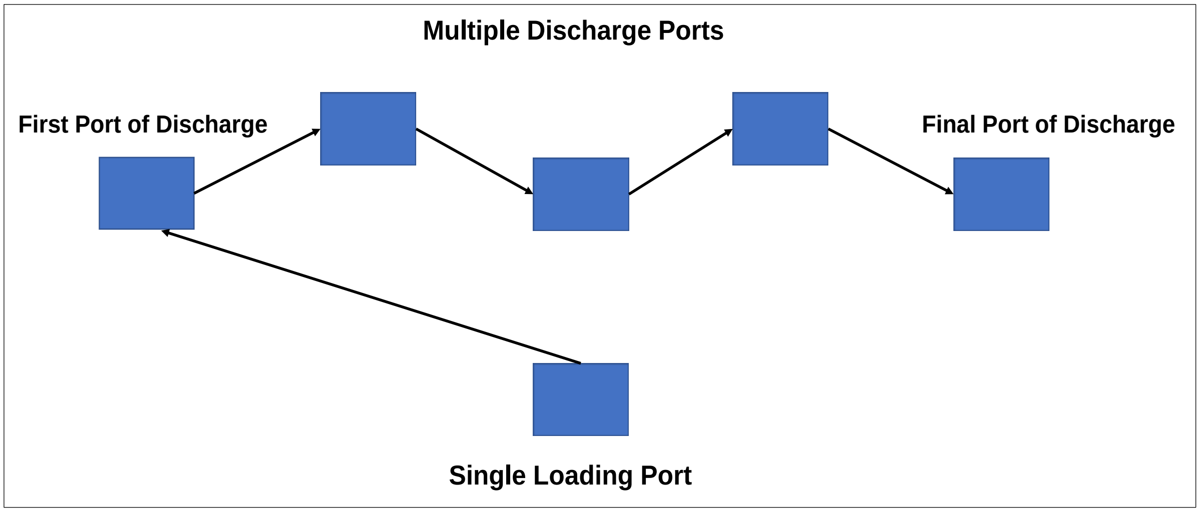

Figure 5: Routing a vessel

Source: Author (2017)

A theoretical model will be formulated in section 3.2.2 to reflect both parts of the identified problem. Furthermore, an experimental case will be used to test the model's validity in section 4.2. The case involves an established shipping company, currently operating out of South Africa. The ship operator holds a commercial function and is in constant pursuit of maximizing the profit earned from selecting a combination of heterogeneous spot cargoes to be shipped together and to match them to a time chartered carrier.

To develop the case, data of available spot cargoes with their respective quantities and freight rates was collected from the South African ship operator. The consolidated real-life data is represented as the available parcel options for selection, a primary input to the testing of the case. All the cargo parcels are less-than-shipload volumes; prompting, the charterer to combine parcels and to be shipped on a single vessel, a reflection of the problem identified. Together with the decision of cargo selection, the charterers may advise the captain of the vessel on the shortest distance sailing route. The experimental case will reflect this secondary decision as the model will strive to find a route so that the sailing distance between South Africa and the Mediterranean is minimized. The ship operators tend to time charter handysize vessels that operate in the tramp market, which will be reflected in the case. The capital-related advantages of a time charter together with the particulars of allowing a vessel to sail to multiple ports on a single voyage, are the main reasons for this chartering choice. Overall, the objective of this tramp ship routing problem is to determine the minimum distance sailed between ports subsequent to the selection of the highest freight rate revenue minor bulk parcels.

To continue with the problem identification, the data collected contains information about minor dry bulk parcels available in South Africa and demanded in the Mediterranean. South Africa is geographically located at the southernmost tip of the African continent, allowing for the opportunity to cooperate on the South-South trade; Far-East trade; both the East and West African regional shipping trades as well as to Europe and the United States of America (Transnet Port Terminals, 2013). South Africa possesses an abundance of natural resources, among others: ores, minerals and other raw material products that are exported. The total quantity of exported dry bulk commodities is reported to be approximately fifteen times the imported quantity, which alludes the country to being a net exporter (Ports Regulators of South Africa, 2016).

Moreover, South Africa's seven primary commercial seaports, indicated in figure 6, are strategically located to conveniently service various commodity flows. There are three main mineral bulk seaports, well known in the exportation of both major and minor dry bulk commodities. Minor bulks specifically are shipped from most accommodating ports in South Africa and these cargoes usually comprise of agricultural products, mineral cargoes, cement, forestry and steel products (Ports Regulator of South Africa, 2015). For the purpose of this research, the port of Richards Bay will be identified as the single port of loading for minor bulk parcels.

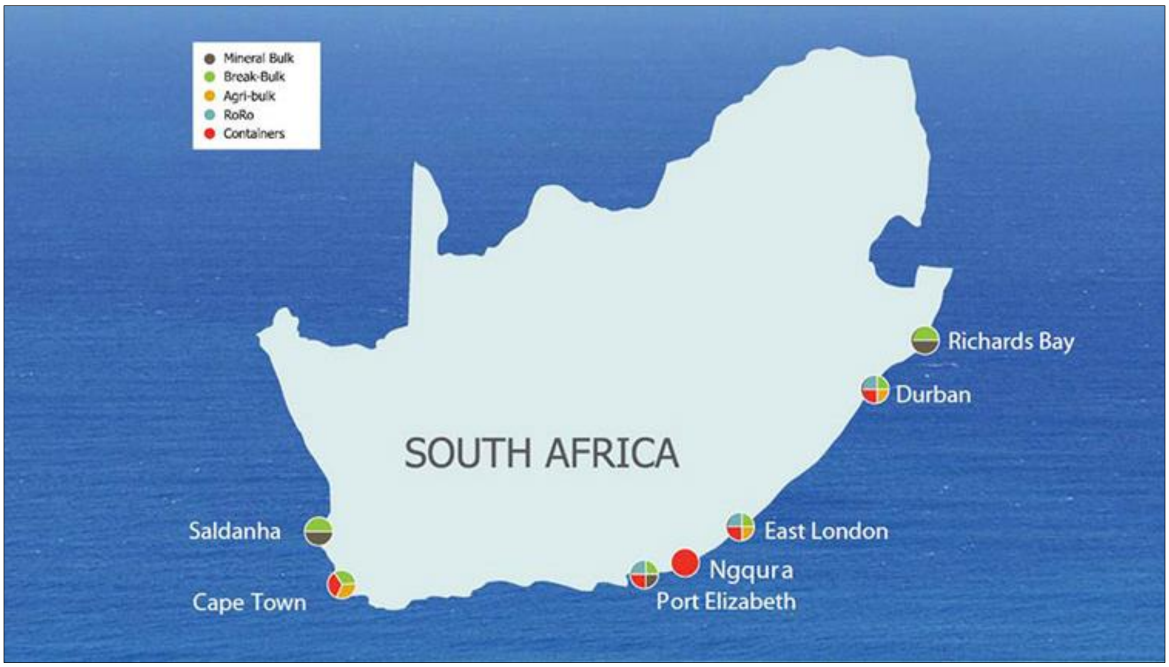

Figure 6: The seven ports in South Africa

Source: Transnet Port Terminals (2013)

In general, the export of minor dry bulk cargo from South Africa is encouraged by the existing demand of these commodities from numerous countries around the world. More specific to the data collected for this research, the focus of this case is pinpointed to the shipment of minor bulks to countries in the Mediterranean region, such as: Spain, France and Italy. There are many seaports in the region, each with individual port specificities and cargo demands. The ports geographically displayed in figure 7 represent the corresponding demand ports of the cargo parcel data collected from the ship operator. All ten ports are considered to be net importers of minor dry bulk commodities and will naturally be included in the experimental case formulation.

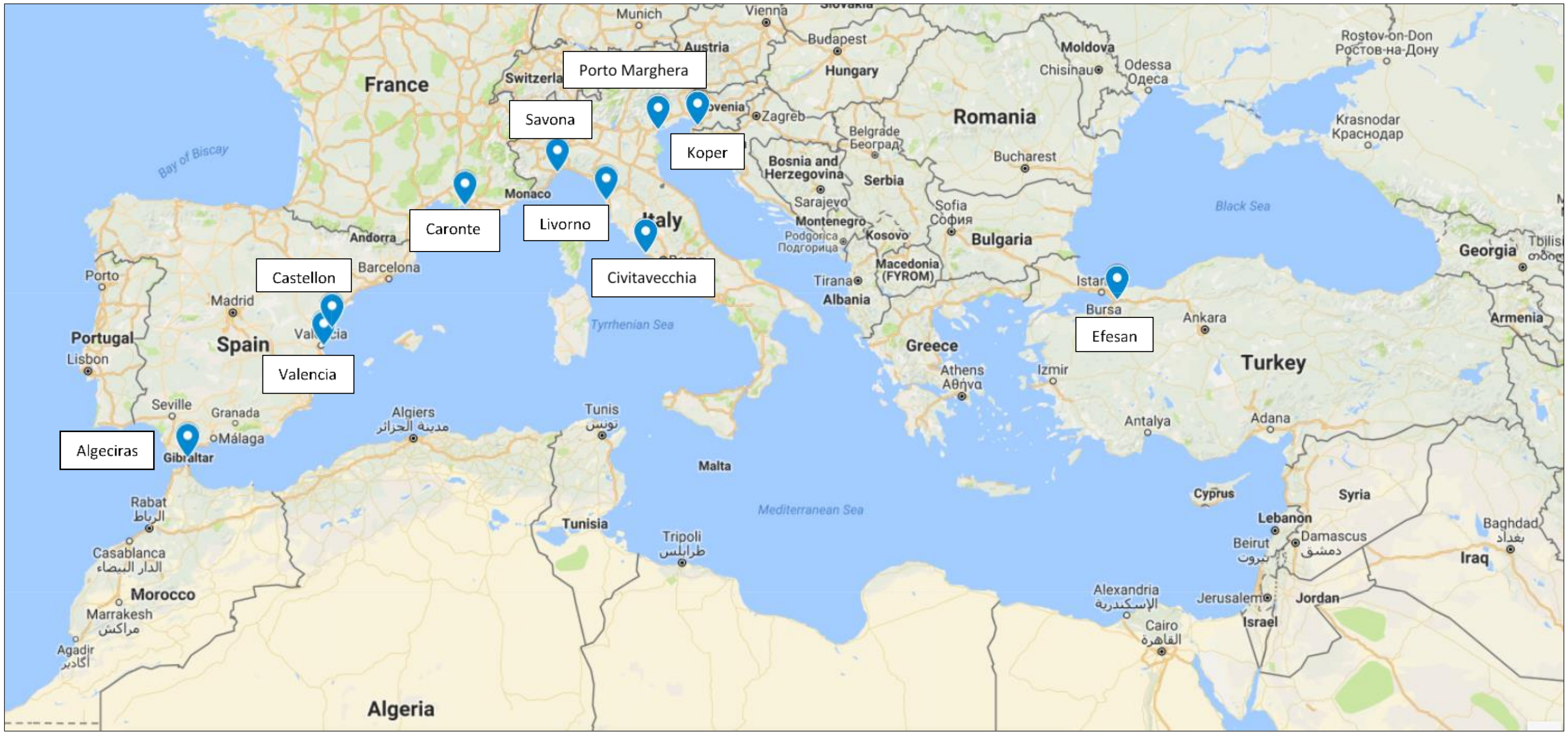

Figure 7: Demand ports located in the Mediterranean

Source: Author via Google Maps (2017)

1.2 *Research Question*

The identified problem can be addressed by solving the following main research question:

> *"How to determine the optimal revenue proceeds from selecting available cargo parcels and routing shipments of dry bulk commodities to multiple demand ports?"*

The main research question that will guide this study contains two core components. The research will firstly consider the possibility of combining less-than-shipload cargo parcels together in order to fully utilise the capacity of a vessel. The selection of available cargo parcels on the spot market is executed with the underlying objective of maximizing the revenue generating potential of the transportation. Secondly, the research will look into the most efficient routing of time chartered vessels from one port of loading to multiple discharge ports. Optimal ship routing presents an opportunity to limit the expense of bunker fuel oil by ensuring that the distance sailed is minimized. The methodological approach employed within this study is based on a SRP, an extension of the well-researched VRP.

The following sub-research questions will be answered in an attempt to establish a methodological approach for determining the optimal revenue proceeds:

> 1. "In what way can tramp ship operations be utilized in the transportation of dry bulk cargo parcels?"
> 2. "What is the most effective way of selecting profitable cargo parcels to be shipped together and routing the vessel to multiple discharge ports?"
> 3. "What are the possible benefits from proactively selecting spot cargo and efficiently routing vessels?"

The three sub-research questions will together assist in concluding the outcome of the main research question. The first question is based on a qualitative literature study. An analysis of available literature will allow the reader to gain an understanding of the topic and identify the gap in research, which this study is attempting to close. The last two questions are based on the outcome of the qualitative modelling of a unique SPR. The modelling of the problem has been completed with realistic, factual and reliable information.

The remainder of this research paper will be divided into four chapters and will be organized as follows. Chapter 2 will consist of the literature review and will subsequently answer the first sub-research question. The primary topics, which this paper is based upon will be investigated in the literature review, namely: shipping operations; charter options; less-than-shipload cargo transportation as well as the fundamental VRP and SRP. In procession, chapter 3 will include an overview of the problem and the methodological approach taken to deduce the research outcomes. The methodology section will comprise of a theoretical framework to describe the concepts and objectives behind the modelling, followed by the mathematical modelling of two individual but related SRPs. The third chapter aims to answer the second sub-research question. Chapter 4 will provide information related specifically to the case, which has been used as input data for the tests conducted. Numerous instance tests are described and the result for each test is incorporated into section 4.2.2. The results from the testing of the theoretical model will be used to answer the third sub-research question. Finally, the conclusions and limitations to the research are presented in chapter 5, together with recommendations for further research.

2. Literature Review

In this chapter, the existing theoretical literature will be reviewed to assess the available research conducted on the respected topics. Section 2.1 will briefly outline the three general modes of operation for shipping companies, with a particular focus on tramp operations and the interest thereof regarding the dry bulk market. Moreover, a detailed explanation of the various types of charter options and how time charters are applicable in the SRP modelling will be included in section 2.2. In addition, section 2.3 aims to outline the concept of less-than-shipload dry bulk cargo parcels and the relevance of full-shiploads in maritime transportation. Finally, section 2.4 addresses the current literature on VRP's and the relevant extension to SRP within the context of tramp operations. The concept of SRP will be further analysed in the modelling and testing of an SRP in chapters 3 and 4. In brief, chapter 2 will investigate the underlying theory of tramp shipping operations with the notion of simultaneously optimizing the routing of time chartered vessels to numerous ports to discharge multiple cargo parcels.

2.1 *Tramp Operations*

Maritime transportation can be split into three general modes of operation, namely: liner, industrial and tramp shipping (Lawrence, 1972). According to Ronen (1982), these modes of operation are not mutually exclusive as a vessel can be moved from one mode to another depending on the owners' preferential choice of operation and if desired, a ship operator can conduct business in all three modes at the same time. Despite the fact that these operational modes are not well defined, a comparison can be made to road transport operations to assist in distinguishing the differences between them.

To begin with, liner operations are often compared and elucidated to an organized bus line service, since these ships, as do busses, follow an itinerary with planned departure and arrival times (Ronen, 1982). Stopford (2009) defines a liner operation as a regular service with a fixed itinerary, and "the obligation to accept cargo from all comers and to sail, whether filled or not, on the date fixed by a published schedule." The success of liner shipping operations originated from the ability to reduce the cost of transportation between regions as well as port time with the unitization of cargo and the use of specialized handling equipment. Liner operations have received a great deal of attention over the last half-century, mainly due to two reasons; firstly, the cost benefits realised and secondly, large operators that dominate the container trade. It is inevitable that the power of these operators will increase due to the numerous mergers and acquisitions occurring within the container market sector. The recent reduction of market players has not yet assisted in achieving the liner operation's primary objective of maximizing profit, obliging the surviving companies to attempt to minimize costs in the hope of continuance; similar to industrial shipping.

Next, industrial operations are similar to the operation of a private truck fleet; where the owner of the cargo has full control over the fleet (Ronen, 1982). In a maritime context, shippers justify the ownership of a fleet of vessels when they require large quantities of cargo to be transported regularly to various cargo interested parties and don't want to expose themselves to uncertainty in the tramp market. Industrial operations are well-known in the trading of specialised commodities as well as when large, vertically integrated cargo owning companies dominate a trade. The objective of industrial operations remains the same; to satisfy the transportation requirements of a company's own cargo whilst minimizing cost and maximizing the use of the vessel. It is common for companies operating within this mode to under supply their continual underlying transportation demands, which implies that they rely on the chartering of alternative vessels on the tramp market to satisfy the fluctuating capacity obligations (Christiansen, *et al*., 2007).

Finally, it is common to compare tramp operations to a taxi-cab service (Ronen, 1982). In the last quarter century, there has been a gradual movement towards tramp shipping operations from industrial shipping. The main reason for this shift is that cargo owners are placing more emphasis on their primary business and outsourcing secondary business activities such as transportation, to third-party shipping companies (Christiansen, *et al*., 2004 and Bronmo, *et al*., 2007). The fairly recent importance of tramp shipping has jointly realised more research into the optimization of tramp operations (Moon, *et al*., 2015). A contributory factor towards the limited work done within this scope can be the large number of small operators that exist within the dry bulk tramp market, unlike the liner market (Ronen, 1982 and Christiansen, *et al*., 2004). Tramp ship operators will aim to maximize their profit by transporting mandatory cargoes in combination with spot market parcels.

Nowadays, tramp shipping represents the large majority of bulk cargo carried around the world (Banas, 2004). The tramp mode of operation can be characterised as an internationally competitive market with the challenge of unstable demand. Tramp shipping is notorious for its unpredictability and spot like utilisation, which goes hand in hand with the demand volatility common in the trading of dry bulk cargoes. The fundamental objective of a tramp operation is to maximise the profit potential of a vessel by carrying a combination of cargoes between ports (Christiansen, *et al*., 2004). By extension, Hemmati, *et al*. (2014), state that "tramp shipping companies try to increase revenue by transporting optional cargoes to maximize profits."

According to Hurd (1922), a spot market voyage consisted of carrying cargo between a point of surplus and a point of shortage. Furthermore, tramp operations are synonymous with vessels that are contracted on an ad hoc basis to transport cargo, usually a whole shipload volume, between two ports within an allocated period of time or alternatively, contracts are agreed upon to make several trips between loading and discharge ports (Gatica & Miranda, 2010). In the same respect, Lin & Liu (2011), claim most of the vessels involved in a tramp-style operation are classified as handysize-design and dry-bulk type, with deadweights ranging from 30 000 to 50 000 tons with a design sailing speed of 10 to 13 knots.

