# Requirements for Cargo Features on New Parcel Tankers

A Study for Stolt Tankers


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# Requirements for Cargo Features on New Parcel Tankers

## A Study for Stolt Tankers

by

**Julius Jansen**

A thesis presented for the degree of
Master of Science in Maritime Technology
in the Specialisation of Shipping Management
at the Delft University of Technology

**Thesis Exam Committee**

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# Summary

Stolt tankers is the largest operator of deep-sea chemical parcel tankers. Parcel tankers differentiate form bulk chemical tankers by the additional features that the ships have, such as cargo cooling, cargo heating, many (small) cargo tanks, highest level of chemical resistant materials and notation to carry the most dangerous chemicals. These features make the parcel tanker versatile compared to other tanker types, however this results in a higher cost. In the last twenty years, a shift has taken place in the deep-sea chemical shipping industry, driven by changes in regulations, funding of ships and macroeconomic factors. These changes have made the playing field of deep-sea chemical tankers more equal and commoditised, resulting in more competition by entries of new, privately funded companies with simple chemical tankers. Currently a large part of the parcel tanker fleet is nearing their end of lifetime and are expected to be recycled in the next five years. This creates the need to determine operating needs and requirements for replacements of Stolt Tankers' ageing parcel tanker fleet.

The goal of this study is twofold, first, is to determine the need for parcel tanker features in the market and, secondly, to determine the value that these features add. The findings have been concluded in terms of a priority for the feature in a new parcel tanker specification according to the MoSCoW prioritising technique.

Analysis of the features is based on D37 parcel tanker class of Stolt Tankers. This typical parcel tanker class is a candidate for recycling in the next 5 years, and therefore a ideal study object for a replacement study. Four features were identified as giving the highest differentiation of a parcel tanker and are analysed in more detail: cargo cooling, cargo heating with thermal oil heating medium, small cargo tanks, and *ship type 1* notation. These features are analysed both qualitatively and qualitatively on its operation in the Stolt fleet, market demand and supply, competition and alternatives. The net added value of the features over the life of the ship has been calculated by means of a discounted cash flow analysis for base-, best and worst case scenarios.

The cargo cooling feature yields the best added value for a new parcel tanker. The thermal oil cargo heating feature has a negative added net present value for only cargoes with this specific requirement. The study of the ship type notation has a low investment cost, however the loss of revenue by the capacity reduction is far more than potential revenues from the type 1 cargoes. The number of cargo tanks has a large impact of the capital cost of the ship. Reducing the number of cargo tanks, i.e. the average tank size, yields a relatively large saving for parcel tanker ship types. Combined with a decrease in the number of small cargoes, makes this a logical development for future parcel tankers. However, more research is required since there is a large discrepancy between the number of small cargoes on different trade routes.

Based on the findings from the market and operational review of the D37 features the following priorities are given to the features. The cargo cooling system has been given a *'Should Have'* priority, the thermal oil cargo heating system has a *'Could Have'* and the ship type 1 notation a *'Won't Have'*. Further research is recommended for the requirement of features of new ships with respect to the total fleet of Stolt Tankers. Secondly, modelling of cargo tank layouts with the statistical trading data is recommended to determine the requirements for the number and sizes ranges of cargo tanks.

*Simplicity is the Ultimate Sophistication*

- Leonardo Da Vinci

# Preface

The thesis was written by Julius Jansen to fulfil the graduation requirements for the 'Shipping Management' specialisation at the Marine Technology department of the Delft University of Technology. The research was proposed by Stolt Tankers a shipping company in the chemical tanker business.

This thesis is the result of months of work at the Technical University in Delft and Stolt Tankers in Rotterdam. The writing process of this thesis has been challenging as well as rewarding. I would like to take the opportunity to thank all who made it possible to do and finish this work. First of all, my special thanks go out to Ir. Loek Dejong, my daily supervisor and project manager newbuilding at Stolt Tankers, who gave me excellent suggestions and many interesting insights in the chemical tanker business. Secondly, I would like to thank my supervisor at the TU Delft, ir. Koos Frouws, for the guidance in the research process. Also my gratitude goes out to prof. dr. Eddy van der Voorde, who made me decide to dive into maritime economics with his inspiring lectures and anecdotes. I would like to thank Stolt Tankers for the opportunity that they gave me to learn the ins and outs of a shipping company as well as the chemical tanker shipping industry. Next, I would like to thank every one of the Newbuilding Department and Projects Department for the support and information that they provided during this process. Also, I would like to thank my friends for the mental support and suggestions. Finally, my parents and sister who have always been supporting me, especially in difficult times during my studies.

Julius Jansen
Delft, April 2019

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# 1. Introduction

Section 1.1 is introducing the background of the subject of the thesis. In section 1.2 the problem statement that comes forward from the background is translated to the objective of this thesis. In section 1.3 the scope of the project is described. Finally, section 1.4 describes the structure of the and activities of the thesis.

## 1.1. Background

The trade of liquid chemicals is a small part of the total world seaborne trade of goods. Chemical shipping accounted in 2017 for 2% of the total world trade in tonnage shipped [1]. Although the volumes are relatively small, the shipment of chemicals is an important factor in the world economy, since chemicals are widely used in production processes such as in the petrochemical industry, consumer goods, food and medical products. The ships that transport these liquid chemicals in bulk, chemical tankers, are specialised ships. Chemical tankers are able to transport a wide variety of products with high environmental and safety hazards. Operating chemical tankers requires experience and thorough knowledge of the ship operations, logistics and markets.

Stolt Tankers is one of the leading companies in the chemical shipping business, owning and operating a fleet of 158 chemical tankers ranging in size and complexity [2]. As one of the pioneers in chemical shipping, Stolt Tankers has gathered years of experience and knowledge of the chemical business and has formed the parcel tankers business. Together with its main competitor, Odfjell, Stolt Tankers has dominated the deep-sea chemical tanker business for years with the largest fleet of sophisticated parcel tankers. These parcel tankers distinguish themselves from the more common chemical tankers by the additional features such as cargo cooling, heating, and more, small cargo tanks. However, the business model where parcel tankers provide services to a niche part of the chemical transport market seems to be under pressure by various changes in the sector.

The last 20 years have seen developments in the chemical shipping sector that possibly have an impact on the trading needs and technical requirements for the future of the deep-sea parcel tankers. A major impact on the chemical tanker business came in the form of the requirement for new oil tankers to have a double hull in 1996[1] and the (accelerated) phase-out of single-hull oil tankers in 2002. While double-hulls were already standard practice on chemical tankers, the new regulations had the result that an oil product tanker and a simple chemical tanker became technically similar ships. In 2007 a new revision IBC code[2] became active. The revisions in the code were mainly aimed towards the re-categorising of chemicals and the ship type requirements [3]. With only some minor extra adaptions a product tanker could also carry a range of commodity chemical[3]. The easy chemical and oil product shipping markets merged, and in bad times of oil trade, the product tankers switched

[1] MARPOL Annex 1, Reg. 19

[2] the IBC code is part of MARPOL Annex 2 which regulates the control of pollution by noxious substances (i.e. chemicals) in bulk

[3] commodity chemicals are chemicals that are traded in large quantities and are used as basic ingredients for specialised chemicals[4]

to chemicals, giving it the name 'swing tonnage'. The result is that the supply of chemical tankers could quickly change, having a negative effect for the traditional chemical-only fleet that in bad times have to compete with cheaper product tankers. Since the financial crisis in 2008/09, the chemical tanker sector is experiencing difficult times, primarily caused by the oversupply of ships. The cause of the oversupply are the deliveries of vessels that were ordered before the crisis and the penetration of cheap, simple chemical tankers as 'swing tonnage'. Changes in the IBC code and MARPOL regulations combined with the possibility to get funds easily through private equity made that new entries saw opportunities to penetrate the chemical business. The oversupply of ships, the competition of cheap and simple tankers and the growth of the tank container business have made the seaborne chemical transportation business very competitive.