The cargo identified in tramp operations can be mandatory or spot cargoes that are flexible in size and are usually bulk cargo, both dry and liquid commodities (Gatica & Miranda, 2010). In accordance with the objective of tramp ship operations, the most profitable spot cargoes should be selected over and above the contracted cargo, in attempt to maximize the revenue earning capability of the voyage (Meng, *et al*., 2015). The most profitable cargoes are indicated partly by those with the highest freight rates, but one also needs to consider common destination ports to alleviate the penalty associated with visiting a new port for the discharge of individual cargo parcels. Ultimately, the main question that presides for tramp operators is, which spot cargo to transport and which to reject in order to optimize the company's objective.

2.2 *Charter Options*

The general modes of operation segregate the maritime industry; a further divide can be made when the charter options of vessels are considered. According to Lee & Kim (2015), chartered ships are costlier than company owned vessels; thus, they suggest only to charter a vessel when there is an opportunity to gain additional profits from cargo on the spot market. On the other hand, according to Clarksons Research (2004) and Stopford (2009), there are three reasons why chartering a vessel is appealing. Firstly, shippers may not want to become ship owners but require the use of a vessel. Secondly, charters can be less costly than buying a vessel, especially if the owner has a larger fleet of ships with low overhead costs. Thirdly, charterers may anticipate a change in the market, in which case, a shorter-term obligation is more attractive than a bare boat charter or financing a long-term investment, especially if the outlook is unfavourable for the charterer.

Conflicting views remain in different segments of the shipping industry with some fore and others against the idea of chartering a vessel instead of taking ownership. The perspective can change according to the charter option under consideration. The most common charter options are bare boat, time and voyage charters. The charter options can be partitioned according to the responsibility and costs incurred by the charterer and the owner of the vessel as well as the quantity, timing and physical characteristics of the cargo (Stopford, 2009).

Firstly, a bare boat charter requires the ship owner to make the necessary financing arrangements, while the charterer covers the voyage expenses and holds all operational responsibility for the vessel. A bare boat charter allows a ship operator to be in full operational and technical control of the vessel, usually for a period of ten to twenty years without the charterer being restrained to the capital costs of owning a ship (Clarksons Research, 2004). The revenue earned by the ship owner is dependent upon the hire rate of the ship and the duration of the charter (Stopford, 2009). For ship owners who have limited knowledge of the industry and prefer to act as investors with no active role in the operation of the vessel, a bare boat charter is the preferred choice (Clarksons Research, 2004).

Secondly, a time charter gives the charterer the use of the vessel, while the ownership and management remains with the ship owner. In this contract, the ship owner is responsible for providing the crew; remains the financier of the vessel and pays for the operational costs of the ship (Clarksons Research, 2004). On the contrary, the charterer covers the voyage expenses and additional voyage insurance (Boston Carriers, 2016). The ship owner receives remuneration based on the duration of the contract as mentioned by Stopford (2009). The length of a charter can vary. For a single trip voyage, the charter pays the owner a fee per day for the duration of the charter. On the other hand, when a period charter is taken for a period of months or years, the charterer can pay a monthly or yearly fee to the ship owner for the utilisation of the ship.

Time charter options usually have a shorter duration than the bare boat charters. Shorter charters are more favourable to a charterer who faces cargo demand volatility or pricing uncertainty and for this reason, ship owners admittedly charge a higher rate for time charters than they do for bare boat charters. Moreover, a time chartered tramp vessel can be routed to various ports during the contract, like with a bare boat charter and unlike a voyage charter. The difference is that with a bare boat charter, the charterer has more time to exploit the vessels capacity so efficient routing is not as imperative and with voyage charters, a vessel only sails between a single loading and discharge port. Under a time charter, the efficient routing from a single loading port to multiple discharge ports can assist in enlarging the profit earned from the charter. If the distance sailed between the ports is minimized, the fuel cost will be adequately reduced, allowing the voyage to generate more profit for the charterer.

Thirdly, voyage charters are useful for charterers who are interested only in paying a price per ton for the transportation of their cargo from one port to another (Clarksons Research, 2004). In this instance, the ship owner pays for the capital, operation and voyage expenses incurred during the voyage in return for a once off negotiated price (Stopford, 2009). For a ship owner, the voyage charter option is the most complex and requires a perpetual commercial focus because the ship management company needs to be able to constantly find cargo on a short-term basis at the final destination port of the previous charter. On the contrary, voyage charters are the least complex and most risk averse option for cargo owners and charterers.

2.3 *Less-than-Shipload Cargo*

It is common in the transportation of major dry bulk commodities for homogeneous cargo to be shipped in full shiploads. A great deal of research has been done regarding the concept of full shiploads where each ship carries at most one cargo at a time (Vilhelmsen, *et al*., 2013; Lee & Kim, 2015; Wen, *et al*., 2016; and Christiansen, 1999). Furthermore, the literature has included the use of homogeneous cargo into the settings of their investigative cases. Moreover, the cargo is usually loaded in one port and either discharged in a single port or in multiple ports. The full shipment approach is recommended for both dry and liquid bulks as a means of achieving scale economies. It is well established that economies of scale can be obtained by transporting a larger volume of cargo output, which results in a reduced cost per ton of cargo shipped for any ship owner and/or charterer.

In the mid-20th century, the transportation of liquid bulk experienced an introduction of specialised tankers in pursuit of shipping a range of cargo parcels, in separated tanks, onboard the same vessel. Such a parcel tanker is designed to carry small liquid bulk cargo lots with a focus on flexibility in operations and reducing cost. The majority of the literature surrounding parcel tankers attempts to solve the challenge of allocating cargo to tanks as well as the routing of ships to multiple delivery points. The tank allocation problem and extensions thereof are addressed in literature, among those the articles published by Hvattum, *et al*. (2009); Siswanto, *et al*. (2011) and Vilhelmsen, *et al*., (2013). Ultimately, it has been noted that the main advantage of using these vessels and by combining cargo lots together on a voyage, is the reduction in transportation cost per ton of cargo shipped with the presence of scale economies. In addition, these vessels provide the convenience of supplying refineries with various types of chemicals and oil from different sources, which assists to accommodate the fluctuations in demand for numerous products (H.P. Drewry, 1977).

Liquid bulk shipping companies such as Stolt-Nielsen and Odfjell popularized the specialised parcel tanker idea. Additionally, the concept of multiple cargo lots can also be possible in the transportation of dry bulk commodities. It has been suggested that although "dry bulk cargo is usually shipped in full shiploads, it is possible to aggregate smaller shiploads of cargo in a mixed load case (Hemmati, *et al*., 2014)." Parcel shipments occur when various commodities are placed on board the same vessel.

An insignificant amount of research has been done into the possibility of parcel shipments for minor dry bulks; whereby, cargo parcels can be united as a shipload and consequently benefit from scale economies. Fagerholt & Christiansen (2000), present the modelling of a multi-allocation problem, whereby a dry bulk vessel has flexible hold partitions to transport various dry bulk cargoes simultaneously. This notion allows smaller cargo parcels of minor bulks to take advantage of scale economies by being shipped together in a full shipload quantity. Moreover, Christiansen, *et al*. (2011), analyse a related case present in the cement industry. In this case, an inventory routing problem is assessed and each compartment of a ship can carry only one grade of cement.

Dry bulk carriers range in size and function as shown in figure 8; however, the cargo hold of the ship remains to be separated into several compartments and each compartment has a defined limiting capacity (Christiansen, *et al*., 2011). Generally, the entire ship is filled with homogeneous cargo; however, it is possible for multiple minor dry bulk cargo parcels to be loaded into the holds of a vessel and separated. When several different bulk cargoes are carried in a single ship and occupying part of a hold, it is traditionally referred to as a "tramping operation (Stopford, 2009)." The correct separation of individual cargo parcels is imperative to avoid the mixing of one shippers' cargo with another. Consequently, the combination of cargo parcels within a compartment, allows for the same benefits to be derived as with specialised parcel tankers.

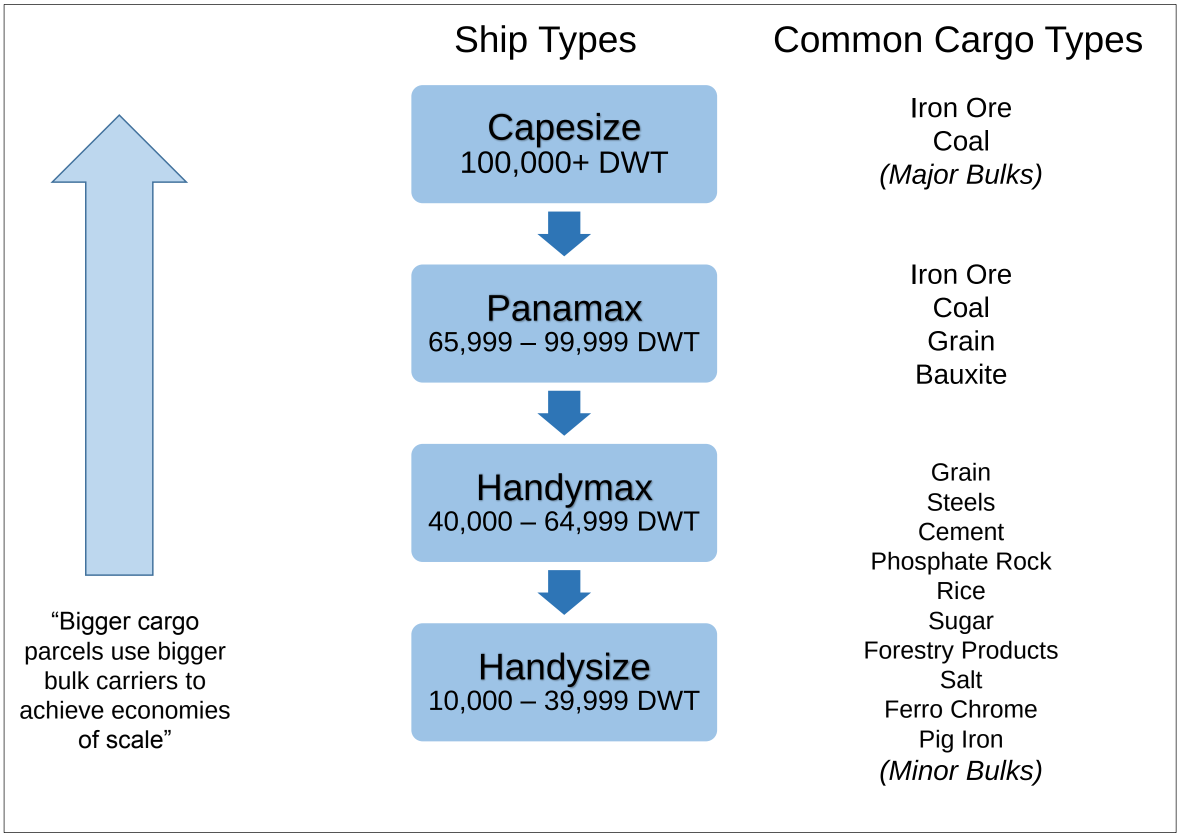

Figure 8: Dry bulk vessel size categories

Source: Author via Clarksons Research (2017c)

2.4 *Ship Routing Problems*

Considering the importance of the shipping industry on facilitating global trade, little applicable research has been published in the domain of tramp ship routing in comparison to the literature on vehicle routing. It has been mentioned by Laporte & Osman (1995) that “vehicle routing is one of the great success stories of operations research.” The improvement of operational processes, such as fleet routing, has facilitated an opportunity for cost reductions, which is applicable to both maritime and road transportation (Lee, *et al*., 2006).

Laporte & Osman (1995) suggest that a VRP can be used to determine a set of minimum cost vehicle routes starting and ending at the same position, whilst visiting each node exactly once. Toth & Vigo (2002), further insist that the solution of a VRP requires a set of routes, each performed by a single vehicle that starts and ends at its own depot, such that all customer requirements are met, all operational constraints are satisfied and all with the aim of minimizing the transportation cost. Similarly, a VRP can be defined as the efficient routing of vehicles with the objective of minimizing the operational cost of vehicles or the number of vehicles required (Romero, *et al*., 2013).

Many variations of the basic VRP have emerged, among others: capacitated and distance-constrained VRPs as well as VRPs with time windows, multiple depots, backhauls or combined pick-up and delivery issues (Toth & Vigo, 2002). However, the same three basic assumptions remain for each variation of VRP. Firstly, each vehicle leaves the depot, visits at least one customer and returns to the depot; each customer must be served. Secondly, each customer is served by only one vehicle. Thirdly, for a vehicle, the total demand of the customers on the pre-determined trip cannot exceed the capacity of a single vehicle, while the duration of the trip should be no more than the time limitation for a single trip (Sen & Bulbul, 2008 and Toth & Vigo, 2002).

There are basic similarities that exist between the modelling of VRPs and SRPs; nevertheless, major differences remain. In the view of Ronen (1982), there are five major differences between standard VRPs and SRPs. These differences are as follows: firstly, ships differ in their operating characteristics in particular, their capacity, and speed. Furthermore, the cyclical nature of the ship market, allows for two identical ships to have differing cost structures. Secondly, ships do not always return to the port of loading. Thirdly, the routing of ships is linked with high uncertainty as voyages are of longer duration and frequently occurring unforeseen events can delay ships arriving in port on time. Fourthly, the operation of a ship never stops, they need to be operated regardless of whether it is day or night, unlike road vehicles that are operated mostly during the day. The continuous operation of vessels leaves little buffer time to accommodate for delays. Lastly, the discharge port for ships may be altered during the sea leg of the voyage, depending on the requested location of the final consignee.

A comprehensive and founding review of the literature focused on vessel routing and scheduling can be found in the papers published originally by Ronen (1982 and 1993) and followed by Christiansen *et al*. (2004 and 2013). Ship routing is a specific kind of routing problem where vessels must be routed within the ocean geography (Romero, *et al*., 2013). In a maritime transportation context, routing can imply that a vessel must sail between two ports in order to minimize the effect of bad weather. However, for the most part, routing refers specifically to the arranged sequence of port calls for ships to follow so to minimize the distance sailed (Ronen, 1983). Most of the research published on ship routing has been conducted within the liner and industrial operations, not tramp. A typical tramp ship routing problem is described by Appelgren (1969 and 1971) in two of his articles that made a pioneering contribution to the literature on SRPs and act as the foundation upon which many other articles have been written. Appelgren's description can be summarized as contract cargo that must be shipped with the option of additional spot cargoes that can be transported by the fleet only when profitable. He continues to declare that ships in the fleet are not allowed to carry more than one cargo at a time.

According to Romero, *et al*., (2013), SRPs, regardless of what market the vessel operates in, include common features, more specifically: overnight trips; separated time windows; pre-specified routes are not always prevalent; and great uncertainty exists with time durations. The authors continue to describe four distinct characteristics of ship routing that are unique and inapplicable to VRP's. These characteristics can be summarized as: extended time horizons prevalent for decision making; the route sailed between two ports is not limited by accessible infrastructure; the route between ports must be carefully decided upon in accordance with the ships capability and existing limitations; and the traveling time between ports cannot be accurately predetermined due to the uncertainty of weather conditions at sea (Romero, *et al*., 2013).

Pre-eminent work exists in the literature surrounding SRPs. Ronen (1982), published a landmark study involving SRPs and ship scheduling. The main contribution from the work done by Ronen (1982) is the identification of the differences between VRPs and SRPs as well as a review of any existing ship routing, scheduling and related models. Ronen (1982), continues to highlight the benefits derived from improving ship routing and the importance of connecting ship routing and scheduling to fleet size and mix decisions. Since 1982, an extended collection of literature has been published about the combined problem of ship routing and scheduling.

The major decision in the majority of the literature concerning tramp ship routing and scheduling, is vessel scheduling. Current literature highlights the potential for improvements by optimizing fleet utilization, the shift from industrial to tramp shipping as well as the increased focus that prevails in the ship routing area of operations. More recently, a repeated review of the literature published in the new millennium was conducted by Christiansen, *et al*. (2013). This study draws attention to the quantity of work done regarding ship routing and scheduling within the last decade together with the complex problems accompanied by varied economic impacts that remain. Contributory aspects made by Christiansen, *et al*. (2004) and Christiansen, *et al*. (2013) to tramp and cargo routing literature has been included in this research.

Romero, *et al*. (2013), adopted the work done by Ronen (1982) and added to literature by identifying the unique characteristics of ship routing as well as present a GRASP algorithm to solve a SRP faced by salmon feed suppliers in Chile. Furthermore, Romero, *et al*. (2013) includes the possibility of split loads between vessels. Nevertheless, the ship routing aspects included in the works of Ronen (1982) and more recently Romero, *et al*. (2013), provide the basic literature upon which research in the field of VRPs and SRPs is based upon.

Tramp specific ship routing problems are addressed by, among others: Hemmati, *et al*. (2014); Meng, *et al*. (2015) and Wen, *et al*. (2016). The main contribution made to literature by Hemmati, *et al*. (2014), is the “range of realistic benchmark instances” for tramp ship cargo routing formulated by an instance generator. Furthermore, the objective in Meng, *et al*. (2015), is to maximize the overall profit by analysing the optimal routing decisions for tramp ships. The extension in Meng, *et al*. (2015), is the inclusion of the consideration regarding the most cost-effective ports to receive bunker fuel from. Moreover, the paper composed by Wen, *et al*. (2016), is written with the theme of full-shipload tramp ship routing, in the context of liquid bulk cargo. The authors consider varying ship sailing speeds and use a Branch-and-Price algorithm to solve a problem faced by a Danish shipping company. Admittedly, a vast range of literature concerning SRPs exists; mostly with the inclusion of ship scheduling and split loads.

In conclusion to the literature review of chapter two, this research will add to what has been published in the field of tramp, time chartered vessels. In particular, ship routing subsequent to the selection of spot market minor bulks. The research acknowledges Hemmati, *et al*. (2014) opinion that tramp operations strive to maximize their profits by transporting additional optional cargoes as the problem assesses the selection of spot cargo parcels. On the other hand, the research differs from Appelgren (1969 and 1971) and Gatica & Miranda (2010) as the problem considers the possibility that multiple parcels can be transported in the same hold compartment; the loading plan is not restricted to a fill-shipload volume of one cargo commodity. Furthermore, this research aims to add to what has been presented by Fagerholt & Christiansen (2000) with the idea of transporting various dry bulk cargoes simultaneously without the consideration of split loads (Romero *et al*., 2013) and ship scheduling (Christiansen, *et al*., 2004 and 2013). However, this problem will include fixed hold partitions similar to that included in Christiansen, *et al*. (2011). Moreover, this research will add to the optimal routing idea fundamental to Meng, *et al*. (2015), with the inclusion of cargo parcel selection and without bunker fuel cost considerations.

3. Problem Description and Methodology

The problem addressed in this research paper was identified in section 1.1, subsequent to the background information suitable to the research. Chapter 2 reviewed the applicable existing literature concerning the relevant topics mentioned in chapter 1. Moreover, chapter 3 will consider the information provided in the previous two chapters and progress with the methodology aimed at finding a solution to the problem. To begin with, an overview of the problem will be stated in section 3.1. Next, section 3.2 will present the methodology behind the simple and extended problems.