These developments in the chemical sector raise the need to investigate the effectiveness of parcel tankers in the current chemical shipping landscape and to determine the requirements for the next series of parcel chemical tankers.

Secondly, a significant percentage of the deep-sea parcel tanker tonnage that is nearing their end of life. This brings up the need to start investigating the needs and strategies for future replacements taking into account the historical performance of the to-be-replaced fleet and the future developments in the markets. More than 40% of the deep-sea parcel tanker tonnage is planned to be recycled between 2020 and 2025. Stolt Tankers and Odfjell are the only shipping companies operating the deep-sea parcel tankers. Their combined fleet consists of 56 vessels of which 23 (39% of the total tonnage) will be older than 25 years (recycling age) in the next 5 years. The figure 1.1 shows the expected removal of the tonnage of the Stolt and Odfjell fleets. This will, if no new parcel tankers come to the market, not only leave a hole in the market supply in terms of tonnage but also special cargo handling features. These types of vessels have special 'features' such as cargo cooling, the capability to carry the most hazardous cargoes (*IBC type 1*), thermal oil heating and small parcel sizes all needed for handling specialty cargoes.

The question that comes forward is how these older ships, that shaped the parcel tanker business for that last 20 years, should be replaced. Is there still a need for the functions and features of these ships, and what will be the technical and operational requirements going forward? These questions imply that there is a need to investigate the requirements of the market and to evaluate the features on board the parcel tanker fleet to fit market requirements.

## 1.2. Objective

The objective of this research is to investigate if the traditional parcel tanker has a future in its current form, and if not, how a replacement for these current types of ships should look like in the deep-sea fleet of Stolt Tankers.

The objective is to determine the trading need for the Stolt fleet on a selection of round services and to present the technical requirements that are economically viable for a future fleet operating in these services.

## 1.3. Scope

The subject of this thesis is the chemical tanker shipping sector, in particular deep-sea parcel tanker shipping. In this thesis the deep-sea chemical tanker segment is defined by the tanker

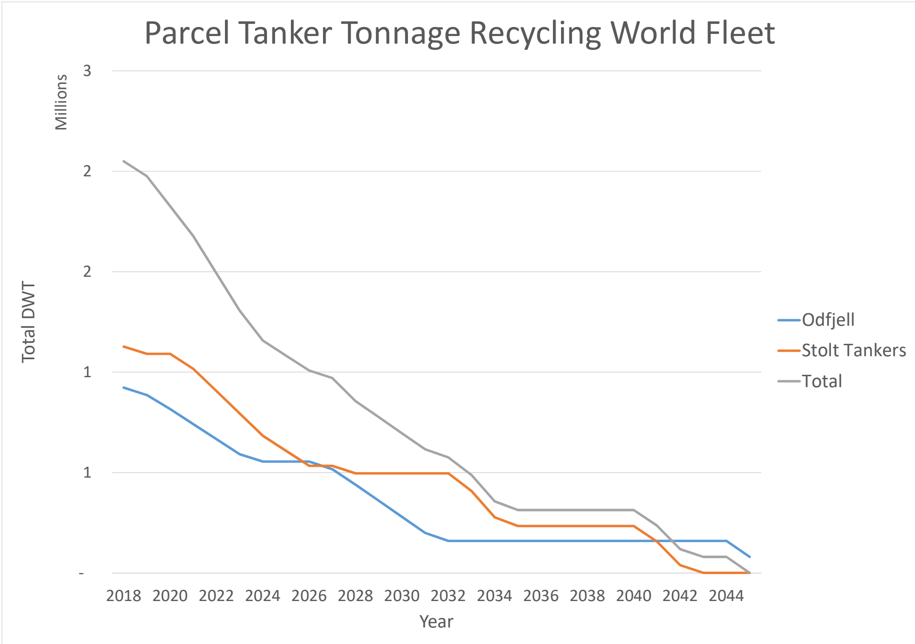



**Figure 1.1.:** Parcel tanker fleet development (expected removals and confirmed newbuildings)
*Source:* Compiled by Julius Jansen from Drewry [5] data.

fleet in the size range of is $15,000 < \mathrm{DWT} \leq 50.000$. This is the size range of ships that operate between continents rather than only in regional areas.

The evaluation of the ship's features is researched on a ship level. The objective for the analysis is one of the ageing series of ships of the Stolt deep-sea fleet, known as the D37 class or 'innovation class'. This D37 class consists of 9 ships that were built between 1995 and 1999 and are, up to today, considered as a trademark parcel tanker. The trading area of these ships are in the North-Atlantic (west- and eastbound) and North-Pacific (west- and eastbound).

The chemical tankers' features only consider the cargo-related equipment, construction and systems. Other engine room machinery, systems and outfitting not part of the cargo carriage and handling are not part of the scope of this research. Examples of machinery not part of the scope are propulsion and power generating machinery and equipment related to crew, navigation and non-cargo related ship operation.

The focus of this approach is from a shipping management perspective, meaning that the focus of the analysis will be on the investment and operational opportunities and risks. The topic has a small overlap with the ship design field regarding the technical analysis of the ships design and systems design. However, the emphasis of this thesis will not be on the specific ship design choices from a technical point of view.

The chemical industry is a relatively closed and nontransparent industry. Scientific research published regarding deep-sea chemical shipping is very limited, therefore the information that is used in this thesis will from a small number of sources. Firstly, Stolt Tankers provided their information on cargo trading, financial and technical detailed of the fleet. Secondly, interviews with various experts in Stolt Tankers contributed to the findings. Third source of information are the reports from various brokers/consultants in the shipping industry, such as Drewry, Clarksons and IHS Markit. Data gathered by these sources on the world chemical tanker fleet, freight rate developments, chemical products as well as insights on other developments in the sector are used in this thesis. While the specific research on chemical tankers is thin, much has been published on shipping in general as well as on other shipping sectors. The work of Stopford [6] is considered a standard work for shipping economics and it will be referenced multiple times in this thesis.

## 1.4. Thesis Structure

The thesis is structured in 7 chapters, starting the introduction. Chapter 2 consists of the analysis of the deep-sea chemical tanker sector. In this chapter, the type of chemical tankers are introduced, the supply and demand characteristics and developments of the last years are studied as well as the competition between companies/ship types. The chapter concludes with a strength, weaknesses, opportunities and threats (SWOT) analysis of the markets on the parcel tanker business of Stolt Tankers. The purpose of this chapter is to give a background on the specifics and developments in chemical shipping sector as these impact requirements for future ships.

Chapter 3.1, contains the study into the features of a parcel tanker and the case study for the future of the D37 class. The chapter starts with a definition of a feature and explores the features that differentiate a parcel tanker. In section 3.2 the case study is introduced including the method that has been used. The sections 3.4 to 3.7 contain the analysis of the individual selected features. Chapter 4 contains the results of the financial evaluation of investment scenarios for the features. In this chapter, the profitability of the features with respect to the investment of a new ship are analysed and compared. The studies is concluded in chapter 5. Finally, chapter 6 will give recommendations for further research.