3.1 *Problem Overview and Details*

This section of the paper provides an overview of the problem, an extension from the identification in section 1.1. The problem is addressed by a theoretical model which aims to maximize profit, whilst concurrently performing two planning decisions, namely: the selection of spot parcels of minor bulk cargo and the optimal routing of a tramp-operated, time chartered vessel. Furthermore, this research problem is comparable to that addressed by Christiansen, *et al*. (2011) regarding the routing of vessels; however, it differs regarding the type of cargo transported. Christiansen, *et al*. (2011), model a cargo problem where the hold compartment partitions are movable and no two cement grades can be transported in the same hold. In contrast, this research problem considers fixed hold compartments, in line with the more modern bulk carriers and various parcels can be loaded within one compartment and remain separated from one another by separation sheets. In short, the problem assesses a variant of a SRP with similar objectives to the literature available regarding tramp shipping operations.

The problem addressed in this research is related to not only ship operators with no desire to own vessels, but also to ship owning companies with active commercial functions. In recent years, the dry bulk shipping industry has experienced major losses stemming from the over-ordering of new builds during the more prosperous times from the end of 2006 to the beginning of 2008, in particular. These favourable months were a result primarily of the undersupply of bulk carriers and secondly the high freight rates offered for the transportation of dry bulk cargo. The flood of dry bulk tonnage into the market at the end of 2009 and the beginning of 2010 presented an oversupply of ships and a subsequent increase in the deficit faced by companies operating in the industry. The market has still not yet fully recovered to peaks experienced approximately a decade ago.

This problem attempts to find a way to recover the losses incurred by various ship operators in the dry bulk industry. For ship owners, their company-owned vessels may currently be stuck in long term contracts and earning a low daily charter rate, which may not cover the operational cost of the vessel. The daily losses incurred by ship-owning companies prompts a solution to recover part of the deficit by chartering a supplementary vessel. In the same way asset-free ship operators' time charter vessels for their benefit, ship-owning companies can do the same.

A favourable opportunity arises to time charter a handysize bulk carrier at a low daily charter rate, with no long term obligation and to fill the vessel with cargo available on the spot market. The accumulation of minor bulk cargo parcels of less-than-shipload quantity and varying freight rates can prompt the chance of a profitable shipment for the charterer. An important decision to consider is the selection of spot cargo parcels. Essentially, parcels with the highest freight rates must be selected for the shipment to ensure the revenue received covers the total cost of the vessel.

It is accepted that by filling a vessel with cargo, scale economies assist to reduce the cost per ton of cargo transported (Stopford, 2009). For this reason, it is imperative that the combined weight of all the parcels is equal to or just less than the total carrying capacity of the chartered bulk carrier. Moreover, to further assist in reducing the cost incurred by the charterer, a ship routing sub-problem must be addressed. The solution of the problem must present a route whereby the vessel visits each demand port once with the shortest sailing distance. By minimizing the sailing distance, the vessel will consume the least amount of bunker fuel oil. Currently, it is possible to purchase bunker suppliers at suppressed rates, which has slightly reduced the attributable percentage of bunker oil cost to the total cost of a time charter. However, a history of the bunker index indicates that from 2010 to the beginning of 2015, inflated crude oil prices were experienced, which resulted in the introduction of slow steaming in an attempt to reduce the fuel oil cost, an expense to time charterers and ship owners alike.

To model the research problem accurately, the theoretical model must address the decision regarding cargo selection as well as the sub-problem of ship routing. The results from the testing of the model will reveal whether the mathematical model accurately selects the previously known cargo parcels with the highest rates to fill the carrying capacity of the chartered vessel and subsequently solves the SRP with a feasible solution.

Additionally, the mathematical modelling of this revenue maximisation and SRP requires a number of underlying assumptions that are applicable. The following basic conceptual details are included in the modelling and pertain to the vessel itself, the loading and discharging ports as well as the cargo. These three detail categories can be considered as assumptions for the modelling of both the basic and extended version of the SRP included in the modelling of this paper.

The first detail category is associated with the vessel itself. The details unique to the vessel used should be known beforehand and the option to time charter the vessel for the time period duration of the voyage should be exercised. The charter rate at which a vessel is leased, varies in accordance with the current supply and demand in the market. The time charter option allows the vessel to sail to multiple ports during a single voyage in accordance with the cargo requirements. It must be noted that in practice when the time charter duration is complete, the charterer is not obliged to cover the ship's cost of sailing back to the port of origin. It is common for the ship owner to take over the operational control of the vessel subsequent to the last discharge port call, unless otherwise agreed upon by both the charterer and ship owner.

Furthermore, the ship is available and empty upon arrival at the single port of loading with all empty hold compartments cleaned and in a condition ready for loading. There are five hold compartments onboard the handysize vessel and each undedicated hold is fixed with an individual cargo carrying capacity limitation. During the sea voyage, the vessel sails at constant design speed and in one trip, the ship can visit more than one unloading port when the capacity of the ship is greater than the amount of cargo to be delivered at a single discharge port.

The second detail category is associated with the loading and discharge ports. The single loading port and multiple discharge ports should be able to receive ships of any deadweight tonnage; thus, have the ability to accommodate the draft of a fully-laden handysize vessel. Both the loading and discharge ports can jointly service more than one vessel at the same time and are presented as nodes in the transport network. Although, in reality, loading and discharge ports can be burdened with varying delays for ships at anchorage in anticipation to enter the port; the timing aspect associated to port calls will not be included in the mathematical modelling; however, a fixed delay period will be included in the case.

The third detail category is associated with the cargo. The information specific to each optional minor bulk cargo parcel must be known beforehand and used as an input to the model. It is assumed that all parcels are available at the port of loading. It is accepted that the ship can carry multiple cargoes; however, due to the nature of the cargo contracts, no two cargoes can be transported in the same cargo hold simultaneously without being separated by separation sheets and it must be considered that the combined weight of the parcels loading in a single hold must not exceed the maximum allowable hold weight. The cargo parcels are categorized as minor bulks and the individual parcel quantities are less-than-shipload. It remains that the most profitable cargo parcels, with the highest freight rates, must be selected by the model. The shipment of less-than-shipload parcels can offer slightly inflated freight rates from shippers due to the opportunity cost of chartering a vessel, in its entirety to ship the cargo.

In addition, if the model were to be extended and more than one vessel is considered, the most profitable cargoes, with the highest freight rates must remain to be selected. However, an additional consideration must be included; the cargo destined for the same port must be placed on the same vessel and at the same time, the cargo parcels selected must be in line with the selection of demand ports covered in the routing. The combining of cargoes according to common discharge ports so to ensure greater efficiency with the routing of ships and to avoid the cost of paying repetitive port dues. Lastly, it is assumed that all cargo is unloaded following the final port of discharge and at the end of the time charter agreement.

3.2 *Methodology*

The methodology section of this paper will comprise of two sections. The first part of section 3.2 will provide a theoretical understanding to the SRP models with details about both the simple and extended versions of the model. The second part of section 3.2 will express the mathematical components used in the formation of the SRP model. Each model will be followed by an explanation of the objective function, unique decision variables as well as the prevailing constraint equations. The material presented in this section of the paper stands as the foundation upon which chapter 4 is built upon.

3.2.1 *Theoretical Foundation*

The theoretical model outlined in this section of the paper considers one dry bulk handysize vessel, sailing from Richards Bay, in South Africa to the Mediterranean. The two part problem faced is the selection of spot market minor bulk parcels together with the selection of a route so to ensure the vessel sails the shortest distance between ports. The model is required to optimize both parts of the problem concurrently. The approach used to find a solution to the problem will include certain aspects as input from the well-known VRP and subsequent SRP as well as research conducted on cargo selection.

The mathematical modelling in this research paper includes a variant of a SRP, which is considered as an extended VRP. Many commonalities exist between VRPs and SRPs as noted in section 2.4; however, the model particulars are specific to SRPs. The model contains nodes within the ship routing network design. Each node represents the individual supply and multiple demand ports. This SRP specifically contains one loading port with multiple discharge ports.

The arcs between the port nodes demonstrate the directional sailing movement of the vessel. Moreover, the vessel is not obliged to sail back to the port of origin, more specifically the port of Richards Bay. However, the model is required to route the vessel to every port, at least once, which will include a retour back to the loading port. Therefore, the model is set to deal with this omission by ignoring the distance of the arc from the last port of discharge back to the original loading port of Richards Bay in the total sailing distance summation. The exclusion of this sailing distance is attributable to the nature of a time chartered vessel.

The mathematical model formulation of a basic SRP commenced with the exclusive consideration of vessel routing. The aim of the initial model is to minimize the distance sailed by effectively routing a vessel. The idea behind the objective stems from the concept that by minimizing the distance sailed, the charterer can limit the quantity of bunker fuel oil consumed during the voyage. According to Vilhelmsen *et al*. (2013), fuel costs make up a large portion of daily operating costs." For a time charter, the fuel costs are covered by the charterer. Furthermore, Meng, *et al*. (2015), suggest bunker costs can amount to more than 50 per cent of the total cost for a tramp shipping company.

The model was then extended to also include the selection of cargo parcels. The objective of the improved model version is to maximize the profit obtainable from the shipment of minor bulk parcels by deducting the total cost of the charter from the freight rate revenue receivable. The aim of the extended model is prevalent in the tramp shipping industry; whereby spot cargoes are transported in addition to mandatory cargo in order to maximize the profit earned from a shipment.

In preparation for the mathematical modelling in section 3.2.2 it must be noted that both the basic and extended models consider a single vessel problem; however, the notation is for multiple vessels signaled by the inclusion of variable k, which means the theoretical model is not one and the same as the modelling of the verifiable case. The use of more than one vessel will require an adjustment to existing and the addition of more constraints to ensure the model achieves the objective. In addition, the issue of sub-cycles should be considered in both version of the model. The existence of sub-cycles is an issue in VRPs as it avoids the result of an optimal route between nodes in a network. The consequence of a sub-cycle is that the outcome of the model indicates vehicles must be routed in an individual loop formation between sets of nodes; for example, one demand node may be visited twice in the same route. The accurate routing of the vehicle would be to all demand nodes exactly once before the return to the supply node. In light of this issue, in the formation of the SRP variants, an assumption was included that only vessels leaving a node can arrive at that same node in the network to avoid the occurrence of sub-cycles.

Besides the aforementioned features of the model, one must be aware that the model includes a multidimensional cost structure. The costs incurred are divided into two parts; the expense incurred during the sailing time of the voyage and the cost associated the vessels port call. Both these cost dimensions are partly dependent upon time; however, calculated slightly differently. Firstly, the voyage cost calculation is based on the sailing distance between ports divided by the sailing distance achievable in a day at a sailing speed of 14 knots to get an approximate number of sailing days. The number of days is then multiplied by both a daily charter rate and a bunker fuel cost, separately. The summation of these costs results in a voyage cost appropriate for the inclusion into the model. Secondly, the port call expense is made up of two parts, a fixed and variable component. The fixed cost is associated with the cost of the actual port call, usually billed by the port authority and it encompasses the use of the berth and any other service costs. Additionally, the variable part of the port call cost is based on the efficiency of the operations in the respectable ports, which is determined by the cargo loading and discharge rates together with an average number of delay days likely to be experienced before entering the port. To summarize, a charterer needs to consider both the voyage and port costs, which both need to be deducted from the freight rate revenue to calculate the attainable profit from the shipment.

3.2.2 ***Mathematical Modelling***

The mathematical modelling of the simple SRP in model one was contrived first and is presented as the groundwork for the extended SRP in model two. The mathematics included in both linear programming models contain similar parameters and notation. The general mathematical notation begins with the objective function of the model. The primary objective embodied in model one is to minimize the distance sailed, which is considered as the starting point for the subsequent profit maximization objective in model two.

The mathematical model begins with a series of nodes and arcs connecting the nodes, which hereafter will be referred to as the transport network V. The arcs between the nodes in the transport network are indexed by both i and j; in the notation (i, j) for every node i and j. The node indexed by $i = 1, 2, 3, \dots I$ represents the port where the vessel is departing from or where the arc commences. Furthermore, the node indexed by $j = 1, 2, 3, \dots J$ represents the port where the vessel is arriving at or where the arc ends. For nodes j, the likely demand ports, the cargo parcels demanded are indicated by $n = 1, 2, 3, \dots N$. The single vessel used to transport cargo between ports and included in the modelling is indexed by k and the total carrying capacity of vessel k is represented by q_k. Each arc (i, j, k) within the network, represents the cargo shipped from node $n(i)$ to node $n(j)$ by vessel k.

There are two main decision variables that are present in either one of or in both the mathematical modelling of models one and two. Both of these decision variables are considered to be binary in nature, meaning they can only take on the values of 0 or 1. The optimum value of these decision variables is determined by solving the models.

X_{ijk} The first decision variable, X_{ijk} is a binary variable and indicates whether the arc (i, j, k) between port i and port j is sailed upon by vessel k or not.

X_{ijk} = 1 If arc (i, j, k) is selected as part of the solution and 0 otherwise.

If x_{ijk} = 1 then arc (i, j, k) is selected, which implies that ship k will serve node i with d_i and will serve node j with d_j immediately afterwards.

Z_n The second decision variable, Z_n represents the decision of whether the cargo parcel n is selected to be shipped or not. The selection function of this decision variable with one of two outcomes allows Z_n to also be considered a binary variable.

$Z_n = 1$ If the cargo parcel n is selected to be shipped and 0 otherwise

The extended mathematical model includes an additional binary variable over and above the aforementioned two, which can also only take on the value of 0 or 1. The inclusion of the third variable is to ensure that a cargo parcel n is only loaded onto the vessel when the demand port j is included in the route that the vessel is set to sail.

$P_{nj} = 1$ If δ_{nj} = 1 for any j and 0 otherwise

Furthermore, included in the modelling of either one of or both the simple and extended SRPs are eight parameters. These parameters represent input information provided in the model and shall be distinctly defined for the purpose of clarity.

S_{ijk} The first parameter represents the distances between nodes in the network V and is represented by S_{ijk}. The distance between ports is directly proportional to the amount of fuel consumed by vessel k whilst sailing along the specified route. This parameter is used only in the simple SRP model.

R_n The second parameter, concerning the cargo selection, is represented by R_n and can be explained as the freight rate revenue earned from cargo parcel n.

δ_{nj} The third parameter is included to ensure that ship k visits port j, which is the recipient port of cargo parcel n. Furthermore, the δ_{nj} parameter is considered to be binary in nature because if the cargo parcel n is selected to be transported to port j then a 1 will be reflected in the model and 0 otherwise.

Q_n The fourth parameter to be considered in the model is the demanded quantity at the discharge ports. The known demanded quantity is represented by Q_n and is an indicator of the quantity of cargo of parcel n.

C_{ij}^{V} The fifth parameter, a representation of C^{Voyage}, is an indicator of voyage cost per arc. The voyage cost is made up partly by a bunker cost and partly by a fixed daily charter rate. Moreover, the voyage cost is incurred whilst the vessel is sailing at sea and is represented as a rate cost per nautical mile.

C^{P} The sixth parameter, a representation of C^{Port}, is an indicator of the port cost per ton of cargo discharged. Similarly, the port cost is made up partly by a bunker cost and partly by a fixed daily charter rate. Moreover, the port cost is incurred whilst the vessel is in port and is represented as a rate cost per ton of cargo discharged.

D_{ijk} The seventh parameter represents port due expense. Port dues are a fixed cost payable per port call and are only incurred when the vessel k enters a demand port j.

$\frac{1}{e_j}$ The eighth parameter is included into the objective function of the extended model and is a representation of the loading or discharge rate at port j.

The mathematical formulation of the initial distance minimization model one, a simple single-vessel SRP, without the inclusion of revenue optimisation, can be listed and explained as follows:

Equation 1

$$min \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} S_{ijk} X_{ijk}$$

Subject to the functional constraints:

Equation 2

$$\sum_{j \in V} X_{ijk} - \sum_{j \in V} X_{jik} = 0 \qquad \forall i \in V, k \in K$$

Equation 3

$$X_{ijk} + X_{jik} \leq 1 \qquad \forall i \in V, \forall j \in V, k \in K$$

Equation 4

$$\sum_{j \in V} X_{ijk} = 1 \qquad \forall i \in V', k \in K$$

Equation 5

$$\sum_{j \in V} d_j \sum_{j \in V} X_{jik} \leq q_k \qquad \forall i \in V$$

Equation 6

$$X_{ijk} \in \{0,1\}$$

The objective function stated in equation 1, states that the aim of the model, which is to minimise the distance sailed between a single loading port and multiple discharge ports. The equations that follow, from 2 to 6 are all considered constraint equations. To continue, equation 2 denotes that each port within the network must contain one incoming and one outgoing arc. If each outgoing arc is deducted from the incoming arc for that node, the result will be 0. In other words, this arc constraint ensures that the vessel must enter the port and once the cargo is discharged, the same vessel must leave the port. Equation 3 is included in an attempt to avoid the possibility of sub-cycles occurring. During a planned voyage, vessels must not be routed to the same port twice in the voyage. Moreover, the avoidance of sub-cycles and effective routing is motivated by two reasons: firstly, to exclude the cost of an additional port call and the consumption of extra bunker fuel and secondly, a saving in the total charter rate by reducing the time duration of the charter contract. Equation 4 ensures that each node in the network is visited exactly once during the period of the time charter. Without the inclusion of equation 4, the model would find a minimum objective function of 0; initiating that no distance is sailed and therefore, no cargo is shipped, which is not the desired outcome. Finally, equation 5 guarantees that the quantity of cargo loaded on board does not exceed the total carry capacity of the vessel. Equation 6 is a binary constraint, which is limited to a value of 1 or 0 depending on if the arc between port i and port j is sailed by vessel k or not

The mathematical formulation of model two is an extension of the single-vessel SRP presented in model one, now with the inclusion of revenue optimisation. The more recently established details of model two can be listed and explained as follows:

Equation 7

$$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C_{ij}^{V} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \ \delta_{nj} Q_n \frac{1}{e_j} C^P$$

Subject to the functional constraints:

Equation 8

$$\sum_{j \in V} X_{ijk} - \sum_{j \in V} X_{jik} = 0 \qquad \forall i \in V, k \in K$$

Equation 9

$$X_{ijk} + X_{jik} \leq 1 \qquad \forall i \in V, \forall j \in V, k \in K$$

Equation 10

$$\sum_{j \in V} \sum_{k \in K} X_{ijk} = k \; if \; i = 1$$

Equation 11

$$M \sum_{i \in V} \sum_{k \in K} X_{ijk} \geq \sum_{n} Z_n \; \delta_{nj} \qquad \forall j \in V$$

Equation 12

$$\sum_{k \in K} \sum_{n} Z_n Q_n \leq q_k \qquad k \in K$$

Equation 13

$$\sum_{j \in V} P_{nj} \geq Z_n \qquad \forall j \in V$$

Equation 14

$$X_{ijk}, Z_n \in \{0, 1\}$$

The primary objective function of the extended model, stated in equation 7, is to maximize the profit earned in the spot shipping market whilst minimizing the routing distance between a single supply port and multiple demand ports. The objective function consists of three terms. The first term reflects the revenue earned from shipping the selected cargo. The second term reflects part of the cost element incurred for the shipment; the voyage cost is a function of the distance sailed and the sailing distance between selected ports. A fixed port call expense for the selected ports is added to the voyage cost. The third term in the objective function reflects another part of the cost element, which is incurred whilst the vessel is discharging cargo in port j. The costs are deducted from the revenue term to indicate the proceeds gained from the shipment, by the charterer. The objective of the model is subject to various constraints. These constraints can be divided into vessel specific and cargo concerning constraints, which will be expanded on in the rest of this section.