# 2. The Deep-Sea Chemical Shipping Sector

This chapter consists of a literature study of the chemical shipping sector. The chapter introduces the chemical shipping definitions as well as the developments that formed the sector in the last decades to what it is now. The aim of this chapter is to appoint these developments and determine the impacts on Stolt's tanker business. This chapter forms the background to the study of the requirements of features on for future parcel tankers in the following chapters. The chapter starts with a look at the chemical supply chain and the role of the chemical tankers in the chain. In section 2.2 the different types of chemical and product tankers will be explained, since further in the report the different types will be often mentioned and compared. An introduction to key rules and restrictions acting on the chemical tankers will be presented in section 2.3 because the of the significance in the way it impacts the chemical tankers operations. In section 2.4 the liquid chemical cargoes and the categorisation that is used in the industry are explained. Section 2.5 focuses on the Stolt chemical tanker fleet and subsequently section 2.6 elaborates on the developments in the chemical shipping markets the last 10 to 20 years. The competition of in the deep-sea shipping sector is studied in section 2.7. The conclusions of these sections have been translated into positive and negative impacts for Stolt Tankers by means of a SWOT analysis in section 2.8.

## 2.1. The Chemical Supply Chain

The general logistics chain for a liquid chemical is pictured in figure 2.1. The seaborne transportation is only a small part of the complete production process from raw material to a final product. The supply chain begins with the raw materials that are extracted from the earth and processed in chemical production plant to (base) chemicals. To ship the produced chemical product it is first transported to a terminal in a port by a tanker, barge, pipeline, train or by a truck in a tank container. The chemical product is pumped from the terminal into a chemical tanker that will bring the product to another port to discharge it there at a terminal that will store the chemical. From here the chemical will again be transported (by road, train, pipeline or ship) to the production plant that will use the chemical to produce other, more specialised, chemicals or make products for end-consumers. The supply chain is sometimes shorter if the production plant is located in a port and the facility has its own storage terminal.

The seaborne trade for organic chemicals is about 16% of the total world plant capacity and the average utilisation, the percentage of production of the total plant's capacity is about 73% [7]. This means that only 12% of the produced chemicals are shipped over sea and 88% is used locally or transported by other means. This puts the shipping part of the supply chain in perspective.

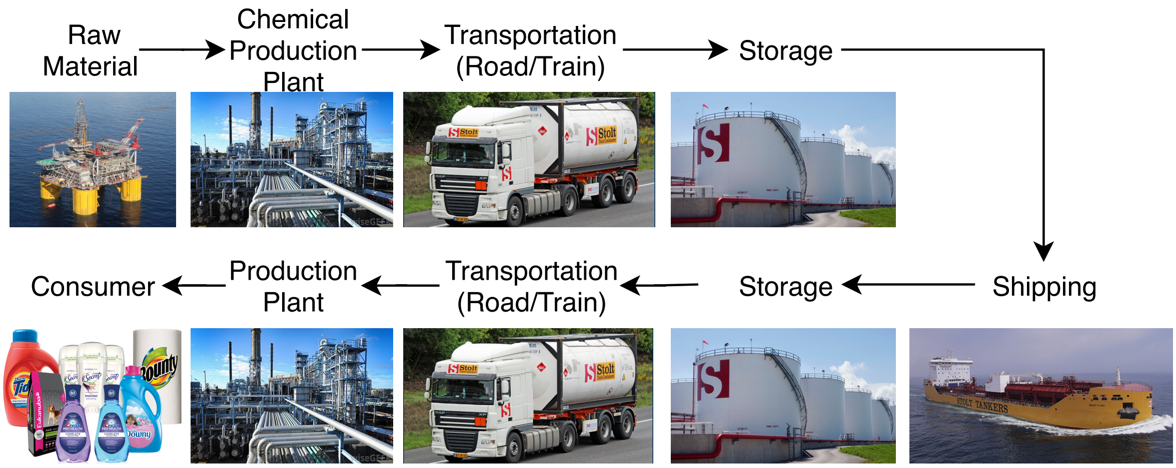



**Figure 2.1.:** Chemical products logistics chain.
*Source:* Own work, pictures used from Stolt and other sources.

## 2.2. Types of Chemical Tankers

A crude oil tanker, a product tanker, chemical tanker and parcel tanker look very similar on the outside. Although all these types have the same purpose to transport liquid cargoes from port to port, there are essential differences between these types of ships that are reflected in the cargoes that are transported, the equipment, materials and construction that is used. This section describes the main characteristics of and differences between the tanker categories that are subject to this thesis. Detailed analysis of the world chemical tanker fleet and the technical characteristics of a chemical tanker are done further in the thesis in sections 2.6.2 and 2.5.

### Chemical Tanker

The chemical tanker fleet can be split into three categories of chemical tankers; the parcel tanker, the (bulk) chemical tanker and the product/chemical tanker. The bulk chemical tanker CT is a type of tanker that is designed to carry chemicals in bulk in multiple tanks, each fitted with its own cargo pump. MARPOL and the IBC code define a chemical tanker as 'a cargo ship constructed or adapted and used for the carriage in bulk of any liquid product listed in chapter 17' of the IBC code [8]. Thus, on a regulatory level a chemical tanker is differentiated by these types of products that it is allowed to ship. There can be a confusion in the use of the term 'chemical tanker' as it is often used for all types of vessels that transport chemical oil products. In this thesis the chemical tanker is considered the 'bulk' chemical tanker or 'commodity' chemical tanker which is defined by the criteria in table 2.1.

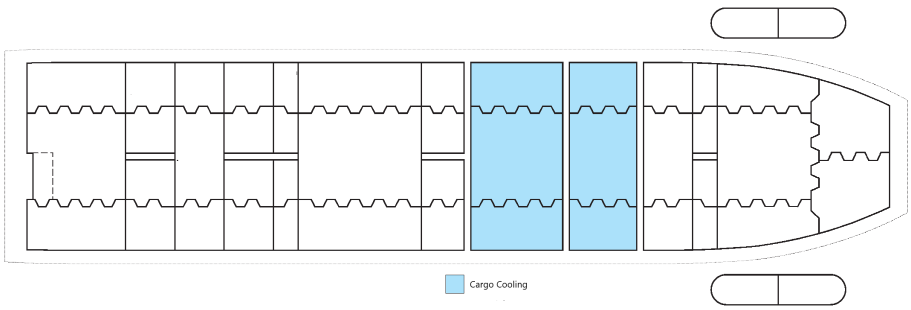
### Parcel Chemical Tanker

The parcel tanker, sometimes referred to as 'super-segregator' or shorted to PT, is a chemical tanker that differentiates from 'normal' chemical tankers and product tankers by the number of segregations (cargo tanks) and the overall complexity of the construction and equipment of the ship. Parcel tankers are able to carry a wide variety of chemicals at the same time in up to 52 different tanks. The expression 'parcel tanker' was coined in the 1950s when Jacob Stolt-Nielsen pioneered with a new tanker design featuring submerged cargo pumps in every cargo tank and more, smaller tanks. There is no universal definition for parcel tanker, as it is mainly used by Stolt Tankers and Odfjell. In this thesis, the following criteria, see table 2.1 is used to define a parcel tanker, chemical tanker and product/chemical tanker.