Firstly, the network design and vessel flow constraints. Equation 8, is identical to equation 2 and ensures that there must be a balance of flows; therefore, for each discharge port that is visited one incoming and one outgoing arc must be present, indicating that the same vessel k must sail into and out of the chosen port. Equation 9 is identical to equation 3 and is present to avoid the occurrence of vessel k being routing back to a port to which it has already discharged cargo. The constraint does not yet completely avoid sub-cycles from forming; nevertheless, it will be tested and checked in all experiment variations of the case. Equation 10 requires that each vessel k must sail from the loading port ($i = 1$ for the loading port). Equation 11 guarantees that a port must only be visited if a cargo parcel, destined for that port is selected to be shipped on vessel k. The variable M is a sufficiently large positive number, most commonly used in the big M method of finding an optimal solution for linear programming problems. The big M variable is added to the constraint equation to ensure that the product of variables X_{ijk} and M remains to be larger than the summation of the product $Z_n\delta_{nj}$ if a port is visited.

Secondly, the loading and unloading cargo constraints. Constraint equation 12 prevents the vessel from being overloaded. Similar to equation 5, the total carrying capacity of a single vessel cannot be exceeded by the combined quantity of cargo parcels loaded onboard. This limiting constraint equation only works for single vessel modelling as the exact carrying capacity of one vessel can be loaded into the model. If the equation 12 is used for multiple vessels then the equation will fail to check that the total carry capacity for individual vessels is not exceeded. Constraint equation 13 is included to ensure that no cargo parcel is chosen to be loaded on the vessel, if the corresponding demand port is not included on the sailing route of vessel k.

Equation 14 contains two binary constraints that are related to the network design and vessel flow constraints. The first variable refers to if an arc is sailed on between port i and port j with ship k then the variable will be 1 and 0 otherwise. The second variable of the equation results in a 1 when the cargo parcel n is selected to be shipped and 0 otherwise.

3.2.3 *General Limitations of the Model*

Both the simple and extended models consider an index of k to represent the vessel chartered to carry out the shipment. However, the model only includes one vessel into the cargo parcel selection and routing decisions. The reason why the model considers k vessels but is only used for one, is that there is an opportunity to further extend the model and to include all the vessels in a company-owned fleet. The constraints specific to each model were formulated for a single chartered vessel; therefore, if the scope is extended to include more than one vessel, a verification of the function of each constraint equations must be executed.

4. Modelling of the experiment

In chapter 4, we use the theoretical model described in chapter 3 and develop an experimental case of a real-life problem experienced by a shipping company established in South Africa. This chapter will pursue to answer the second sub-research question stated in section 1.2. Furthermore, chapter 4 deals primarily with satisfying the objective function of the mathematical model with case specific inputs. Section 4.1 will make use of the introductory background information described in chapter 1 and further provide the assumptions used and the case specifics as inputs into the model. Moreover, section 4.1 will be broken down into six sub-sections; namely: the model details pertaining to the setting of the experiment; the vessel; bunker fuel oil; cargo parcel characteristics; the ports and finally, the voyage and port cost calculations. Section 4.2 incorporates the information from section 4.1 and provides the testing of different instances. Section 4.2.1 provides a description of and tabulates each case instance tested. The testing of different instances is used to examine the feasibility and sensitivity of the theoretical model. The results of the various computational tested instances are mentioned in section 4.2.2. In addition, noteworthy insights and significant results will be described in detail.

4.1. Experiment Case Specifics

The presented opportunity to ship less-than-shipload cargo parcels from a single loading port in South Africa to multiple discharge ports in the Mediterranean region provides the basis of the experimental case. Specific data gathered and included in the case settings was gathered from three experts who are affiliated with the South African based shipping company and who handle cargo parcel shipments on a daily basis. The sources provided information related specifically to the company as well as information available to all companies operating in this niche parcel service market. Actual data relating specifically to the case together with realistic assumptions have been included in the settings of the experiment to accomplish a valid and reliable result. Empirical and estimated data together with preceding calculated values will be divided into six sub-sections and together serve as the necessary knowledge to fully understand the experimental input settings.

4.1.1 *Developing the Experimental Case*

The first topic that will be addressed in section 4.1 is the development of the case. The settings and solutions to the case, focused upon in this research paper, was completed using an add-in function to Microsoft Excel. OpenSolver, is an "open source linear, integer and non-linear optimizer" that enhances the power of Microsoft Excel's built-in Solver (OpenSolver for Excel, 2017). The development of the case can be carried out using another optimization platform; however, a screenshot diagram of results of the Microsoft Excel case construction is included in appendices 2 to 6. The illustrations clearly display the objective function, one decision variable and the costs as is explained in chapter 3.

4.1.2 *The Vessel*

The second topic that will be addressed in section 4.1 relates to the vessel itself. The vessel type used as an input dimension to the computational testing of the experiment, is a handysize bulk carrier. What is certain is that a handysize vessel has five undedicated hold compartments, which can simultaneously hold a number of different products. Although the categories for vessel size dimensions is not concrete, a handysize vessel can be classified as having a deadweight tonnage of between 10,000 and 40,000 tonnes (Clarksons Research, 2017b). To remain genuine and in line with reality, the exact dimensions of the handysize bulk carrier MV Louisa Bolten are included in the setting of the case. The MV Louisa Bolten was in fact one of the vessels chartered by the South African based shipping company to transport minor bulk parcels. Furthermore, the single-deck bulk carrier vessel was built in 2009 and has a deadweight tonnage of 30,800 tonnes with fixed hold compartments (August Bolten William Miller's Nachfolger, 2017). Consequently, the carrying capacity of the MV Louisa Bolten is the most important dimension to include in the case as this is a limiting factor to the number and volume of cargo parcels that can be selected to be loaded.

The use of the handysize vessel is mainly due to its accessibility into most global seaports; including the port of Richards Bay and all the known demand ports in the Mediterranean region. Furthermore, handysize vessels are versatile, efficient in operation, more flexible than vessels of larger tonnage and it is recognised that this size vessel can carry several different cargoes in various cargo hold compartments to be delivered to various ports (Boston Carriers, 2016). Admittedly, the advantages of handysize vessels are aligned with cargo parcel transportation and discharge port draft requirements; thus, for these reasons, a handysize vessel is utilised in the case.

More specifically, the case considers the MV Louisa Bolten to be a time chartered handysize vessel operating in the tramp market, at an average daily charter rate of $7000, in line with what was mentioned in the introduction section of this paper (International Seaborne Market, 2017a). The time charter option allows the ship to sail to multiple ports, which is aligned with the required outcome of shipping multiple cargoes parcels to their individual discharge ports. Once the charterer has completed the contractual obligations stipulated in the charter contract, the operation and expense of the vessel is returned to the ship owner. Secondly, tramp vessels can be used to service both contract and spot market cargo; however, in this experiment, only realistic minor bulk cargo options available on the spot market will be focused upon.

4.1.3 *Bunker Fuel Oil*

The third foundation element to consider in the experimental case is the inclusion of the cost of bunker fuel oil. The fuel oil received in the port of Richards Bay must comply with the International Convention for the Prevention of Pollution from Ships (MARPOL), under the regulations of the International Maritime Organization (IMO) as well as the European Union (EU) Directive 2016/802. The compliance is enforced because the discharge ports in the investigated case are located in the Mediterranean Sea, which has been classified as an emission controlled area (ECA), as shown in figure 9 (Jacques, 2015). In January 2010, "a 0.1 per cent maximum sulphur requirement for fuel used by ships at berth and anchorage in EU ports was introduced (European Maritime safety Agency, 2017)."

The sulphur limitation for ports in the EU came into effect in January 2015, ensuring that vessels sailing into the Mediterranean must use low sulphur fuel oil (LSFO) (Maritime

Cyprus Admin, 2014). To guarantee compliance with the requirement; the fuel oil included in the setting of the case is intermediate fuel oil (IFO) 180, a LSFO "with a mix of 88 per cent of residual oil and 12 per cent of distillate oil (Rozmarynowska & Oldakowski, 2012)." The details regarding the MV Louisa Bolten stipulate that the vessel consumes IFO 380 (August Bolten William Miller's Nachfolger, 2017). However, it can be assumed in this investigated case that the vessel consumes the same about of IFO 180 as it is noted with IFO 380. If in the future, the Mediterranean Sea region becomes a sulphur emission controlled area (SECA) from an ECA or if the IMO global sulphur emission limitations change in 2020 as predicted; the bunker fuel oil requirements and calculations included in the setting of this case should be reassessed.

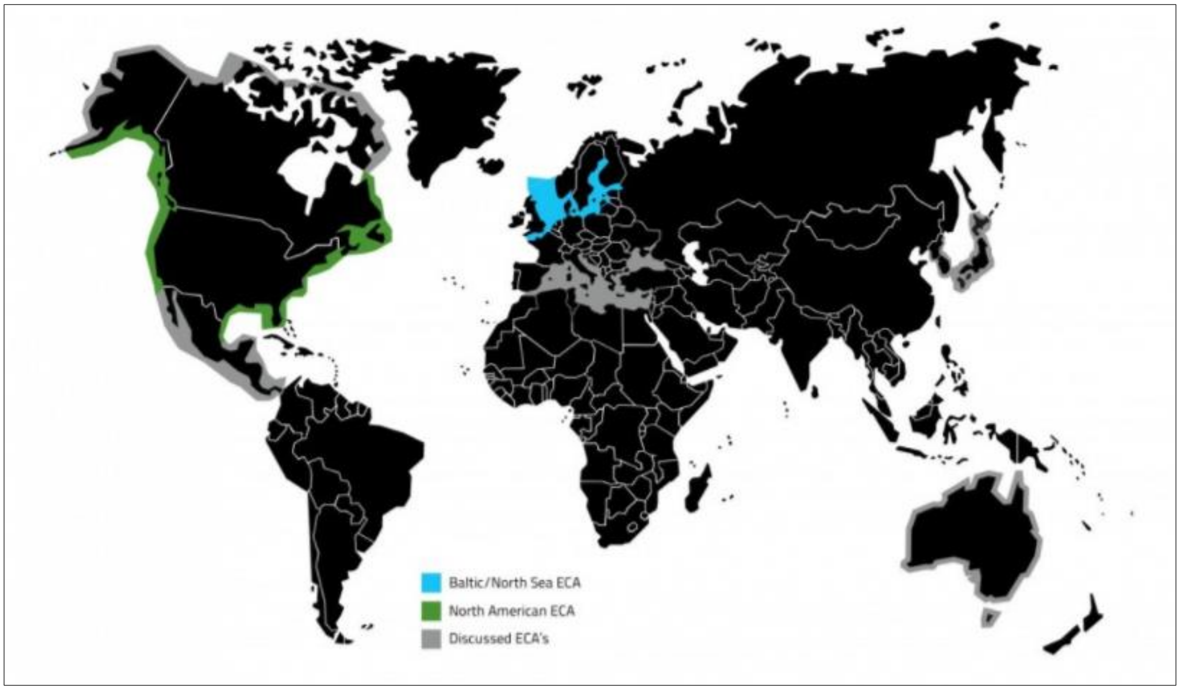

Figure 9: A world map of emission controlled areas

Source: Jacques (2015)

The cost per nautical mile of IFO 180 bunker fuel in the setting of this experiment was calculated using the following description and formulation. The MV Louisa Bolten has a design sailing speed of 14 knots when fully laden with dry bulk cargo and consumes approximately 25 metric tons of IFO 180 per full sailing day (Louisa Bolten, 2017). The vessel will continue to sail at a constant design speed between ports. The imminent overcapacity in the dry bulk vessel market favours slower sailing speeds (Rex, 2016). What is more, the concept of slow steaming is a benefit to charterers as lower bunker fuel costs are a direct consequence of the recent trend.

It is assumed that the vessel will be filled with bunker fuel IFO 180 before its departure from the port of Richards Bay and this will be enough to cover the sea journey in its entirety. During the vessel's voyage between demand ports, it can be assumed that all bunker fuel, ballast water and cargo allocation requirements are met to ensure a safe trim for partially loaded sea legs. To avoid the complication involved in ensuring that these requirements are met, the model will not include the element of vessel stabilisation in the case.

According to the Ship and Bunker website on 7 July 2017, the cost for IFO 180 was $359 per metric ton in Richards Bay (Ship & Bunker, 2017). Yet, according to du Toit (2017), in July 2017, the IFO 180 price per ton in Richards Bay was $300. Due to the differences in IFO 180 prices, the bunker fuel cost calculation will be completed with both quotations.

$$14\ knots\ \times 24\ hours = 336\ nautical\ miles\ per\ day$$

$$25\ tons\ of\ fuel\ burned\ in\ a\ day\ \div 336\ nautical\ miles = 0.0744\ tons\ per\ nautical\ mile$$

$$0.0744\ tons\ per\ nautical\ mile\ \times \$\mathbf{359}\ per\ ton = \$26.71\ per\ nautical\ mile$$

$$0.0744\ tons\ per\ nautical\ mile\ \times \$\mathbf{300}\ per\ ton = \$22.32\ per\ nautical\ mile$$

Both the price estimates of $26.71 and $22.32 per nautical mile were used in the modelling of the case. The use of both prices was done to verify the sensitivity of changes to the price of bunker fuel oil in the experiment. The fuel cost value in both instances was multiplied by the total nautical mile distance sailed by the vessel, which was then added to a fixed daily charter rate to get a voyage cost estimation. The voyage cost is deducted from the revenue gained from the selection of various cargo parcels in the case to induce a profit gained from the shipment.

4.1.4 *The Cargo Parcels*

The fourth element to be addressed in section 4.1 relates to the optional and available cargo parcels. The spot cargo parcel quantities, as listed in table 2, were made available by brokers to all interested parties in the industry. However, due to the publically closed nature of this information, the data was collected from a shipping company based in South Africa. The parcels' characteristics fit with the vessel described in section 4.1.2. It is evident that not all the parcels can be loaded on board the vessel simultaneously. Furthermore, all the commodities are classified as minor dry bulks and it is accepted that all spot cargoes are compatible with one another. This compatibility can be extended to assume that cargo parcels can be placed in the same hold so long as the individual parcels are separated by sheeting, to avoid cross-contamination of parcels belonging to different consignees. Furthermore, the combined cargo weight of all the parcels loaded into one load must not exceed the hold capacity limitation.

Table 2: Available spot cargo parcels

Port of Discharge	Cargo Parcel	Quantity (metric tonnes)
Algeciras	Ferro Chrome	6000
	Ferro Chrome	4000
Caronte	Zircon	2000
	Zircon	1750
Castellon	Zircon	5500
Civitavecchia	Ferro Chrome	2000
	Ferro Chrome	3000
	Ferro Chrome	2000
	Ferro Chrome	6000
	Ferro Chrome	3000
	Ferro Chrome	5000
Efesan Port	Pig Iron	4500
Koper	Pig Iron	2000
Livorno	Zircon	3000
	Zircon	3450
Porto Marghera	Ferro Chrome	2000
	Ferro Manganese	800
	Pig Iron	3300
	Pig Iron	2700
	Pig Iron	500
	Chrome Ore	4000
	Ferro Chrome	3000
Savona	Pig Iron	3000
Valencia	Zircon	4000

Source: Author via a South African based shipping company (2017)

4.1.5 *The Loading and Discharge Ports*

The fifth section of section 4.1 will address the details pertaining to the loading and discharge ports specific to the case. The transportation of cargo parcels in this experiment takes place between South Africa, a net exporter of dry bulk commodities, and countries in the Mediterranean region. More specifically, the port of Richards Bay, will be set as the single port of loading in this case and has the ability to load numerous demanded cargo parcels in one vessel (Ports Regulator of South Africa, 2016). What is more, is that the port call cost is approximately $25,000 for a handysize vessel similar to that of the MV Louisa Bolten, as included in table 3 (Camminga, 2017). A typical cost breakdown of the total port call expense for a handysize vessel at the port of Richards Bay can be seen in appendix 1. This port call cost is not fixed and varies according to the size of the vessel and how long the vessel remains loading on the berth.

The case recognizes the demand for minor bulks of less-than-shipload quantities in multiple ports throughout the Mediterranean region, such as: the port of Valencia in Spain; the port of Livorno in Italy and the port of Caronte in France. The commercial demand seaports included in this case are all considered as net importers of minor dry bulk commodities and have differing and variable port call costs as shown in table 3. Moreover, these ports are displayed geographically in figure 7. The demand for bulk cargo at each port is somewhat limited to the size of the geographical region to which the port services. The limitation supports the receipt of one vessel with multiple parcels of minor dry bulk commodities as these cargo types are not demanded in large enough quantities to full an entire vessel. For this reason, the demand for minor bulks at multiple ports in the Mediterranean region, for a period of three months, as listed in table 2, will be used in the modelling of the experiment.

Table 3: Port call cost

Supply Port	**Port Call Expense ($)**
Richards Bay	$25,000
Demand Ports	
Algeciras	$40,000
Caronte	$35,000
Castellon	$35,000
Civitavecchia	$35,000
Efesan	$40,000
Koper	$35,000
Livorno	$35,000
Porto Marghera	$40,000
Savona	$35,000
Valencia	$35,000

Source: Author via Camminga and Addington (2017)

4.1.6 *Voyage and Port Cost Calculations*

The sixth and final element of section 4.1 relates to the voyage and port costs. Both the voyage and port cost figures included are specific to this case. Furthermore, these costs are both made up partly of a bunker fuel cost and partly of a daily charter rate; however the calculation specifics differ. Section 4.1.6 will provide a detailed example of the calculations that were made to conclude these costs figures for their inclusion into the case.

Firstly, the voyage cost (C^V) is a cost per mile incurred during the sailing time of the vessel's voyage. The voyage cost is dependent upon the sailing distance between ports and the sailing speed of the vessel. A distance matrix illustrated in table 4, consists of the sailing distances between the single supply port and multiple demand ports and was used as the basis for the voyage cost matrix. Each distance was converted into a voyage cost using the following calculations:

$$Sailing\ Speed \times Number\ of\ Hours\ per\ day = Distance\ Sailed\ per\ day$$

$$14\ knots\ \times 24\ hours = 336\ nautical\ miles\ (Distance\ Sailed\ per\ day)$$

$$\frac{Distance\ between\ Ports}{Distance\ Sailed\ per\ day} \times Daily\ Charter\ Rate = Voyage\ Charter\ Cost$$

$$\frac{Distance\ between\ Ports}{Distance\ Sailed\ per\ day} \times Fuel\ Consumption \times Fuel\ Cost = Voyage\ Fuel\ Cost$$

$$Voyage\ Charter\ Cost + Voyage\ Fuel\ Cost = Voyage\ Cost\ per\ nautical\ mile\ (C^V)$$

A value of 336 nautical miles was used as the sailing distance per day in this case, which was calculated using the MV Louisa Bolten's design sailing speed of 14 knots and a time period of 24 hours; identical to the calculation in section 4.1.3 (August Bolten William Miller's Nachfolger, 2017). In addition, an average daily time charter rate of $7,000, as referred to in section 4.1.2, was included in the 'voyage charter cost' calculation.