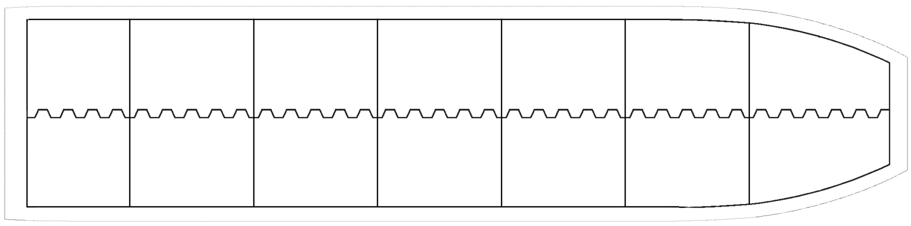
**Table 2.1.:** Tanker type criteria definition

| Criteria | Parcel Tanker | Chemical Tanker | Product/Chemical Tanker |
|---|---|---|---|
| Average tank size [1] | $\leq 1,000$ | $1,000 <$ and $\leq 3,000$ | $> 3,000$ |
| Ship type | type 1/2/3 | type 2 | type 2/3 |
| Cargo Tank Coating | STST | STST/coated | coated |
| Cargo segregation | Full segregated | Full segregated | $\leq$ full segregated |

The number of deep-sea parcel tankers in the chemical world fleet is relatively small with 56 vessels representing 2.3% of the world chemical tanker fleet in 2017 [9]. Figure 2.2a shows a typical tank layout of a parcel tanker. Larger tanks ($2,000m^3 - 3,000m^3$) are alternated with smaller sized tanks ($< 500m^3$). Often a selection of tanks is able to carry cooled cargoes and other tanks have the ability to heat the cargo using thermal oil, instead of the standard hot water. Many parcel tankers have deck tanks for the reason that some cargoes have requirements to be transported in tanks that do not contribute to the integral structure of the vessel. Parcel tankers require high capital investments compared to the other tanker types, but this is justified by the ability to sail consistently with higher loading factors (fewer ballast legs) than the other tanker types.




**(a)** Parcel tanker



**(b)** Product/chemical tanker

**Figure 2.2.:** Tank plans for typical parcel and chemical/product tanker.
*Source:* Stolt Tankers

## Product/Chemical Tanker

The product tanker is a tanker designed to transport oil products and the easy chemical oil products. There are two types of product tankers, the Clean Petroleum Product (CPP)

[1] $\left(\frac{DWT}{\text{no. cargo tanks}}\right)$

tankers and the Dirty Petroleum Product (DPP) tankers. Clean Petroleum Product are oil products produced from crude oil refinements, such as gasoline, kerosene, naphtha and clean condensates. Dirty Petroleum Product are crude oil, heavy fuel oil and diesel oil. This thesis will only focus on Medium Range (product) tanker (MR) type product tankers that range in size from 35,000 to 55,000 DWT as this size range is competing with the chemical/parcel tanker fleets. The product tanker is much less complex compared to a chemical tanker and parcel tanker. It has fewer but larger cargo tanks that are coated instead of stainless steel. Figure 2.2b shows a typical tank layout of a MR product tanker with 14 segregated cargo tanks. A product tanker can change trade from dirty to clean products or from clean product to easy chemicals by special cleaning its cargo tanks. This makes this type of vessel very flexible to adapt to changes in market demand. Drewry defines two types of product tankers, with and without coated tanks [10]. The product tankers with coated cargo tanks that are able to carry type 2 or 3 chemical cargoes and with an average cargo tank size greater than $3,000m^3$ are part of the scope of this project. These ships are called 'swing tonnage' because they can 'swing' from the oil product market to the (commodity) chemicals market.

### Deep-Sea Chemical Tankers

A distinction between chemical tankers can be made based on the area where they trade or the trade route they are operating on. Ships that operate between continents are referred to as deep-sea ships, while regional ships are operated in a specific area, not crossing oceans. The deep-sea vessels are trading between the main chemical hubs (ports such as Rotterdam, Antwerp, Houston, and Singapore) according to the hub-and-spoke model. According to the hub-and-spoke model the large ships trade between hubs and regional ships trade between smaller ports and/or these main hubs with the goal to reduce the number of routes for a ship, increasing efficiency. The regional vessels are in general smaller in capacity than the deep-sea vessels. There is not a strict criterion for the size of a deep-sea or regional vessel. In general ships smaller than 15,000 DWT are operated in the regional trade, while ships larger than 15,000 DWT are generally operating on deep-sea trade routes. The cross-over range is between 10,000 and 15,000 DWT. Vessels in this range are used for both regional as well as deep-sea trading. In this thesis vessels larger than 15,000 DWT and smaller than 50.000 DWT are considered as chemical deep-sea vessels. When deviating from this definition a note will be made. This can happen in cases where the available data set uses a different convention.

### Chemical Tankers Compared to Other Tanker Types

Figure 2.3 shows the relation for the specialisation of the vessels against the profit variability for different tanker types. The group of chemical tankers can be described as highly specialised with relatively stable profits. The diversity of the different cargoes that can be carried on a chemical tanker and the barrier for new entries in the market ensures stable profits. The complexity of operating chemical tankers forms this barrier and is due to many rules and cargo planning requirements. This is less the case with other tanker types, hence the lesser specialisation and profit stability. Sub-types can be identified for chemical tankers that differ in complexity and ability to carry different chemicals.

#### Lateral Cargo Mobility

Lateral cargo mobility LCM is the principle that shipowners can redeploy their surplus vessels into more profitable applications in other sectors of the market [6]. The lateral mobility is the

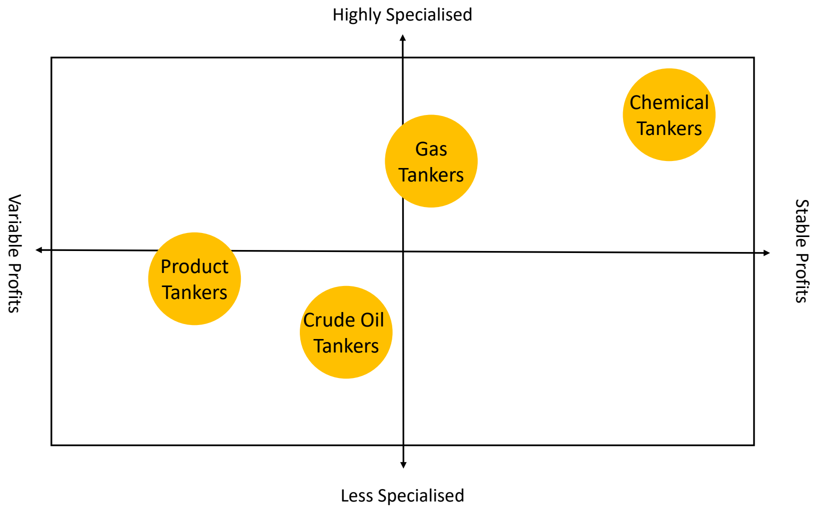



**Figure 2.3.:** Specialisation to profit relation of tanker markets generalised. According to figure in MOL Mitsui O.S.K. Lines [11]
*Source:* Julius Jansen

flexibility, by the design of the ship, to change between specialisations in the market. Parcel tankers have a high lateral mobility in the liquid bulk markets as they are able to operate in different sectors of the bulk liquid markets. Figure 2.4 shows the various tanker types and the cargo types that they are able to transport. The number in the circles shows the lateral cargo mobility rating (LCM rating), the sum of the number of cargo types the ship is able to transport. The parcel tanker has the highest score followed by the bulk chemical tanker. The solid lines in the figure present the core business of the ships and the products, while the dashed lines show the non-core business. The non-core business of the ships means that the ship is technically capable to carry the type of product, but it is not economically viable. Only in exceptional cases will ships diverge to non-core business cargo operations. For many cases a parcel tanker is not a viable when competing with better suited ships or because of the lower income from these cargoes that do not offset the high cost of operating a parcel tanker.

## 2.3. Rules and Regulations for Chemical Tankers

The chemical transportation comes with risks to the environment, the ship and its crew. Hazards that are part of transporting chemicals are for instance fire/explosion, corrosive, toxic, etc. To control these hazards rules and regulations are of major importance for the safe operation of chemical tankers. Many of the rules for chemical transport are internationally made by the IMO and classification societies. The rules have a large influence on the way ships are constructed and operated. The most important regulations will be described below.

### 2.3.1. IMO/IBC Chemical Tanker Types

The IMO has adopted the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (International Bulk Chemical Code), often shorted to IBC Code, in 1983 in order to provide international design and equipment standards for the carriage of chemicals in bulk by sea. The code defines rules for ship construction and equipment depending on the type of cargoes that are transported. The code defines three ship

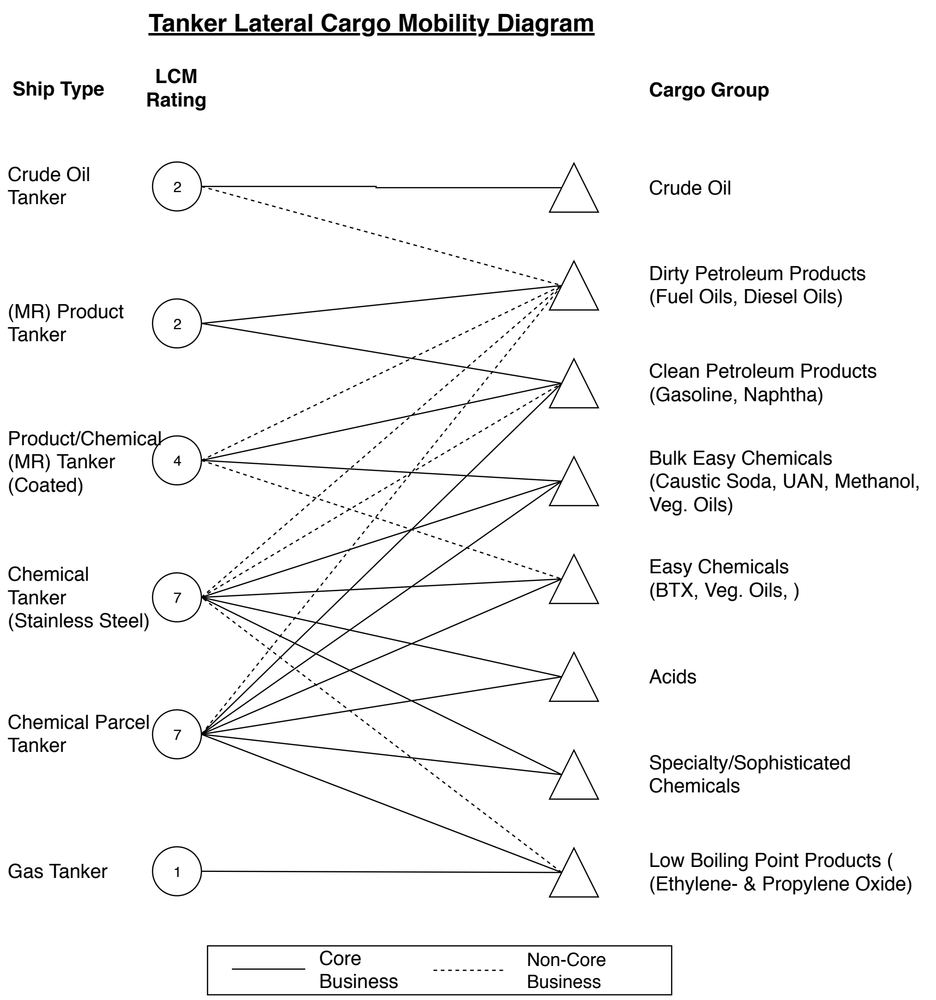



**Figure 2.4.:** Generalised overview of the lateral cargo mobility of tanker types
*Source:* Own contribution, based on example in Stopford [6]

types that are intended to transport chemical cargoes of increasing safety and environmental hazards. The three ships types are defined as following [8]:

- A *type 1* ship is a chemical tanker intended to transport chapter 17 oil products with very severe environmental and safety hazards which require maximum preventive measures to preclude an escape of such cargo.
- A *type 2* ship is a chemical tanker intended to transport chapter 17 oil products with appreciable severe environmental and safety hazards which require significant preventive measures to preclude an escape of such cargo.
- A *type 3* ship is a chemical tanker intended to transport chapter 17 oil products with sufficiently severe environmental and safety hazards which require a moderate degree of containment to increase survival capability in a dangerous condition.

Chapter 17 of the IBC Code lists the chemical oil products and their the minimum requirements, such as ship type, tank type, venting arrangement, environmental control, fire protection and other required equipment. A type 1 ship automatically has the ability to carry type 1, type 2 and type 3 oil products, while a type 2 ship can carry type 2 and type 1 oil products. Location and construction of cargo tanks for the cargo/ships types are subject to the following restrictions, see figure 2.5. The tank configuration requirements for type 3 vessels are practically obsolete for tankers with the 'oil tanker' classification, because of the OPA90 and MARPOL requirements for double hull tankers and the phase-out of single hull tankers. Note that the double hull requirement is applicable to ships that are defined as "oil tanker" and not for chemical tankers. However, almost all chemical tankers also have the oil tanker classification in order to comply to the rules to carry oil products. Thus, in practice all chemical and product tankers have double hulls[2].

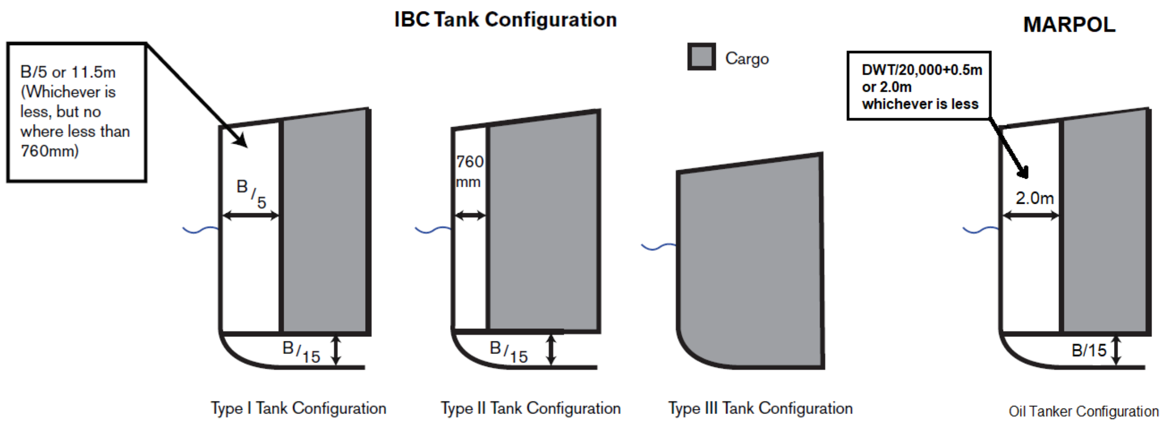



**Figure 2.5.:** Location of cargo tank by ship type.
*Source:* Compiled by Julius Jansen using example from Intertanko [3]