Furthermore, the MV Louisa Bolten consumes 25 metric tonnes of fuel per day whilst sailing and a cost of $300 per metric ton of fuel oil was applied in the calculation; similar to the bunker fuel oil cost calculation in section 4.1.3 (August Bolten William Miller's Nachfolger, 2017). Hence, the sum of the 'voyage charter cost' and 'voyage fuel cost' for every arc of the voyage except the arc from the last port of discharge back to the port of loading, results in a 'voyage cost per nautical mile' (C^V). The final voyage cost calculations included a fuel cost of $300 and a daily charter rate of $7000 and are demonstrated in table 5.

Secondly, the 'port cost' is calculated with the summation of the cost of bunker fuel oil consumed and the daily charter rate, both during the time spent in port. It is assumed in this case that no loading of cargo occurs at the demand ports, only discharging operations. In addition, it is assumed that the discharge and loading rates remain constant whilst the vessel is on the berth and different rates or the non-operation on Saturdays, Sundays and holidays in certain ports is not included. The outcomes of the demand 'port cost' (C^P) computations are illustrated in table 6; yet, a more detailed explanation of the method and inputs included in the 'port cost' calculations follows:

$$\frac{Parcel\ Quantity}{Discharge\ Rate\ (mt\ per\ day)} + delay\ time = Time\ in\ Port\ (days)$$

$$Time\ in\ Port * Fuel\ Consumption \times Fuel\ Cost = Port\ Bunker\ Fuel\ Cost$$

$$Time\ in\ Port\ \times\ Daily\ Charter\ Rate = Port\ Charter\ Rate$$

$$Port\ Bunker\ Fuel\ Cost + Port\ Charter\ Rate = Port\ Cost\ (C^P)$$

The discharge rates and delay times specific to each demand port was collected from Addington (2017), an expert in the field who arranges weekly shipments to various ports in the Mediterranean region. These reliable figures, as shown in table 7, were used in the port cost calculations and vary according to the efficiency of the port as well as cargo related and berthing delays.

The ‘time in port’ calculation per demand port, measured in a number of days, was computed by selecting the maximum value from the ‘time to discharge’ column in table 6 and adding the number of expected ‘delay days’ to be experienced for that each individual port. The maximum value of discharge time was used in the port cost calculation as more than one cargo commodity can be discharged at the same time; therefore, the time taken to discharge the largest cargo parcel is the minimum amount of time a vessel must remain on the berth and in port.

Conversely, the optimal loading rate for the port of Richards Bay is approximately 100 metric tonnes per hour, which can be rounded off to 2,500 metric tonnes per day (Camminga, 2017). The loading rate for a vessel with parcel cargoes varies considerably as different commodities have different loading specifications. For example, the stowage plan may stipulate that weather bound cargo may be loaded in the same hold as non-weather bound cargo; however, if it starts to rain during the loading operation, the hold hatches need to be closed to preserve the weather bound cargo, which also stops the loading of the non-weather bound cargo and this can then delay the entire loading process. Nevertheless, according to industry experts, a handysize vessel should not remain in port for longer than two days when loading various parcels with a total quantity of about 30,000 metric tonnes; regardless of the time needed to fix the separation sheets between commodities or slight weather delays. A two day loading period may be possible; however, the port of Richards Bay is burdened with long waiting times at anchorage and unforeseen delays usually stemming from loading inefficiencies. Since 2010, the extended port detention for vessels in Richards Bay can be anywhere between two and twelve days, as shown in figure 10. Moreover, the running average number of lost days per vessel, since the beginning of 2010, is approximately six and this can significantly increase the ‘time in port’ cost for a charterer.

The ‘time in port’ calculation was computed slightly differently for the single loading port. It is assumed that the ships gear is used to load all the cargo, a quantity of roughly 30,000 metric tonnes. The MV Louisa Bolten has three cranes on board and it is assumed that each can load an equal amount of, on average, 10,000 tonnes. This optimal rate of productivity would result in 30 hours of loading or 1.25 days. Ideally, with half a day turnaround time included, the vessel should have a ‘time in port’ of two days; however, this is not the case due to common unforeseen delays. In the modelling of this case, a two day port time is added to a six day delay time, concluding to an eight day ‘time in port’ figure. Admittedly, 30 000 tonnes of cargo are not loaded on board the vessel in each test case; however, because charterers continuously aim to load vessels to their full capacity to gain maximum revenue and the existence of prevailing loading uncertainties in Richards Bay, the eight day total port time period is considered realistic to include in the settings of the case.

According to August Bolten William Miller’s Nachfolger (2017), whilst in port the MV Louisa Bolten consumes approximately three metric tonnes of bunker fuel oil per day. To calculate the ‘port bunker fuel cost’, a fuel oil cost of $300 per metric ton is used in each instance except when otherwise stated (du Toit, 2017). In addition, to calculate the ‘port charter rate’, an average daily time charter rate of $7,000 was included. Both the fuel oil and charter rates included in the port cost calculation are undifferentiated from the voyage cost calculation. Consequently, the sum of the ‘port bunker fuel cost’ and ‘port charter rate’ result in a ‘port cost’ (C^V) included in the modelling of the case.

The six elements described in section 4.1 have all been included in the setting of the experimental instance tests. Varying tests were done to measure the sensitivity of different elements on the outcome of the case. An explanation of each instance together with the outcome will follow in sections 4.2.1 and 4.2.2, respectively.

Table 4: The sailing distance between ports (S_{ijk})

	Distance Matrix (Nautical Miles)										
	Richards Bay	Algeciras	Valencia	Castellon	Caronte	Savona	Livorno	Civitavecchia	Porto Marghera	Koper	Efesan
Richards Bay	0	6471	6260	6283	6561	6702	6736	6755	7537	7517	7673
Algeciras	6471	0	389	412	690	831	865	884	1666	1646	1802
Valencia	6260	389	0	35	342	493	534	572	1404	1384	1550
Castellon	6283	412	35	0	314	465	506	552	1395	1375	1541
Caronte	6561	690	342	314	0	196	244	324	1232	1212	1390
Savona	6702	831	493	465	196	0	93	203	1130	1110	1288
Livorno	6736	865	534	506	244	93	0	118	1054	1034	1212
Civitavecchia	6755	884	572	552	324	203	118	0	941	921	1099
Porto Marghera	7537	1666	1404	1395	1232	1130	1054	941	0	60	1169
Koper	7517	1646	1384	1375	1212	1110	1034	921	60	0	1148
Efesan	7673	1802	1550	1541	1390	1288	1212	1099	1169	1148	0

Source: Sea-Distances (2017)

Table 5: Voyage costs (C_{ij}^{V})

	Voyage cost ($)										
	Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	0.00	298513.39	346766.37	347688.99	309169.64	302665.18	353962.80	288779.76	310738.10	289840.77	311614.58
Algeciras	298513.39	0.00	75931.55	76854.17	38334.82	31830.36	83127.98	17944.94	39903.27	19005.95	40779.76
Koper	346766.37	75931.55	0.00	2767.86	51205.36	55910.71	52958.33	63845.24	47699.40	63430.06	42486.61
Porto Marghera	347688.99	76854.17	2767.86	0.00	52127.98	56833.33	53927.08	64767.86	48622.02	64352.68	43409.23
Savona	309169.64	38334.82	51205.36	52127.98	0.00	9041.67	59416.67	22742.56	4290.18	21450.89	9364.58
Caronte	302665.18	31830.36	55910.71	56833.33	9041.67	0.00	64122.02	15776.79	11255.95	14485.12	14946.43
Efesan	353962.80	83127.98	52958.33	53927.08	59416.67	64122.02	0.00	71502.98	55910.71	71087.80	50697.92
Valencia	288779.76	17944.94	63845.24	64767.86	22742.56	15776.79	71502.98	0.00	24633.93	1614.58	26386.90
Livorno	310738.10	39903.27	47699.40	48622.02	4290.18	11255.95	55910.71	24633.93	0.00	23342.26	5443.45
Castellon	289840.77	19005.95	63430.06	64352.68	21450.89	14485.12	71087.80	1614.58	23342.26	0.00	25464.29

Source: Author (2017)

Table 6: The port cost per demand port (C^P)

Demand Ports	Commodities	Parcel Quantities	Time to Discharge (Days)	Time in Port (Days)	Fuel Consumed (metric tons)	Bunker Fuel Cost ($)	Daily Charter Cost ($)	Total Port Cost
Algeciras	Ferro Chrome	6,000	1.20					
	Ferro Chrome	4,000	0.80	1.70	5.10	$1,530	$11,900	$13,430
Caronte	Zircon	2,000	1					
	Zircon	1,750	0.88	4	12.00	$3,600	$28,000	$31,600
Castellon	Zircon	5,500	1.38	2.38	7.13	$2,138	$16,625	$18,763
Civitavecchia	Ferro Chrome	2,000	0.40					
	Ferro Chrome	3,000	0.60					
	Ferro Chrome	2,000	0.40					
	Ferro Chrome	6,000	1.20					
	Ferro Chrome	3,000	0.60					
	Ferro Chrome	5,000	1.00	1.70	5.10	$1,530	$11,900	$13,430
Efesan Port	Pig Iron	4,500	0.90	1.40	4.20	$1,260	$9,800	$11,060
Koper	Pig Iron	2,000	0.40	1.40	4.20	$1,260	$9,800	$11,060
Livorno	Zircon	3,000	0.75					
	Zircon	3,450	0.86	1.36	4.09	$1,226	$9,538	$10,764
Porto Marghera	Ferro Chrome	2,000	0.40					
	Ferro Manganese	800	0.16					
	Pig Iron	3,300	0.66					
	Pig Iron	2,700	0.54					
	Pig Iron	500	0.10					
	Chrome Ore	4,000	0.80					
	Ferro Chrome	3,000	0.60	2.80	8.40	$2,520	$19,600	$22,120
Savona	Pig Iron	3,000	0.75	1.75	5.25	$1,575	$12,250	$13,825
Valencia	Zircon	4,000	1.33	3.33	10.00	$3,000	$23,333	$26,333

Source: Author (2017)

Table 7: Demand port productivity

Demand Port	Cargo Discharge Rate (e_j) (tonnes per day)	Delay Days
Algeciras	5000	0.5
Caronte	2000	3
Castellon	4000	1
Civitavecchia	5000	0.5
Efesan Port	5000	0.5
Koper	5000	0.5
Livorno	4000	0.5
Porto Marghera	5000	2
Savona	4000	1
Valencia	3000	2

Source: Author via Addington (2017)

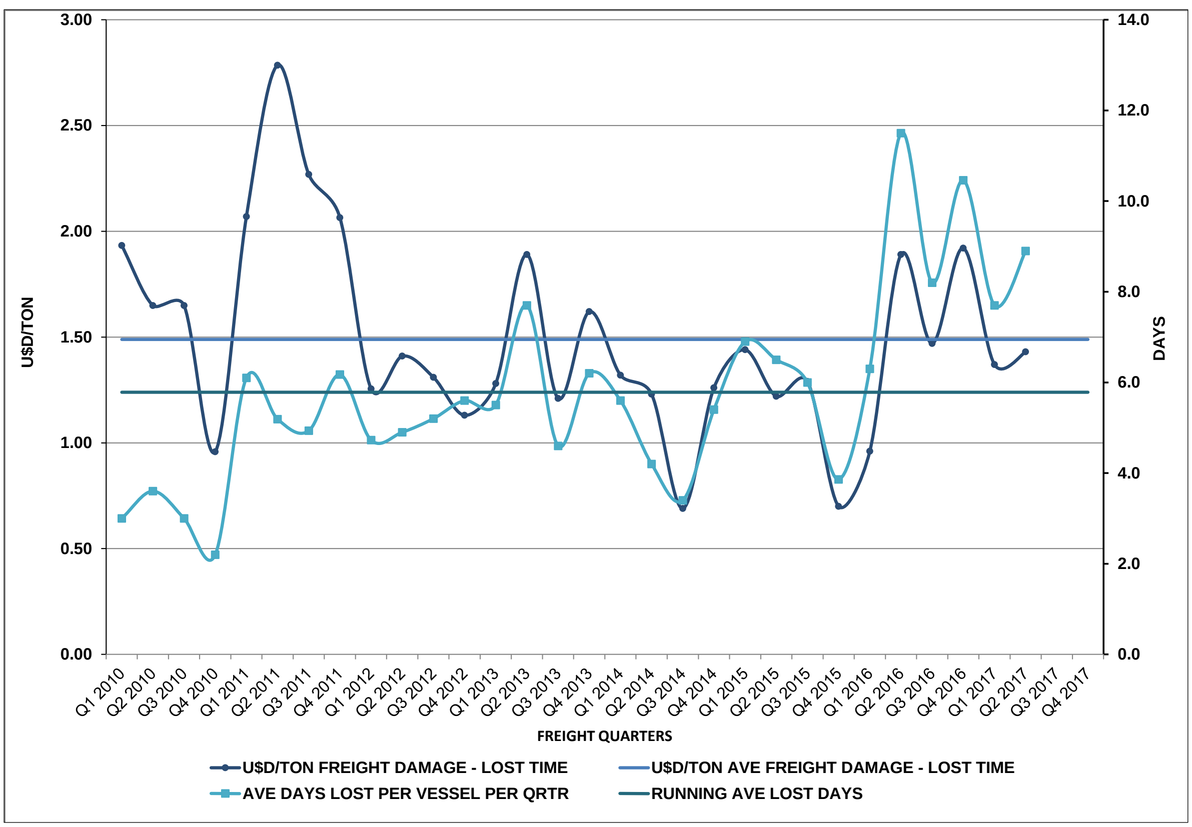

Figure 10: Time and cost of delays at the port of Richards Bay

Source: Author via Camminga (2017)

4.2 Experimental Test Cases

This section presents the computational experiments performed with the inclusion of the information mentioned in section 4.1, to assess the extended mathematical model described in section 3.2.2. For each test instance, the same two decisions were made regarding parcel selection and vessel routing, both underlying the procedure to attain a reliable result. A solution to each instance was identified by firstly selecting the cargo parcels in accordance with the highest freight rate earnable. As previously mentioned, this decision takes into consideration the quantity of each individual parcel together with the aggregated volume of all the parcels, which cannot exceed the vessel's carrying capacity. At the same time, a sailing route of the vessel needs to be decided upon. This secondary routing decision is based upon the parcels selected with their corresponding demand ports and secondary, the route with the minimum sailing distance between ports.

A summary of each test instance variation is included in table 8 and all tests are further described in more detail in section 4.2.1. What is more, the results of each instance will be provided in section 4.2.2. For each instance variation, except the one with all eleven ports, the demand ports have been selected antecedent and correspondingly, the parcel options are those demanded at each chosen ports. Moreover, the instances tested differ according to the number of ports, from five to eleven; the accumulated spot cargo quantity of all the parcels available; the quantity of each parcel on offer, the freight rates of individual parcels; and finally, multiple changed variables to compare input and result sensitivity.

4.2.1 *Individual Test Case descriptions*

The computational experiments were all conducted with only the extended mathematical model, not for the simple model detailed in equations 1 to 6 of section 3.2.2. Multiple tests were conducted to get a full understanding of how various input manipulations affect the ultimate result of the case, regarding both parcel selection and vessel routing. The input variations specific to each tested instance are listed in table 8 and additional information for each is provided in this section of the paper. The instance test variations will be categorized into different sets to avoid repetition and for clear comprehension.

In set 1, two instances were tested that both include five ports; one supply and four demand ports. The total quantity of all the available spot cargo parcels is less than the carrying capacity of the vessel. The accommodation of cargo volume by the vessel insinuates that the routing of the vessel is the main questionable outcome of both the tests. In short, the first and second instance tests are replicas of each other; however, a different set of ports is included in each to stand as verification of the results.

In set 2, four additional tests of five port instances were conducted. The instances varied by input manipulations; however, the total summed quantity of cargo demanded for all tests in set 2 is greater than the carrying capacity of the single vessel. These instances were developed to gauge the parcel selection criteria. In each instance parcels with high freight rates were selected and the total loaded quantity corresponds to the carrying capacity limitation of the vessel. Instance 3 was used in this set as a base case to which the other instances could be compared to. In instance 4, the quantity of the original 2,000 tonnes of pig iron was manually increased to 3,000 tonnes. In instance 5, a focus was placed on freight rates as a parcel not previously selected with a rate of $21 was then selected when the rate increased to $25 and the deselection of another parcel worth $21 occurred simultaneously. Instance 6 reflects a multiple case change with both the freight rate of an originally non-selected parcel and the quantity of a different parcel.

In set 3, an additional demand port was added to the input data of instance tests 7 and 8. With six ports in total, the tests were conducted with a total available parcel quantity of less than 30,000 tonnes. Instance tests 7 and 8 were conducted with a different set of demand ports to validate the results of the tests. Along the same lines, set 4 contains instances 9 to 12, which were tested with the same set of six ports. The instances vary with differing parcel quantities, freight rates and a combination of both. As displayed in table 8, instance 9 serves as the base case for set 4 and the instance upon which the other three tests are compared to. Instance 11 was repeated with three different freight rates.

In set 5 and more specifically, in instances 13 to 15, the input number of ports was extended to seven; with six demand ports and one supply port. The aggregated parcel quantities tested are less than 30,000 tonnes of cargo in instances 13 and 14 with slightly different demand ports. Whereas, the summed quantity of cargo parcels available in instance 15 is greater than 30,000 tonnes. Each instance in this category was tested with the existence of sub-cycles under scrutiny.

Set 6 contains the instance testing from 16 onwards, all of which comprise only of spot cargo parcels with a combined quantity of more than 30,000 tonnes. The large quantity of combined optional tonnage insinuates that the selection of the correct parcel will always be tested in combination with the vessels routing. Instances 16, 17 and 18 include the input of eight, nine and ten ports, respectively in the setting of the case.

The case with an input of eleven ports was first tested in set 7; all ten demand ports as well as the one constant loading port. Instance 19 is solely included in set 7 as it serves as the base case for sets 8, 9 and 10 to be comparable to.

In set 8, instances 20 and 21 are different versions of instance 19, whereby certain parcel quantities have been adjusted to test the sensitivity of selected parcels. The sensitivity of the case outcome to the cost of bunker fuel oil and port call costs is tested in instances 22 and 23, respectively. The cost related to the time spent in port is considered to be fixed in this case; however, in reality it can vary according to the length of time a vessel spends on the berth and for this reason the port call cost of Caronte was increased $50,000 in instance 23. The last cost related test is instance 24 of set 8, which assesses a change in the daily charter rate, from $7,000 to $8,000 per day.

In set 9, the case containing eleven ports was repeatedly tested with differing freight rates. Instances 25 to 28 were tested methodically to measure the impact of various rates on the outcome of the case. In particular, instances 25 and 26 analyse parcels not originally selected and aim to find the minimum threshold for a change in the result of the case. Furthermore, instances 27 and 28 evaluate the trade-off of freight rates in the selection of two parcels demanded at separate ports.

Besides the testing of various instances, three multiple case scenarios were tested in set 10 to evaluate the impact of various changes made simultaneously. The real-life reflected scenario summaries are included in table 7; yet, each will be described in more detail below.

Scenario one places a focus on two commercial seaports, namely: the port of Caronte in France and the port of Algeciras in Spain. The port of Caronte is synonymous with berthing delays and slow discharge rates for dry bulk cargo parcels (Addington, 2017). To increase the attractiveness of the port for charterers, an improvement was made by increasing the discharge rate from 2,000 to 4,000 tonnes per day and reducing the number of delay days from three to one. The manual manipulations made are both in line with multiple other ports in the Mediterranean region and are not considered to be unrealistic. On the other hand, the port of Algeciras demands a higher volume of a lower grade ferro chrome at a reduced freight rate, unlike the Civitavecchia port of Rome. The cargo quantities and freight rates for Algeciras have been influenced by adjusting the demand from 6,000 and 4,000 tonnes to 2,000 and 3,000 tonnes, both with a rate of $36.50, similar to the demand in Civitavecchia.

The vessel size included in the case is a single handysize vessel, with a deadweight of 30,800 tonnes. In scenario two, all else remains constant except for the vessel's carrying capacity, which is doubled to 61,600 tonnes; representing a handymax sized bulk carrier, as illustrated in figure 8. This scenario is plausible when a shipping company can foresee a large enough volume of spot cargo available to full this enlarged sized vessel. The daily charter rate for a handymax vessel is less than the cost of chartering two handysize carriers, as shown in figure 4 with a comparison of the handysize and supramax indices.

Scenario three assesses the inclusion of an additional constraint with the requirement that the vessel has to load the parcel demanded at the port of Castellon. This addition is an indication of how the routing would differ with the inclusion of contract cargo, an occurrence fit in line with general tramp shipping operations of contract and spot cargo. The contract cargo stipulation was enforced by the mandatory selected of the parcel demanded in Castellon for loading in Richards Bay. Together with this constraint, it was assumed that charterers only accept individual parcels of 1,000 tonnes or more. The quantity limitation meant that the parcel of 800 and 500 tonnes of ferro manganese and pig iron, respectively were altered to be 1000 tonnes. The scenario was also assessed in a different version with a constraint not allowing cargo parcels of less than 1,000 tonnes to be selected for loading. For both versions of the scenario, the two constraints added to the already mentioned mathematical model in section 3.2.2 are the following:

$$Z_n = 1 \; only\ the\ 5{,}500\ ton\ parcel\ of\ zircon\ demanded\ in\ the\ port\ of\ Castellon$$

More specific to the second version of scenario three, two additional constraints were further added to ensure the 800 and 500 ton spot cargo parcels could not be selected in the outcome of the case, these were:

$$Z_n = 0 \; repeated\ twice\ for\ both\ the\ 800\ and\ 500\ ton\ parcels$$

Table 8: Instance input settings

Instance Test Inputs							
Set Number	**Instance Number**	**Total Number of Ports**	**Number of Demand Ports**	**Number of Optional Parcels**	**Total Quantity of Parcels (metric tonnes)**	**Input Manipulated**	**Experiment Testing**
1	1	5	4	11	29,750		Vessel routing
	2	5	4	11	27,550	Demand ports	
2	3	5	4	12	34,750		Base case
	4	5	4	12	35,750	Parcel quantity	Parcel selection and routing
	5	5	4	12	34,750	Freight rate	
	6	5	4	12	36,750	Quantity and freight rate	
3	7	6	5	8	25,200		Vessel routing
	8	6	5	7	24,250	Demand ports	
4	9	6	5	13	31,500		Base case
	10	6	5	13	33,500	Parcel quantity	Parcel selection and routing
	11	6	5	13	34,500	Freight rate	
	12	6	5	13	32,500	Quantity and freight rate	
5	13	7	6	9	29,200		Vessel routing
	14	7	6	9	29,700	Demand ports	
	15	7	6	14	39,550		Parcel selection and routing
6	16	8	7	15	43,550	Number of ports	Increased number of ports
	17	9	8	17	50,000	Number of ports	
	18	10	9	18	55,500	Number of ports	
7	19	11	10	24	76,500	Number of ports	Base case
8	20	11	10	24	72,700	Parcel quantity	Parcel selection and routing
	21	11	10	24	75,500	Parcel quantity	
	22	11	10	24	76,500	Fuel oil cost	
	23	11	10	24	76,500	Port call cost	
	24	11	10	24	76,500	Daily chater rate	
9	25	11	10	24	76,500	Freight rate	
	26	11	10	24	76,500	Freight rate	
	27	11	10	24	76,500	Freight rate	
	28	11	10	24	76,500	Freight rate	
10	Scenario 1	11	10	24	71,500	Port productivity	
	Scenario 2	11	10	24	76,500	Vessel size	
	Scenario 3	11	10	24	77,200	Contract cargo	

Source: Author (2017)

4.2.2 *Computational Test Results*

This section of the paper will be structured chronologically according to the order the tests were conducted within each set. The results for each set will be summarized and tabulated; however, for the individual instance and scenario tests, a more detailed description will be reported. The focal outcomes from each instance and scenario concerns an approximation of the potential profit, the main objection, realised from the shipment; the cargo parcels chosen to be loaded at the port of Richards Bay as well as the vessel's routing in port call succession.

Set 1

The results from the elementary tests conducted on instances 1 and 2 are very similar. In both variations, the total quantity of all the available spot cargo demanded at the four demand ports, is below the carrying capacity of the vessel. Therefore, the selection of all the optional parcels was anticipated as it is in accordance with the aim of the objective function; to maximize the profit potential from the chartered vessel. The selection of all available cargo is verified in the selection of 11 out of 11 parcels in the tabulated results. With the pre-selected demand ports, the revenue earned from the second instance was higher than the first. The greater revenue was by reason that Caronte was included as a demand port in instance 2. The parcels demanded in Caronte present two of the highest freight rates conceivable from the available spot parcels; thus the model's selection of all the parcels would lead to an inflated revenue earning. In short, the results from the first test together with confirmation from the results of the second, indicate that the computational results of set 1 are in agreement with the mathematical model's decisions and objectives.

Instance Number	**Profit Indication ($)**	**Cargo Parcels Selected**	**Vessel Routing**
1	**311,450.30**	All parcels for all demand ports **11 out of 11**	Richards Bay - Valencia - Savona - Livorno - Porto Marghera
2	**354,470.48**	All parcels for all demand ports **11 out of 11**	Richards Bay - Caronte - Savona - Porto Marghera - Efesan

Set 2

The instances included in set 2 are an extension of set 1; however, the total tonnage of the optional parcels is greater than the vessel's carrying capacity. It is noticeable in the results of instance 3 that the parcels awarding the highest freight rates are selected and their corresponding demand ports are included in the routing. The parcel selection confirmation is realised concurrent to the correct sequential routing to and between ports in order to minimize the sailing distance. Furthermore, the third tested instance represents the foundation upon which instances 4 to 6 varies. By increasing the quantity of the pig iron parcel demanded in Koper from 2,000 to 3,000 tonnes the total quantity of selected items exceeded the permissible carrying capacity of one vessel. The result concluded with the correct deselection of two parcels potentially earning lower rates than that of the manipulated parcel. On the other hand, instance 5 tested the effect of differing freight rates, which concludes that by increasing the freight rate of an originally non-selected parcel to a rate higher than that of a selected parcel with a similar quantity, the cargo is then selected to be loaded. A combination of the changes made in instances 4 and 5 are presented in instance 6. A change in the freight rate and quantity of the 6,000 ton parcel of ferro chrome demanded in Algeciras and 4,000 ton parcel of chrome ore demanded in Porto Marghera, respectively results in a profit lower than that in instances 3, 4 and 5.

Instance Number	Profit Indication ($)	Cargo Parcels Selected	Vessel Routing
3	**309,446.61**	All parcels except one parcel demanded in Porto Marghera **11 out of 12**	Richards Bay - Algeciras - Livorno - Koper - Porto Marghera
4	**329,816.61**	All parcels except one parcel demanded in Algeciras and two demanded in Porto Marghera **9 out of 12**	Richards Bay - Algeciras - Livorno - Koper - Porto Marghera
5	**325,446.61**	All parcels except one demanded in Algeciras **11 out of 12**	Richards Bay - Algeciras - Livorno - Koper - Porto Marghera
6	**307,371.61**	All parcels except one demanded in Livorno and one demanded in Porto Marghera **10 out of 12**	Richards Bay - Algeciras - Livorno - Koper - Porto Marghera

Set 3

Both the tests conducted in set 3 are focused upon the model's interpretation of vessel routing as the carrying capacity of the vessel can accommodate the volume of each and every parcel simultaneously. The resultant selection of all parcels is in attempt to realise the highest revenue and to prompt the highest profit for the charterer. The testing of instances 7 and 8 provide the confirmation that no sub-cycles exist with the input of six ports. What is more, the demand ports included in instance 8 result in the lowest profit value from all the tests conducted, at approximately $93,000. The low return is mainly due to two reasons. Firstly, the selection of parcels with inherent and comparably low freight rates. Secondly, the totalled sum of cargo quantity loaded is marginally above 24,000 tonnes. The full carrying capacity of the vessel is not utilised, which offers an opportunity to load more spot cargo, demanded at the same selected ports, in order to gain from extra revenue whilst the costs remain marginally the same.

Instance Number	Profit Indication ($)	Cargo Parcels Selected	Vessel Routing
7	**232,161.25**	All parcels for all demand ports **8 out of 8**	Richards Bay - Algeciras - Caronte - Savona - Livorno - Koper
8	**92,755.83**	All parcels for all demand ports **7 out of 7**	Richards Bay - Algeciras - Valencia - Caronte - Koper - Efesan

Set 4

The results for set 4 are composed of instances 9 to 12. These four tests were conducted as an extension of instances 7 and 8 as they too contain six input ports; however, instances 10, 11 and 12 must be compared to the base case of instance 9, not instances 7 and 8. The demand ports included in all four tests remain the same and the total quantity of all the spot cargo available is now more than the carrying capacity of the vessel. The chosen vessel route remains the same in all instance tests but there is an exchange in the parcel selection.

In particular, instance 10 reaps the highest profit reward of all the instance tests conducted at approximately $572,400 as shown in the tabulated results. When compared to the base case, the zircon parcel of 2,000 tonnes demanded at Caronte, was increased to a quantity of 4,000 tonnes, which changed the selection of parcels. The result of instance 9 shows the selection of a 3 000 ton parcel of ferro chrome demanded at Porto Marghera; however, with the quantity manipulation, the vessel's carrying capacity is not large enough for an additional 2,000 tonnes of zircon and the 3 000 ton parcel. Therefore, the model accurately deselects the 3,000 ton parcel and instead selects the 800 ton parcel of ferro manganese. Furthermore, instance 11 focuses on the effects of changing freight rates. In the base case, the same 3,000 ton parcel as referred to above, was not selected; when the freight rate was changed from $21 to $25 per ton, the parcel still wasn't selected. The non-selection was due to the fact that another selected parcel reaped a higher reward even with a lower freight rate as the quantity was larger; 4,000 tonnes at $21 per ton results in a revenue of $84,000, which is more than 3,000 tonnes at $25 per ton proceeding in $75,000. The freight rate was again changed from $25 to $28 per ton, which still resulted in the non-selection of the parcel as the earnable revenue was $84,000, equal to that of the 4,000 ton parcel. Only when the freight rate was increased to above $28 per ton, was the parcel selected. In this instance, a value of $30 per ton was used and a resultant profit of approximately $507,600 would be made from the shipment, as included in instance 12. For instance 12, the last test containing six ports, the quantity of a parcel was increased and the freight rate of another parcel was increased, which lead to the deselection and selected of the parcels, respectively. Consequently, the computational tests conducted in set 4 conclude that the model accurately selected the parcels based on individual freight rates and complying quantities and no existence of a sub-cycle in the vessel routing emerged.

Instance Number	**Profit Indication ($)**	**Cargo Parcels Selected**	**Vessel Routing**
9	**480,574.82**	All parcels except one parcel demanded in Porto Marghera **12 out of 13**	Richards Bay - Caronte - Savona - Livorno - Koper - Porto Marghera
10	**572,434.82**	All parcels except for one parcel demanded in Porto Marghera **12 out of 13**	Richards Bay - Caronte - Savona - Livorno - Koper - Porto Marghera
11	**507,574.82**	All parcels except for one parcel demanded in Porto Marghera **12 out of 13**	Richards Bay - Caronte - Savona - Livorno - Koper - Porto Marghera
12	**486,074.82**	All parcels except for two parcels both demanded in Porto Marghera **11 out of 13**	Richards Bay - Caronte - Savona - Livorno - Koper - Porto Marghera

Set 5

The model is tested in set 5 by adding another port, whereby instances 13 to 15 all contain the input of seven ports. The first two tests in this set differ with the seventh port being either Valencia or Efesan. In these tests, all demand ports were including in the vessel's routing consequently to selection of all the available spot cargo. With the non-existence of sub-cycles, instance 15 tests the parcel selection with a total cargo quantity more than what can be accommodated by the vessel. The last instance test in this set results in the selection of 12 out of 14 available parcels and a total of about 29,550 tonnes of dry bulk cargo.

Instance Number	Profit Indication ($)	Cargo Parcels Selected	Vessel Routing
13	**263,058.57**	All parcels for all demand ports **9 out of 9**	Richards Bay - Algeciras - Valencia - Caronte - Savona - Livorno - Koper
14	**354,894.58**	All parcels for all demand ports **9 out of 9**	Richards Bay - Algeciras - Caronte - Savona - Livorno - Koper - Efesan
15	**371,837.44**	All parcels except both parcels demanded in Algeciras **12 out of 14**	Richards Bay - Caronte - Savona - Porto Marghera - Koper - Efesan

Set 6

Set 5 consists of instances 16, 17 and 18, which include an input of eight, nine and ten ports, respectively. The testing of these instances was focused on the potential existence of sub-cycles. All three tests contained the option of more cargo than what is permissible to be loaded on one vessel. Furthermore, no sub-cycles in the vessel's routing emerged and all the ports included were the related demand ports of the parcels selected.

Instance Number	Profit Indication ($)	Cargo Parcels Selected	Vessel Routing
16	**313,928.21**	All parcels except both the parcels demanded in Algeciras and one demanded in Porto Marghera **12 out of 15**	Richards Bay - Caronte - Valencia - Savona - Port Marghera - Koper - Efesan
17	**393,181.73**	All parcels except both the parcels demanded in Algeciras; three parcels in Porto Marghera and one in Valencia **11 out of 17**	Richards Bay - Caronte - Savona - Livorno - Porto Marghera - Koper - Efesan
18	**339,419.23**	All parcels except both the parcels demanded in Algeciras; three Porto Marghera as well as the parcels demanded in Castellon and Valencia **11 out of 18**	Richards Bay - Caronte - Savona - Livorno - Porto Marghera - Koper - Efesan

Set 7

Set seven is made up of only one instance testing and will be used as the base case for sets 8, 9 and 10 to be compared to. From instance 19 onwards, the input number of ports is at a maximum of eleven; ten demand ports with and one loading port. The eleven ports represent the option of 24 cargo parcels to choose from. Moreover, without any manipulations to the data, 13 out of 24 parcels were selected with a combined quantity of 30,550 tonnes as shown in the results of appendix 2. The proposed routing sequence of the base case vessel can be seen geographically in figure 11.

Instance Number	Profit Indication ($)	Cargo Parcels Selected	Vessel Routing
19	**368,098.45**	All parcels except both the parcels demanded in Algeciras; three in Porto Marghera as well as the parcels demanded in Castellon and Valencia **13 out of 24**	Richards Bay - Caronte - Savona - Livorno - Civitavecchia - Porto Marghera - Koper - Efesan

Figure 11: Routing of instance 19

Source: Author via Google Maps (2017)

Set 8

Set 8 incorporates the testing of five different instances. More specifically, instance 20 confirms that regardless of how small the quantity of a parcel offering a low freight rate becomes, the parcel will not be selected because the option remains for other parcels with higher rates to be selected first, filling the carrying capacity of the carrier. A reduction of the quantity of a parcel, occurs in the testing of instance 21. The resultant selection of the manipulated parcel doesn't however, change the route of the vessel as other parcels demanded at that same port were previously selected for loading.

The testing of instances 22, 23 and 24 remain to use eleven ports as an input; however, instead of manipulating cargo quantities or freight rate, costs are altered. For instance 22, the fuel oil cost was changed from $300 to $360 per ton to assess the sensitivity of the cost on the overall result. The results of the instance and the updated voyage cost figures are shown in appendix 3. The outcome of instance 22 compared to that of instance 19, showed no significant difference in the parcel selection and vessel routing. In both tests, 13 out of the possible 24 parcels were selected and the vessel was routed from Richards Bay to Caronte, Savona, Livorno, Civitavecchia, Porto Marghera, Koper and Efesan. The insignificant change concludes that the cost of bunker fuel oil doesn't have a big influence on the computational results and when replicating the case, the focus does not need to be placed on this cost input figure.

Moreover, the testing of instance 23 focuses on the influence of the input of port call cost. The parcels demanded at the port of Caronte are selected in the base case and correspondingly, the vessel is routed to the demand port; however, the expense associated with a port call in Caronte, is increased from $35,000 to $50,000 in instance 23. The same test was conducted with the Civitavecchia port, the port of Savona and then all three at the same time, to test the sensitivity of the port call expense on the outcome. No significant change in the final routing and parcel selection occurred. The only change was a reduction in the overall profit figure; indicting that the expense of a port call does not influence the two part fundamental decisions of parcel selection and vessel routing.

Instance 24 tests the impact of a change in charter rate. Appendix 4 shows the updated voyage costs with a new daily charter rate of $8,000, instead of $7,000. The charter rate of handysize vessels fluctuates frequently, as mentioned in chapter 1 and it is realistic to assume this change can happen in a very short time period. Although, when compared to the base test, no change occurred in the route and parcel selection; but the revenue was reduced from about $368,000 in instance 19 to $341,000. No significant change in the two primary decisions suggests that when the mathematical model is replicated, the daily charter rate will have an important impact on the resultant profit value; however, not on the parcel selection and vessel routing decisions made during the process of finding a solution.