## 2.3.2. Cargo Tank Restrictions and Cargo Placement Limitations

The ship types and products that were discusses in section 2.3.1 are not the only limitations that are subject to chemical tankers. There are many rules in place to mitigate/reduce the risk of dangerous situations. The IBC, Class rules, Procedures & Arrangements manual give

[2]According to Drewry [12] there are no internationally trading chemical tankers anymore with a single hull

rules and guidelines for proper loading and transport of chemicals. An important rule is that no toxic chemicals can be placed in neighbouring tanks with edible products (vegetable oils/animal fats). Slops (product residues that remain after stripping and tank cleaning) cannot be collected in the same slop tank or transported through the same lines, if they react with each other. Products that can react with water are not allowed to be carried in cargo tanks next to loaded water ballast tanks nor heated by hot water. Thermal oil should be used instead as a heating medium for these products. When the product does not require heating the heating coil should be blown-through with with nitrogen, cleaned and closed-off from the heating medium supply. Some cargoes are not to be exposed to excessive heat, as heat can cause a self-reactive process. Those types of cargoes cannot be stored in a parcel next to a heated parcel or in deck tanks. It is recommended (not required) to not place cargoes with a low boiling point in a parcel next to a heated product. This is recommended in order to reduce the vapour hazard or the polymerisation of the cargo.

The cargo coating or stainless steel type can also have a limitation of the cargoes that can be carried. Coating specifications or requirements by the IBC can state products that are allowed to be carried. Duplex stainless steel is considered to have the highest chemical resistance. More detailed analysis of cargo tank coatings and materials is done in section 3.6.

### 2.3.3. Port and Flag State, and Customer Safety and Quality Demands

Not only the regulatory bodies set requirements for chemical tankers. The owners of the cargoes, often oil- or chemical majors (Dow, Shell, etc.) have requirements in place in order to safeguard their products and limit the risk of pollution and contamination. The cargoes are very valuable and an accident can lead to large losses and negative publicity for the cargo owner. Therefore chemical tankers and cargo handling are subject to strict vetting requirements made by the cargo owners that have gathered in the Oil Companies International Marine Forum (OCIMF). The two predominant vetting regimes are the SIRE and CDI. The regimes follow a risk assessment based on the ships certificates and an inspection of the condition of the ship and systems. The score of the assessment is kept in a database available for the cargo owning company. Based on the score a charterer can exclude a vessel or shipping company from transporting their cargo.

Many owners of edible products require that the last three cargoes are tracked. Depending on the type of these last three cargoes it can be that a new cargo is not allowed to be carried in that cargo tank. For example, a 'list of banned previous cargoes' is maintained by the FOSFA (Federation of Oils, Feeds and Fats association) in order to control the risk of containment of edible products with other (toxic) chemicals [13].

Charterers, ports or states can make restrictions regarding the operation of a vessel above a certain age. For example, the state of Israel has an age restriction of 20 years for vessels that transport chemicals in bulk in the Israeli territorial waters [14]. In general, Western European and North-American states have age limits to 15 years for specific products, while Asian countries are a bit more flexible in allowing older vessels. A result of these age restrictions the fleet of chemical tankers is relatively young compared to other vessel types depending on trading area.

When carrying 40 different cargoes on board a vessel, each with a different owner, the vetting, cargo handling operations and safety procedures can be complex and time-consuming. It requires a sophisticated stowage, fleet logistics, planning and administrative tools as well as knowledge of the products and the rules to efficiently and effectively operate a fleet of chemical and parcel tankers.

## 2.4. Liquid Chemicals

To understand why chemical tankers are constructed and operated in the way they are, the cargo that they are carrying needs to be studied. The products that are transported by chemical tankers are very diverse. Products of type 1,2 and 3, as described in chapter 17 of the IBC code, consist of hundreds of oil products. Figure 2.6 shows the distribution of number of cargoes over the three chemical classes[3]. Oil products can be divided into 4 groups based on their chemical composition:

- Organic chemicals
- Inorganic chemicals
- Vegetable oils, animal fats and molasses
- Other

Organic chemicals are chemicals that contain carbon molecules, petrochemicals such as ethylene, propylene, toluene, benzene. Products derived from the crude oil refining process are organic chemicals such as naphtha, kerosene, gasoline, and other oil distillates. The group of organic chemicals is the most traded chemical group totalling 117.6 million tonnes in 2017, 48% of the total seaborne chemical trade [10]. Inorganic chemicals are chemicals that do not consist of carbon molecules, examples are acids, bases, salts (ionic compounds). The annual trade of inorganic chemicals in 2017 was 33.5 million tonnes, 14% of the total seaborne chemical trade. The third group consists of the vegetable oils and animal fats. These oil products are generally less hazardous than organic and inorganic chemicals. The main transported vegetable oils are palm oil, coconut oil, soybean oil, linseed oil. The animal fats, such as tallow and lard, have to be transported while being heated in order to keep it liquid. The vegetable/animal oils and fats count for 32% of the total chemical trade. The last 6% count for other products such as ethanol (which is actually an organic product), molasses and urea ammonia nitrate (UAN). Molasses are a by-product of the sugar refining process and are characterised by the high viscosity. An example of a molasses product is syrup.

In literature often the distinction is made between specialty and commodity chemicals. The definition of both is not well defined and therefore it is difficult to quantify the traded amount by the different ship types. The general consensus is that a specialty chemical is a chemical that is used on basis of their function or performance for a specific purpose rather than their composition. A commodity chemical, or bulk chemical, is a product that functions as the building block of other products or processes, are independent on the producing party (i.e. no brand) and are generally produced and shipped in larger quantities than specialty chemicals. Concluding, there are different ways to group chemicals products. Chemicals can be grouped according to their hazards (IMO), according to their origin (organic, inorganic, vegetable) or according to their use (commodity, specialty).

## 2.5. The Stolt Deep-Sea Fleet and Trade

The Stolt Tankers deep-sea fleet consist of 70 ships ranging from simple chemical tankers to complex parcel tankers. The deep-sea vessels in the Stolt fleet are grouped in ship classes that consist of ships that are designed and build with the similar specifications. The deep-sea ships of Stolt are grouped in 19 ship classes, with 1-9 ships per class. For analysis further on

[3] From the database of all actively traded products from Stolt Tankers

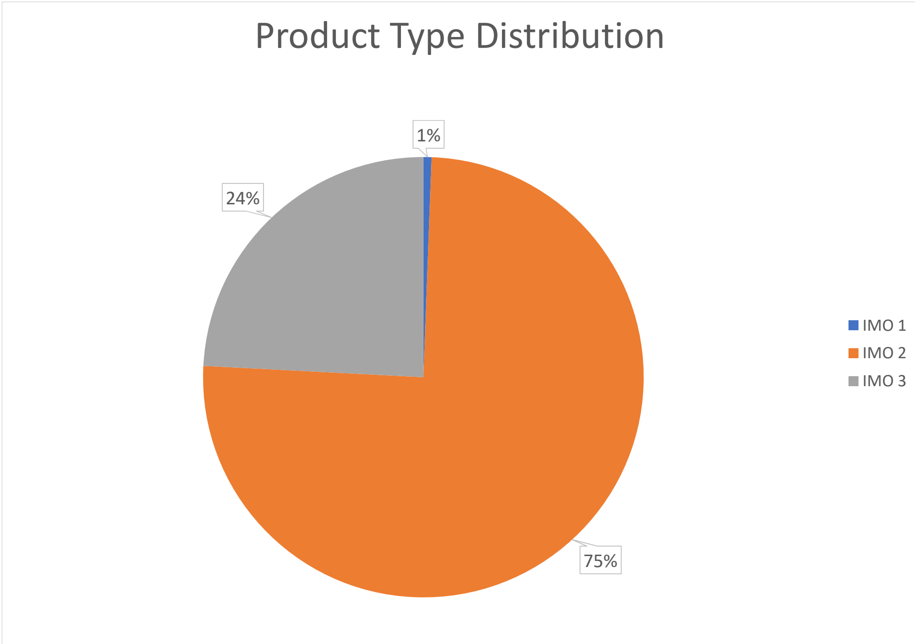



**Figure 2.6.:** Product type distribution by number of unique product names in Stolt's active product database
*Source:* Compiled by Julius Jansen from Stolt Tankers databases