The vessel routing in instances 20, 22 and 23 contains the same ports; yet, differs from the routing in instances 21 and 24. The difference is the way the vessel is routed between Porto Marghera and Koper. When analysing the geographical location of these two ports, they appear approximately 60 nautical miles apart. In set 2, the resultant routing of all the instances instructs the vessel to sail to Koper and then to Porto Marghera. On the other hand, in sets 5 and 6, the resultant routing of instances 15 to 18 instructs the vessel to sail to Porto Marghera and then to Koper. Whereas, as shown in the tabulated summary of results, set 8 contains a mixture of routing. Three instances result in the route from Porto Marghera to Koper and other two instances conclude with the route from Koper to Porto Marghera.

Instance Number	Profit Indication ($)	Cargo Parcels Selected	Vessel Routing
20	**368,098.45**	All parcels except both the parcels demanded in Algeciras; three in Porto Marghera as well as the parcels demanded in Castellon and Valencia **13 out of 24**	Richards Bay - Caronte - Savona - Livorno - Civitavecchia - Porto Marghera - Koper - Efesan
21	**376,155.30**	All parcels except both the parcels demanded in Algeciras; three in Civitavecchia and Porto Marghera; one in Livorno as well as the parcels demanded in Castellon and Valencia **13 out of 24**	Richards Bay - Caronte - Savona - Livorno - Civitavecchia - Koper - Porto Marghera - Efesan
22	**327,397.56**	All parcels except both the parcels demanded in Algeciras; four in Civitavecchia; two in Porto Marghera; one in Livorno as well as the parcels demanded in Castellon and Valencia **13 out of 24**	Richards Bay - Caronte - Savona - Livorno - Civitavecchia - Porto Marghera - Koper - Efesan
23	**323,098.45**	All parcels except both the parcels demanded in Algeciras; four in Civitavecchia; two in Porto Marghera; one in Livorno as well as the parcels demanded in Castellon and Valencia **13 out of 24**	Richards Bay - Caronte - Savona - Livorno - Civitavecchia - Port Marghera - Koper - Efesan
24	**329,885.95**	All parcels except both the parcels demanded in Algeciras; four in both Civitavecchia and in Porto Marghera; one in Livorno as well as the parcels demanded in Castellon and Valencia **12 out of 24**	Richards Bay - Valencia - Caronte - Savona - Livorno - Civitavecchia - Koper - Port Marghera - Efesan

Set 9

Set 9 contains the final testing of instances 25 to 28 with a manipulation of freight rates. The tested instances identify the threshold to which a change in the freight rate of a parcel has an impact on the computational objective function and vessel routing. More specifically, instance 25 identifies that the minimum threshold value, for the parcel demanded in Valencia, as a rate of $36.50 per ton before the cargo is selected for loading. Following this rate increase, the freight rate for the parcel demanded in Castellon needs to be increased to $35.20 from $20 per ton before the parcel and respective port are selected in the outcome. However, the parcel demanded in Valencia is now no longer included in the loading plan. The deselection triggers a trade-off between the 5,500 ton parcel of Zircon demanded in Castellon and the 4,000 ton parcel of Zircon demanded in Valencia. The trade-off is made more apparent in instance 27. When comparing instances 26 and 27, it is clear that more revenue is gained when the 5,500 ton parcel demanded in Valencia is selected; at about $369,600 compared to $375,300. The trade-off is counterbalanced when the freight rate of the 4,000 ton parcel remains at a rate of $37.20 and a manipulation of the rate for the 5,500 ton parcel to $35.30 per ton is made. Instance 28, tests the final changes and shows that in this instance, both parcels are selected, amongst others and the profit earned is $375,850, the highest value of all four instances.

Instance Number	Profit Indication ($)	Cargo Parcels Selected	Vessel Routing
25	**375,296.07**	All parcels except both the parcels demanded in Algeciras; three in Civitavecchia; two in Porto Marghera; one in Livorno as well as the parcel demanded in Castellon **11 out of 24**	Richards Bay - Caronte – Castellon - Savona - Livorno - Civitavecchia - Koper - Port Marghera - Efesan
26	**369,577.32**	All parcels except both the parcels demanded in Algeciras; four in both Civitavecchia and in Porto Marghera; one in Livorno as well as the parcel demanded in Castellon **12 out of 24**	Richards Bay - Caronte - Valencia - Castellon - Savona - Livorno - Civitavecchia - Koper - Port Marghera - Efesan
27	**375,841.01**	All parcels except both the parcels demanded in Algeciras; five in Civitavecchia; six in Porto Marghera and one parcel demanded in Livorno **10 out of 24**	Richards Bay - Algeciras - Valencia - Castellon - Caronte - Savona - Livorno - Civitavecchia - Koper - Port Marghera - Efesan
28	**340,964.52**	All parcels except both the parcels demanded in Algeciras; four in Civitavecchia; two in Porto Marghera; one in Livorno as well as the parcels demanded in Castellon and Valencia **13 out of 24**	Richards Bay - Caronte - Savona - Livorno - Civitavecchia - Port Marghera - Koper - Efesan

Set 10

Lastly, the results of the three real-life scenarios are included in set 10. The first realistic scenario assesses the impact of operational improvements in the port of Caronte as well as differing demands for certain cargo grades in the port of Algeciras. An improvement induces the port to be more attractive to charterers as they need not include daily charter expenses and port costs associated with delays or slow operations. As illustrated in appendix 4, the port cost for Caronte was reduced from $31,600 to $15,800 due to more efficient discharge operations. The adjusted cargo demand in Algeciras offers a higher and more attractive freight rate to charterers. The test outcome presented the selection of parcels demanded at both the ports of Caronte and Valenci with a higher overall revenue of $379,305.60 when compared to the results of instance 19, the base case.

The second realistic scenario determines the gain in revenue from chartering a larger sized vessel; categorically, a handymax vessel. Provided the demand for such a large vessel is present, the profit earned, as shown in appendix 5, increases by more than double from $368,098.45 ($\$368{,}098.45 \times 2 = \$736{,}196.90$) to $982,209.17, when compared to the base case of instance 19. The reasons for such a large increase could be attributable partly to the non-adjustment of discharge and port times and partly to the fact that the vessel can load more cargo; therefore, more parcels can be selected. Scenario 2 is a feasible option for charterers so long as there is enough cargo demanded on the spot market to fill the vessel with minor bulk parcels. Overall, more revenue is earned from transporting additional cargo parcels while the cost only slightly increases with three additional port call costs.

The third and final scenario, mentioned in appendix 6, looks at a case whereby it is mandatory to load the 5,500 ton parcel demanded at the port of Castellon together with a parcel quantity limitation, all parcels under 1,000 tonnes are not to be selected. The first requirement of the scenario is adhered to as the 5,500 ton contract cargo parcel was selected with the additional constraint mentioned in section 4.2.1; even though the parcel has a very low freight rate. Consequentially, as shown in figure 12, the port of Castellon was included in the vessel's routing. Moreover, for the second scenario requirement, the potential 1,000 ton cargo limitation from charterers was assessed in two ways; firstly, the parcel quantities smaller than the lower load limit were manipulated to be 1,000 tonnes and secondly, non-complying parcels were eliminated from the list of available spot cargoes. The resultant profit for both versions is exactly the same at $315,344.88 because the manipulated and restricted parcels were not selected in both the outcomes, as shown in appendix 6. Furthermore, the profit is lower than the base case by reason that the 5,500 ton compulsory parcel offers a very low freight rate of only $20 per ton, which would not have been selected under normal case conditions.

Figure 12: The routing of scenario 3

Source: Author via Google Maps (2017)

In line with the identification of the Koper – Porto Marghera vessel routing discrepancy in set 8; set 10 identifies the same matter for the ports of Castellon to Caronte. Due to the low freight rate offered for the parcel demanded in Castellon, the parcel was not been selected in any of the instances, except in set 9 when the freight rate was manipulated and in scenario 2 when the vessels' carrying capacity doubled. Geographically, it makes logical sense for a vessel to be routed from Castellon to Caronte, which is what the results show in instance 27 as well as scenarios 2 and 3. However, in instances 25 and 26, the resultant routing shows the vessel to be routed from Caronte to Castellon.

Instance Number	Profit Indication ($)	Cargo Parcels Selected	Vessel Routing
Scenario 1	**379,305.60**	All parcels except three parcels demanded in Civitavecchia; six in Porto Marghera; one parcel demanded in Livorno as well as the parcels demanded in Castellon and Valencia **12 out of 24**	Richards Bay - Algeciras - Caronte - Savona - Livorno - Civitavecchia - Port Marghera - Koper - Efesan
Scenario 2	**982,209.17**	All parcels except four parcels demanded in Civitavecchia **20 out of 24**	Richards Bay - Algeciras - Valencia – Castellon - Caronte - Savona - Livorno - Civitavecchia - Port Marghera - Koper - Efesan
Scenario 3 version 1 and 2	**315,344.88**	All parcels except both the parcels demanded in Algeciras; three in Civitavecchia; six in Porto Marghera; one in Livorno as well as the parcel demanded in Valencia **11 out of 24**	Richards Bay - Castellon - Caronte - Savona - Livorno - Civitavecchia - Port Marghera - Koper - Efesan

To review the results of all ten sets, the concluding monetary benefits from the tests conducted are bifold. The charterer's profit indication for the transportation of minor bulk parcels considers the highest revenue attributable to the shipment as well as the lowest cost incurred by ensuring the sailing distance is kept to a minimum. The voyage cost minimization stems from the idea that by reducing the sailing distance of the vessel, the bunker fuel oil cost, which represents a substantial portion of the total cost for the charterer, is minimized.

To conclude section 4.2.2, the extended theoretical model outlined in section 3.2.2 provides a feasible solution for the set of demand ports included in the case. The results for each instance and scenario testing shows an accurate selection of the available minor bulk parcels and at the same time, provides an answer to the SRP. The most effective selection of cargo parcels occurs in accordance with the highest freight rates, relative to all those available and for each test, the maximum permissible combined weight of parcels was selected. Moreover, the corresponding demand ports for the selected parcels needed to be included in the vessel's proposed sailing route. The results concurrently displayed a distance-minimizing solution to the multiple port SRP.

5. Conclusions

The final section of this paper will touch on the valuable contributions of this research, linking the paper's noteworthy features into a coherent conclusion. The concluding aspects together with any limitations will be included in section 5.1; followed by the recommendations for further research in section 5.2.

5.1 *Research Conclusions*

The focal idea investigated in this research paper is the transportation of less-than-shipload cargo quantities together in a handysize bulk carrier. Minor dry bulks can be loaded in an undedicated hold compartment of a vessel and separated by sheeting to avoid cross-contamination of cargoes. The part hold loading is achievable so long as each commodity is compatible with one another. The selection of spot cargo parcels, stowed together in a time chartered vessel and routed to multiple demand ports from one supply port, is the main concept addressed in the literature review and theoretical model of this research.

This research paper has achieved success in three areas. Firstly, a gap in literature is identified regarding spot cargoes of less-than-shipload cargo quantities with time chartered vessels. The paper serves to inform this gap by introducing a theoretical mathematical model for the selection of available dry bulk spot cargoes in conjunction with effective ship routing to ensure the chartered vessel consumes the least amount of bunker fuel oil. Secondly, a simplified model focused on vessel routing exclusively was developed; followed by the development of an extended model in pursuit of solving the combined problem of parcel selection and vessel routing. Thirdly, a real-life case study was used in the computational testing of the theoretical model. The case tests involved spot cargo data, collected from an established South African shipping company as well as pragmatic assumptions, which were used as inputs. The results from numerous instance and scenario test variations, suggest the mathematical formulation accurately expresses the outcome of the parcel and routing decisions as well as the attainment of the main profit objective. The outcomes display a systematic selection of parcels with the highest freight rates to fill the vessel, whilst not exceeding the vessels carrying capacity and at the same time providing a sequential sailing route for the vessel between multiple ports.

The research conducted is primarily involved in the activities common to one part of the logistics network. More specifically, verification of the computational case test results confirmed the formulated theoretical model can be applied to the maritime transportation of minor dry bulk cargo by time-chartered handysize carriers within a tramp operation. Regardless of the specificity for the included case, the fundamental idea of the research is applicable to other forms of shipping and cargo. Two applicable cases could be the routing for a shipment of full-shipload major bulks or the selection and routing of less-than-shipload liquid cargo parcels; both with the obligation of multiple port discharges. This functional factor is paired with minor limitations in the testing of the case.

A range of limitations were encountered during the research; mainly related to the development of the computational case. Due to the data collected, the setting of the case was limited to ten demand ports and one supply port. Although, no sub-cycles emerged in the computational results, it is uncertain whether the correct solution will be found with either an increase in the number of input ports or if the ports are not geographically contained in one region. Furthermore, two limitations are present in the input data. First of all, the port call costs are included as fixed expenses and the loading time for the port of Richards Bay is included as a fixed time period with the loading of approximately 30,000 tonnes; which, in reality, are both variable numbers. Secondly, all available spot cargo parcels are assumed to be known by charterers in advance with the choice to load any one of them; however, this is rarely the case. What is more, charterers aim to fill their time chartered vessel with cargo before the departure date in order to sail a full shipload. Yet, the demand to fill a vessel with cargo is time pressured and may lead to charterers accepting cargo with lower freight rates to hedge against the risk that no other spot parcels with higher freight rates become available before the deadline to submit the loading plan to the port authorities.

The results of the tests conducted in the computational case ensure that the scope of literature covered and data collected is accurately represented. Independent of the novelty of the theoretical model, various insights can be learned from the results of the case investigation. First of all, the case allows for practicality in the sense that the results are applicable to short term and time constrained decision making. Charterers are often under time pressure to charter a vessel and select cargo for the shipment. The results of the computational case show a relatively quick selection of the most profitable spot cargo parcels. As noted in the results of instance 11, parcel selection must not only be dependent upon the offered freight rate but also on the quantity of the parcel. The multiplication of freight rate and quantity for each parcel needs to be considered for parcel selection with the underlying vessel capacity constraint.

Next, the practical insights gained from the computational results concern the profit potential for charterers. The results from scenario 1 prove the possible profit amount is enlarged for charterers when the parcels selected are corresponding demanded at operationally efficient ports. Although the freight rates may be slightly lower; the saving remains with more productive ports as less delay days are experienced and the vessel can be chartered for a shorter time period. On a side note, it is possible to estimate the number of expected delay days and the total charter duration with the results of the model, which is essential in concluding the time charter contract for the hiring of the vessel. If the total charter period is estimated accurately, this can have a significant effect on the shipment’s profitability. As a result, the indicated potential profit figure allows the charterer to gauge if the charter is worthwhile in the short term and to ensure that the shipment will not lead to a loss.

Lastly, managerial insights are obtained from the results of scenarios 2 and 3. The magnified vessel capacity included in the testing of scenario 2 signals that it is more profitable for charterers and managers alike, to charter a larger vessel; on condition that there is a high enough demand to fully utilize the ship’s capacity. The testing of scenario 3 ensures the theoretical model is applicable to ship operators who are faced with a combination of contract and spot market cargoes. The combination of mandatory and optional cargoes is in line with typical tramp operations. In this instance, the model remains applicable so long as the additional constraint mentioned in section 4.2.1 is included.

5.2 *Recommendations*

The limitations provide a starting point for recommendations when conducting further research in this area. To extend the computational model, a second vessel could be added with the inclusion of a decision to determine the selection of parcels specific to each individual vessel. Furthermore, from a technical perspective, the model could be advanced by ensuring stability of the vessel during the sea voyage; accounting for compartment cargo allocations, discharging cargo at demand ports and bunker fuel requirements. The extensions would allow the model to be more applicable and operable to other sectors within the maritime context. Moreover, from an operations perspective, the tested outcome of instance 23 presents a recommendation. The cost of a port call should be included in the decision making process of the model, not only as a result of the parcel and routing decisions concluded. In short, this research can be used as a foundation to build a more comprehensive parcel selection and vessel routing problem to better explain a more complex range of SRP's.

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Appendix 1

An estimated disbursement account

PORT				**RICHARDS BAY**
OPERATOR				**Wezzo Naidu**
VESSEL				**MV GLOBAL HORIZON**
GRT				**21192**
PORT STAY				**3 DAYS**
PRINCIPAL				**Island View Shipping**
ESTIMATED R.O.E. (1USD = ZAR)				**13.6**
CARGO WORKED				**Loading 30 000 Mt MPT sized coal in bulk**
TNPA PORT CHARGES				
ZAR			**USD**	
R	51 556.28	USD	3 790.90	Port Dues
R	16 487.24	USD	1 212.30	Light Dues
R	7 629.12	USD	560.96	Vessel Tracking Services
R	25 770.72	USD	1 894.91	SAMSA Levy
R	8 009.70	USD	588.95	Berthing Services
R	44 208.86	USD	3 250.65	Pilotage Services
R	68 178.74	USD	5 013.14	Tugs / Craft Assistance
R	932.70	USD	68.58	Refuse Removal
R	-	USD	-	
R	**222 773.36**	**USD**	**16 380.39**	**TOTAL TNPA PORT CHARGES**
MISCELLANEOUS CHARGES				
ZAR			**USD**	
R	600.00	USD	44.12	Seafareres Club - Levy
R	100.00	USD	7.35	Port Health - Levy
R	250.00	USD	18.38	Saasoa Levy
R	250.00	USD	18.38	NSRI - Levy
		USD	-	
R	**1 200.00**	**USD**	**88.24**	**TOTAL MISCELLANEOUS CHARGES**
AGENCY CHARGES				
R	80 460.00	USD	5 916.18	Cargo Agency
R	17 777.00	USD	1 307.13	Owners / Port Agency
R	15 768.00	USD	1 159.41	Recoverable Daily Expenses
R	-	USD	-	Additional Agency Charges
R	**114 005.00**	**USD**	**8 382.72**	**TOTAL AGENCY CHARGES**
TOTAL ESTIMATED D/A				
R	222 773.36	USD	16 380.39	Total TNPA Port Costs
R	1 200.00	USD	88.24	Total Miscellaneous Charges
R	114 005.00	USD	8 382.72	Total Agency
R	-	USD	-	VAT
R	**337 978.36**	**USD**	**24 851.35**	**TOTAL ESTIMATED D/A**

Source: Author via a shipping company based in South Africa (2017)

Appendix 2

Instance 19

Objective Function max $368,098.45

$$max \sum_{n} R_n Z_n Q_n - \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}\left(C^V S_{ijk} + D_{jk}\right) - \sum_{j\in V}\sum_{n} Z_n\ \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b 0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b 0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	b 1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	b 1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	b 0
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	b 1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	b 1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	b 1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	b 0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	b 1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	b 1
Zircon	4,000	23.50	0	0	0	0	0	0	0	1	0	0	0	b 0
														13

$X_{ijk}(C^V S_{ijk})$	Cost of Planned Transport											
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	283138.39	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	0.00	0.00	0.00	49541.67	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	8458.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	0.00	40608.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	0.00	2589.29	40608.63	8458.33	283138.39	49541.67	0.00	4013.39	0.00	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk}+D_{jk})$		**$25,000.00**	**$40,000.00**	**$37,589.29**	**$80,608.63**	**$43,458.33**	**$318,138.39**	**$89,541.67**	**$35,000.00**	**$39,013.39**	**$35,000.00**	**$40,092.26**
												$783,442
$\sum_{j\in V}\sum_{n} Z_n\ \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Appendix 3