in the project a distinction is made for the Stolt ship classes based on the size and complexity. Table 2.2 gives the sorting criteria and the Stolt's ship classes that corresponds to the defined masterclasses. The complexity relates to the number of segregations (segs) and the size (small, medium, large) to the DWT capacity. Stolt does not have ships that could classify as 'Small Simple' and 'Medium Simple'. The size of the vessels and number of segregations per DWT are not the only factors that define the complexity of the ship.

The Stolt fleets stands out in the chemical tanker sector by the scale as well as the number of Large Very Complex ships, the parcel tankers. Stolt tankers has the largest pure chemical tanker fleet[4]. Stolt and its main competitor Odfjell are the only two companies operating Large Very Complex tankers. For Stolt this vessel type counts for the majority of the tonnage in its fleet and it therefore the core or the business operations.

### Traded Products and Parcel Quantities

Since there are so many different products that are transported, it is easy to lose sight of the trade flow of products. In this sense the chemical trade differentiate from crude oil where the product homogeneous and trade routes are main trade routes are fixed. The diverse variety of product results in a blurred overview of importers and exporters. Therefore each type of product and trade should be analysed separately in order to understand to total chemical trade. Based on the trade data from the deep-sea fleet of Stolt Tankers, a map is made to see which product (groups) are transported from the different trade routes by which ships.

Figure 2.7 shows the average parcel quantity (tonnes and CBM) per product group. The product groups liquid fertiliser, inorganic acids and methanol are not displayed in the figure.

[4]when not counting the product tanker fleets

**Table 2.2.:** Stolt deep-sea vessel classes and criteria
*Source:* Compiled by Julius Jansen from Stolt's data

| **Code** | **Master Class** | **Ship Type** | **Ship Classes** | **Criteria** | **Ship Price** |
|---|---|---|---|---|---|
| SC | Small Complex | CT | J19, J23, S22 | 19-24.9 kdwt, $\geq$ 21 segs | m$ 25-35 |
| MC | Medium Complex | CT | J25, I27 | 25-29.9 kdwt, $\geq$ 27segs | m$ 30-40 |
| LC | Large Complex | CT | J33, C33, C30, J30 | $\geq$30 kdwt, 27-36 segs | m$ 30-60 |
| LVC | Large Very Complex | PT | C38, D37, F37,N37 N43, N38 | $\geq$30 kdwt, $\geq$ 37 segs | m$ 60-90 |
| LS | Large Simple (STST) | CT | J32, N30, J33 | $\geq$30 kdwt, $<$27 segs | m$ 35-45 |
| LS | Large Simple (coated) | MR/CT | K44 | $\geq$30 kdwt, $<$27 segs | m$ 30-40 |

The average parcel sizes of these products are much larger than the other products, namely 22,000, 20,000 and 7,500 tonnes respectively.

On of the main design dilemmas of chemical shipping is the amount and volume of the cargo tanks that a chemical tanker has to have to efficiently trade a range of products. As was explained in section 2.6.1 there are commodity and specialty chemicals that both fall in the trade portfolio of parcel chemical tankers. The types of these cargoes come in ranging quantities. Figure 2.8 shows the number of cargoes and the volumes per parcel size as percentage of the total. The figure shows that 50% of the products traded by the Stolt Fleet total only accounts for 14% of the total tonnes transported. At the same time a small percentage of parcels (15%) accounts for the majority of the tonnage transported (55%). The freight revenue is based on the freight rate ($/tonne), so the large volume cargoes have a large part in the total freight revenue. The specialty chemicals often come in small volumes ($< 1000m^3$), while many commodity chemicals are shipped in larger quantities. The IBC code restricts that the quantity to be carried on board shall not exceed $1,250m^3$ for *type 1*- and $3,000m^3$ for *type 2* cargo tanks (note that a specialty product is not the same as a *type 1* product). The largest cargo tanks of the Stolt ships are smaller than $3,000m^3$ in order to load the maximum quantity of type 2 product and still to be flexible when larger volumes have to be carried in multiple tanks. However, of the 55 %vol. of the cargoes that come in quantities larger than $3,000m^3$ 31% are type 2 products, 33% are type 3 products and 9% has no IBC requirements. These 9% are oil and CPP products that do not categorise as chemical products. This means that 37% of the total volume transported is *type 3* or non-chemical and larger than $3,000m^3$. From a competitive perspective, these products are ideally transported in one tank instead of multiple tanks. Product tankers have a lower cost per cargo tank and are therefore more cost efficient in handling these large volumes parcels compared to parcel tankers that may need multiple tanks for one large cargo.

This example shows the cost of flexibility in a market that partly consist of commodities in large volumes and partly of specialty cargoes in small volumes. A parcel tanker that ships both the specialised cargoes as well as the commodity cargoes has a higher running cost than a MR tankers. Since the price of cargoes is determined by the lowest bidder, the prices for the commodity cargoes are generally set by the rates of the MR tankers. The parcel tanker thus has a cost disadvantage compared to these ships and this puts a stress on the rates of small cargoes that have to make good the relative difference in income. Note that figure 2.8