Instance 22

Objective Function max $327,397.56

$$\max \sum_{n} R_n Z_n Q_n - \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}\left(C^V S_{ijk} + D_{jk}\right) - \sum_{j\in V}\sum_{n} Z_n\, \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	0
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	1
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	1
Zircon	4,000	23.50	0	0	0	0	0	0	0	1	0	0	0	0
														13

$C^V S_{ijk}$		Voyage costs										
Node i	**Node j**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia
Richards Bay	1	-	308,142.86	357,952.38	358,904.76	319,142.86	312,428.57	365,380.95	298,095.24	320,761.90	299,190.48	321,666.67
Algeciras	2	308,142.86	-	78,380.95	79,333.33	39,571.43	32,857.14	85,809.52	18,523.81	41,190.48	19,619.05	42,095.24
Koper	3	357,952.38	78,380.95	-	2,857.14	52,857.14	57,714.29	54,666.67	65,904.76	49,238.10	65,476.19	43,857.14
Porto Marghera	4	358,904.76	79,333.33	2,857.14	-	53,809.52	58,666.67	55,666.67	66,857.14	50,190.48	66,428.57	44,809.52
Savona	5	319,142.86	39,571.43	52,857.14	53,809.52	-	9,333.33	61,333.33	23,476.19	4,428.57	22,142.86	9,666.67
Caronte	6	312,428.57	32,857.14	57,714.29	58,666.67	9,333.33	-	66,190.48	16,285.71	11,619.05	14,952.38	15,428.57
Efesan	7	365,380.95	85,809.52	54,666.67	55,666.67	61,333.33	66,190.48	-	73,809.52	57,714.29	73,380.95	52,333.33
Valencia	8	298,095.24	18,523.81	65,904.76	66,857.14	23,476.19	16,285.71	73,809.52	-	25,428.57	1,666.67	27,238.10
Livorno	9	320,761.90	41,190.48	49,238.10	50,190.48	4,428.57	11,619.05	57,714.29	25,428.57	-	24,095.24	5,619.05
Castellon	10	299,190.48	19,619.05	65,476.19	66,428.57	22,142.86	14,952.38	73,380.95	1,666.67	24,095.24	-	26,285.71
Civitavecchia	11	321,666.67	42,095.24	43,857.14	44,809.52	9,666.67	15,428.57	52,333.33	27,238.10	5,619.05	26,285.71	-

$X_{ijk}(C^V S_{ijk})$		Cost of Planned Transport										
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	312428.57	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	0.00	0.00	0.00	54666.67	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	2857.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4428.57	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	9333.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	365380.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5619.05
Castellon	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	0.00	44809.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	365380.95	0.00	2857.14	44809.52	9333.33	312428.57	54666.67	0.00	4428.57	0.00	5619.05
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk}+D_{jk})$		**$25,000.00**	**$40,000.00**	**$37,857.14**	**$84,809.52**	**$44,333.33**	**$347,428.57**	**$94,666.67**	**$35,000.00**	**$39,428.57**	**$35,000.00**	**$40,619.05**
												$824,143
$\sum_{j\in V}\sum_{n} Z_n\, \delta_{nj}\, Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Instance 23

Objective Function max **$323,098.45**

$$\max \sum_{n} R_n Z_n Q_n - \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}\left(C^V S_{ijk} + D_{jk}\right) - \sum_{j\in V}\sum_{n} Z_n\, \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b 0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b 0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	b 1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	b 1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	b 0
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	b 1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	b 1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	b 1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	b 0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	b 1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	b 1
Zircon	4,000	23.50	0	0	0	0	0	0	0	1	0	0	0	b 0
														13

$X_{ijk}(C^V S_{ijk})$	Cost of Planned Transport											
		Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	283138.39	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	0.00	0.00	0.00	49541.67	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	8458.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	0.00	40608.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	0.00	2589.29	40608.63	8458.33	283138.39	49541.67	0.00	4013.39	0.00	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$50,000	$50,000	$40,000	$35,000	$35,000	$35,000	$50,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk}+D_{jk})$		**$25,000.00**	**$40,000.00**	**$37,589.29**	**$80,608.63**	**$58,458.33**	**$333,138.39**	**$89,541.67**	**$35,000.00**	**$39,013.39**	**$35,000.00**	**$55,092.26**
												$828,442
$\sum_{j\in V}\sum_{n} Z_n\, \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Instance 24

Objective Function max $392,885.95

$$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C^V S_{ijk} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \, \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b 0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b 0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	b 1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	b 1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	b 0
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	b 1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	b 1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	b 1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	b 0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	b 1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	b 1
Zircon	4,000	36.50	0	0	0	0	0	0	0	1	0	0	0	b 1
														12

$X_{ijk}(C^V S_{ijk})$	Cost of Planned Transport											
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	270148.81	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	0.00	0.00	0.00	0.00	50447.92	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	8458.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	14758.93	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	39745.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	0.00	39745.54	2589.29	8458.33	14758.93	50447.92	270148.81	4013.39	0.00	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i \in V}\sum_{j \in V}\sum_{k \in K} X_{ijk}(C^V S_{ijk} + D_{jk})$		**$25,000.00**	**$40,000.00**	**$74,745.54**	**$42,589.29**	**$43,458.33**	**$49,758.93**	**$90,447.92**	**$305,148.81**	**$39,013.39**	**$35,000.00**	**$40,092.26**
												$785,254
$\sum_{j \in V}\sum_{n} Z_n \, \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Instance 25

Objective Function max **$375,296.07**

$$\max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C^V S_{ijk} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \, \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	5,500	35.20	0	0	0	0	0	0	0	0	0	1	0	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	1
Zircon	4,000	36.50	0	0	0	0	0	0	0	1	0	0	0	0
														11

$X_{ijk}(C^V S_{ijk})$	Cost of Planned Transport											
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	283138.39	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	0.00	0.00	0.00	0.00	50447.92	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13550.60	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	20066.96	0.00	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	39745.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	0.00	39745.54	2589.29	20066.96	283138.39	50447.92	0.00	4013.39	13550.60	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk} + D_{jk})$		**$25,000.00**	**$40,000.00**	**$74,745.54**	**$42,589.29**	**$55,066.96**	**$318,138.39**	**$90,447.92**	**$35,000.00**	**$39,013.39**	**$48,550.60**	**$40,092.26**
												$808,644
$\sum_{j\in V}\sum_{n} Z_n \; \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Instance 26

Objective Function max $369,577.32

$$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C^V S_{ijk} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \, \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	5,500	35.20	0	0	0	0	0	0	0	0	0	1	0	0
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	1
Zircon	4,000	37.20	0	0	0	0	0	0	0	1	0	0	0	1
														12

$X_{ijk}(C^V S_{ijk})$		Cost of Planned Transport										
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	283138.39	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	0.00	0.00	0.00	0.00	50447.92	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14758.93	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1510.42	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	20066.96	0.00	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	39745.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	0.00	39745.54	2589.29	20066.96	283138.39	50447.92	14758.93	4013.39	1510.42	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk}(C^V S_{ijk} + D_{jk})$		**$25,000.00**	**$40,000.00**	**$74,745.54**	**$42,589.29**	**$55,066.96**	**$318,138.39**	**$90,447.92**	**$49,758.93**	**$39,013.39**	**$36,510.42**	**$40,092.26**
												$811,363
$\sum_{j \in V} \sum_{n} Z_n \, \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Instance 27

Objective Function max **$375,841.01**

$$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C^V S_{ijk} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \; \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports												Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia		
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b	0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b	0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	b	1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	b	1
Zircon	5,500	35.30	0	0	0	0	0	0	0	0	0	1	0	b	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b	0
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b	0
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b	0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b	0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b	0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	b	1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	b	1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	b	1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	b	0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	b	1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	b	0
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	b	0
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	b	0
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	b	0
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b	0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b	0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	b	1
Zircon	4,000	37.20	0	0	0	0	0	0	0	1	0	0	0	b	1
															10

$X_{ijk}(C^V S_{ijk})$		Cost of Planned Transport										
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	279254.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16787.20	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	0.00	0.00	0.00	0.00	50447.92	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	8458.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1510.42	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	0.00	13550.60	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	39745.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	279254.46	39745.54	2589.29	8458.33	13550.60	50447.92	16787.20	4013.39	1510.42	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk}(C^V S_{ijk} + D_{jk})$		**$25,000.00**	**$319,254.46**	**$74,745.54**	**$42,589.29**	**$43,458.33**	**$48,550.60**	**$90,447.92**	**$51,787.20**	**$39,013.39**	**$36,510.42**	**$40,092.26**
												$811,449
$\sum_{j \in V} \sum_{n} Z_n \, \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Instance 28

Objective Function max **$340,964.52**

$$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C^V S_{ijk} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \, \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b 0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	b 0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	b 1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	b 1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	b 0
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	b 1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	b 0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	b 1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	b 1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	b 1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	b 0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	b 1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	b 1
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	b 0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	b 1
Zircon	4,000	23.50	0	0	0	0	0	0	0	1	0	0	0	b 0
														13

$C^V S_{ijk}$	Node j	Voyage costs										
		Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia
Node i												
Richards Bay	1	-	298,513.39	346,766.37	347,688.99	309,169.64	302,665.18	353,962.80	288,779.76	310,738.10	289,840.77	311,614.58
Algeciras	2	298,513.39	-	75,931.55	76,854.17	38,334.82	31,830.36	83,127.98	17,944.94	39,903.27	19,005.95	40,779.76
Koper	3	346,766.37	75,931.55	-	2,767.86	51,205.36	55,910.71	52,958.33	63,845.24	47,699.40	63,430.06	42,486.61
Porto Marghera	4	347,688.99	76,854.17	2,767.86	-	52,127.98	56,833.33	53,927.08	64,767.86	48,622.02	64,352.68	43,409.23
Savona	5	309,169.64	38,334.82	51,205.36	52,127.98	-	9,041.67	59,416.67	22,742.56	4,290.18	21,450.89	9,364.58
Caronte	6	302,665.18	31,830.36	55,910.71	56,833.33	9,041.67	-	64,122.02	15,776.79	11,255.95	14,485.12	14,946.43
Efesan	7	353,962.80	83,127.98	52,958.33	53,927.08	59,416.67	64,122.02	-	71,502.98	55,910.71	71,087.80	50,697.92
Valencia	8	288,779.76	17,944.94	63,845.24	64,767.86	22,742.56	15,776.79	71,502.98	-	24,633.93	1,614.58	26,386.90
Livorno	9	310,738.10	39,903.27	47,699.40	48,622.02	4,290.18	11,255.95	55,910.71	24,633.93	-	23,342.26	5,443.45
Castellon	10	289,840.77	19,005.95	63,430.06	64,352.68	21,450.89	14,485.12	71,087.80	1,614.58	23,342.26	-	25,464.29
Civitavecchia	11	311,614.58	40,779.76	42,486.61	43,409.23	9,364.58	14,946.43	50,697.92	26,386.90	5,443.45	25,464.29	-

$X_{ijk}(C^V S_{ijk})$		Cost of Planned Transport										
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	302665.18	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	0.00	0.00	0.00	52958.33	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	2767.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4290.18	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	9041.67	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	353962.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5443.45
Castellon	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	0.00	43409.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	353962.80	0.00	2767.86	43409.23	9041.67	302665.18	52958.33	0.00	4290.18	0.00	5443.45
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk}+D_{jk})$		**$25,000.00**	**$40,000.00**	**$37,767.86**	**$83,409.23**	**$44,041.67**	**$337,665.18**	**$92,958.33**	**$35,000.00**	**$39,290.18**	**$35,000.00**	**$40,443.45**
												$810,576
$\sum_{j\in V}\sum_{n} Z_n\, \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Appendix 4

Instance 19

Objective Function max: $379,305.60

$$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C^V S_{ijk} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \; \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	3,000	36.50	0	1	0	0	0	0	0	0	0	0	0	1
Ferro Chrome	2,000	36.50	0	1	0	0	0	0	0	0	0	0	0	1
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	0
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	1
Zircon	4,000	23.50	0	0	0	0	0	0	0	1	0	0	0	0
														12

$X_{ijk}(C^V S_{ijk})$		Cost of Planned Transport										
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	279254.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	29776.79	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	0.00	0.00	0.00	49541.67	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	8458.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	0.00	40608.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	279254.46	2589.29	40608.63	8458.33	29776.79	49541.67	0.00	4013.39	0.00	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk}+D_{jk})$		**$25,000.00**	**$319,254.46**	**$37,589.29**	**$80,608.63**	**$43,458.33**	**$64,776.79**	**$89,541.67**	**$35,000.00**	**$39,013.39**	**$35,000.00**	**$40,092.26**
												$809,335
$\sum_{j\in V}\sum_{n} Z_n\, \delta_{nj}\, Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	15,800.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$219,784.58

Appendix 5

Scenario 2

Objective Function	max **$982,209.17**	$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} (C^V S_{ijk} + D_{jk}) - \sum_{j \in V} \sum_{n} Z_n \; \delta_{nj} Q_n \frac{1}{e_j} C^P$												
δ_{nj}	Q_n	R_n												
			Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	1
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	1
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	1
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	1
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	1
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	1
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	1
Zircon	4,000	23.50	0	0	0	0	0	0	0	1	0	0	0	1
	76,500													20

$X_{ijk}(C^V S_{ijk})$		Cost of Planned Transport										
		Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia
Richards Bay	1	0.00	279254.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16787.20	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	0.00	0.00	0.00	49541.67	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	8458.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1510.42	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	0.00	13550.60	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	0.00	40608.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	279254.46	2589.29	40608.63	8458.33	13550.60	49541.67	16787.20	4013.39	1510.42	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk}+D_{jk})$		**$25,000.00**	**$319,254.46**	**$37,589.29**	**$80,608.63**	**$43,458.33**	**$48,550.60**	**$89,541.67**	**$51,787.20**	**$39,013.39**	**$36,510.42**	**$40,092.26**
												$811,406
$\sum_{j\in V}\sum_{n} Z_n\,\delta_{nj}Q_n\frac{1}{e_j}C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Appendix 6

Scenario 3: Version 1

Objective Function max **$315,344.88**

$$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C^V S_{ijk} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \ \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	1
Ferro Manganese	1,000	35.50	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	1,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	1
Zircon	4,000	23.50	0	0	0	0	0	0	0	1	0	0	0	0
														11

$X_{ijk}(C^V S_{ijk})$		Cost of Planned Transport										
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271141.37	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	0.00	0.00	0.00	49541.67	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	8458.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	0.00	13550.60	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	0.00	40608.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	0.00	2589.29	40608.63	8458.33	13550.60	49541.67	0.00	4013.39	271141.37	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk} + D_{jk})$		**$25,000.00**	**$40,000.00**	**$37,589.29**	**$80,608.63**	**$43,458.33**	**$48,550.60**	**$89,541.67**	**$35,000.00**	**$39,013.39**	**$306,141.37**	**$40,092.26**
												$784,996
$\sum_{j\in V}\sum_{n} Z_n \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58

Scenario 3: Version 2

Objective Function max $315,344.88

$$max \sum_{n} R_n Z_n Q_n - \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} X_{ijk} \left(C^V S_{ijk} + D_{jk} \right) - \sum_{j \in V} \sum_{n} Z_n \, \delta_{nj} Q_n \frac{1}{e_j} C^P$$

δ_{nj}	Q_n	R_n	Ports											Z_n
Cargo Commodity	**Quantity**	**Freight Rate**	Richards Bay	Algeciras	Koper	Porto Marghera	Savona	Caronte	Efesan	Valencia	Livorno	Castellon	Civitavecchia	
Ferro Chrome	6,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Ferro Chrome	4,000	21.00	0	1	0	0	0	0	0	0	0	0	0	0
Zircon	2,000	63.23	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	1,750	57.00	0	0	0	0	0	1	0	0	0	0	0	1
Zircon	5,500	20.00	0	0	0	0	0	0	0	0	0	1	0	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	3,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	2,000	36.50	0	0	0	0	0	0	0	0	0	0	1	1
Ferro Chrome	6,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	3,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Ferro Chrome	5,000	16.50	0	0	0	0	0	0	0	0	0	0	1	0
Pig Iron	4,500	49.63	0	0	0	0	0	0	1	0	0	0	0	1
Pig Iron	2,000	59.27	0	0	1	0	0	0	0	0	0	0	0	1
Zircon	3,000	57.00	0	0	0	0	0	0	0	0	1	0	0	1
Zircon	3,450	23.50	0	0	0	0	0	0	0	0	1	0	0	0
Ferro Chrome	2,000	45.50	0	0	0	1	0	0	0	0	0	0	0	1
Ferro Manganese	800	35.50	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,300	33.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	2,700	32.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	500	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Chrome Ore	4,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Ferro Chrome	3,000	21.00	0	0	0	1	0	0	0	0	0	0	0	0
Pig Iron	3,000	46.78	0	0	0	0	1	0	0	0	0	0	0	1
Zircon	4,000	23.50	0	0	0	0	0	0	0	1	0	0	0	0
														11

$X_{ijk}(C^V S_{ijk})$		Cost of Planned Transport										
		Richards Bay	**Algeciras**	**Koper**	**Porto Marghera**	**Savona**	**Caronte**	**Efesan**	**Valencia**	**Livorno**	**Castellon**	**Civitavecchia**
Richards Bay	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	271141.37	0.00
Algeciras	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Koper	3	0.00	0.00	0.00	0.00	0.00	0.00	49541.67	0.00	0.00	0.00	0.00
Porto Marghera	4	0.00	0.00	2589.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Savona	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4013.39	0.00	0.00
Caronte	6	0.00	0.00	0.00	0.00	8458.33	0.00	0.00	0.00	0.00	0.00	0.00
Efesan	7	331126.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Valencia	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Livorno	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5092.26
Castellon	10	0.00	0.00	0.00	0.00	0.00	13550.60	0.00	0.00	0.00	0.00	0.00
Civitavecchia	11	0.00	0.00	0.00	40608.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C^V	331126.49	0.00	2589.29	40608.63	8458.33	13550.60	49541.67	0.00	4013.39	271141.37	5092.26
$X_{ijk}(D_{jk})$	D_{jk}	$25,000	$40,000	$35,000	$40,000	$35,000	$35,000	$40,000	$35,000	$35,000	$35,000	$35,000
$\sum_{i\in V}\sum_{j\in V}\sum_{k\in K} X_{ijk}(C^V S_{ijk} + D_{jk})$		**$25,000.00**	**$40,000.00**	**$37,589.29**	**$80,608.63**	**$43,458.33**	**$48,550.60**	**$89,541.67**	**$35,000.00**	**$39,013.39**	**$306,141.37**	**$40,092.26**
												$784,996
$\sum_{j\in V}\sum_{n} Z_n \ \delta_{nj} Q_n \frac{1}{e_j} C^P$		63,200.00	13,430.00	11,060.00	22,120.00	13,825.00	31,600.00	11,060.00	26,333.33	10,763.75	18,762.50	13,430.00
												$235,584.58