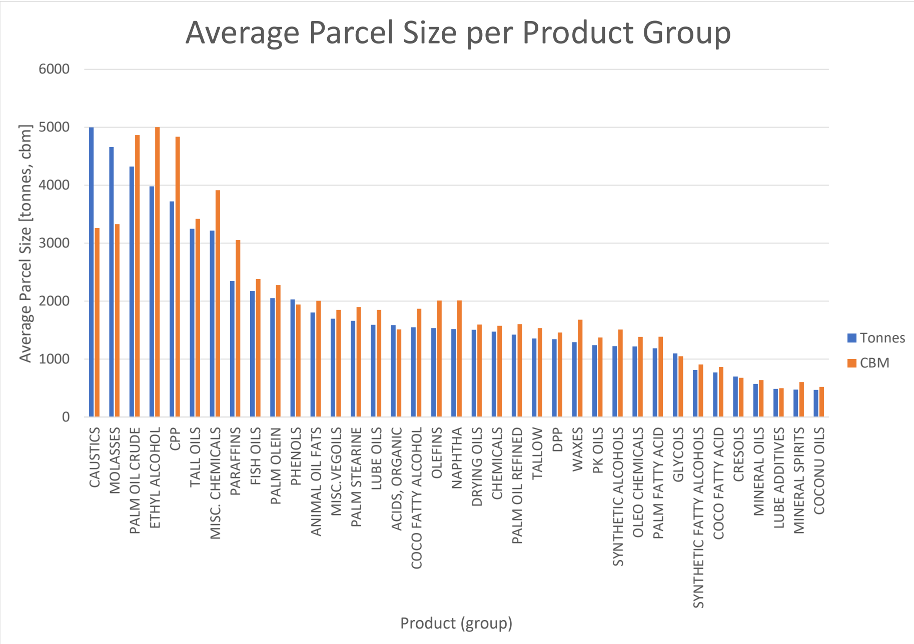



**Figure 2.7.:** Average parcel size per cargoes group
*Source:* Compiled by Julius Jansen from Stolt data

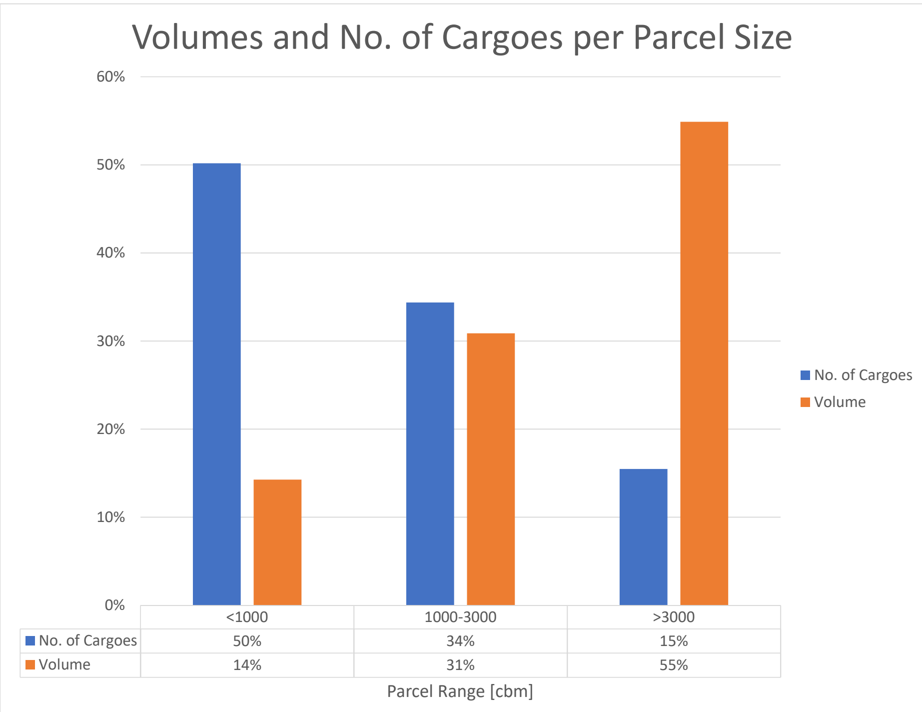



**Figure 2.8.:** Percentage of number and total volumes traded per parcel size range.
*Source:* Compiled from 7 years trade data of Stolt deep-sea fleet.

represents the Stolt D37 parcel tanker trade portfolio, it does not reflect the total chemical market. Other chemical transporting companies might show different ratios based on their fleet and trade portfolio. Comparing the the large and simple ship classes against the large complex classes the ratios change to 32%/5% (no.cargoes/volume) and 55%/18% respectively for the small parcel size ($< 1,000m^3$).

### Parcel Tanker Liner Service

The Stolt deep-sea fleet is operating in different pools on multiple leg and round services. The parcel tanker trade is characterised by a liner service type logistic. Parcel tankers operate in a pool of tankers that rotate ports in a certain schedule. For example, for the North-Atlantic fleet, a ship loads and discharges cargo in Antwerp and Rotterdam and sails to the US Gulf where is will call multiple ports and terminals to load and discharge before it sails back to Europe. The port call order varies based on variables such as available cargoes and/or time available for contracted cargoes. This operating approach is different from the other crude and bulk trades that operate with no schedule (tramp shipping). The container liner services that have often weekly schedules of ships entering a port. However, large container ships schedules and spend a relatively short time in port. Parcel tankers, have a high number of movements in port compared to other ship types, because of the different products that are loaded and discharged and the distribution of different producers and terminals in ports [15]. The number of ships that operate on a round service determines the time between ships calling a port. If a typical round trip on the North-Atlantic service takes 42 days to complete for one ship, this means that a port (like Rotterdam) is visited once every 42 days. With 2 ships this time reduces with 21 days and with 3 to 14 days between ships in a port. The number of ships on a route is optimised for the best returns given the available freight in the ports and fuel prices. Multiple studies have tried to model and optimise these logistics of parcel tanker services with linear programming approaches [16].

## 2.6. The Deep Sea Chemical Shipping Markets

This section will analyse the supply and demand of the global deep-sea chemical transportation markets. The section elaborates on the developments in the last 15 years and the future outlooks. In section 2.6.1 the developments in the demand side of the chemical transportation market is analysed. The section looks at the world economy, the supply and demand of chemicals and the trade flows that follow it. Section 2.6.2 covers the supply side of the seaborne chemical transport and its global chemical tanker fleet. In section 2.6.3 the freight markets are reviewed. And the section is concluded with 2.6.4 where the historic and expected future developments are summarised.

### 2.6.1. The Demand for Chemical Seaborne Transportation

The demand for transport of chemicals is determined from the geographical imbalance of the producers and consumers of chemicals. The global demand for certain chemicals comes from the countries or regions that experience a deficit. Demand for seaborne trade is created by connecting exporting areas with importing areas over the world. Areas in the world where chemical production facilities have a production surplus will export to to countries that have otherwise a deficiency of the products. The demand for sea transport is influenced by five determinants according to Stopford [6]. These five determinants are the world economy, seaborne trade, average haul, political factors and transport cost. In this section, the demand for chemical seaborne trade is studied by analysing these five determinants.

#### Correlation with the World Economy and Other Shipping Markets

Figure 2.9 shows world merchant trade per commodity type over the period 2000-2017. Steady ton-mile trade growth of 2-6% is noticeable in all sectors over the 17 years. The seaborne chemical trade is relatively small compared to the total merchant seaborne trade. With a trade of 1039 billion ton-miles in 2017, the chemical trade counted for only 2% of the total seaborne trade. This gives a perspective of the size of the chemical trade compared to the total world trade. The chemical tanker trade growth averages 3.8% over the last 17 years, including the dip in 2009 caused by the global economic crises.

The world seaborne trade, as well as the trade growth of chemicals, are closely correlated with the growth of the world economy. The growth of the world economy can be measured using the world GDP, which is the sum the GDPs of all countries. The world GDP grew between 2002 and 2017 on average 3.1% year on year, while the seaborne trade grew on average 4.0% [1]. Figure 2.10 shows the seaborne chemical trade and the world GDP. The figure shows that there is a strong correlation between the world economy and the seaborne chemical trade. The correlation coefficient of the two data sets is 0.83 which is considered a strong positive correlation. The chemical trade grows on average between 1.0% and 1.5% faster than the world economy every year. The figure shows that in 2008 the chemical trade declined compared to the world GDP and in 2009 this was followed by the dip in the global economy while the chemical trade recovered, this is shown in the figure by the zigzag. More recently, 2015 and 2016 were years where the chemical tonne-mile trade grew, while the global economy (world GDP) decreased below values of 2013 and 2014. In these two years the global economy slowed, caused by the slowdown in economic activity in China and other emerging economies, dropping commodity prices and declining investments [17]. The chemical trade growth increased due to the increase in demand and shipping distances (average haul).

The seaborne chemicals market, the oil products market and the crude oil market are strongly correlated. This can be expected since oil products, as well as a large part of the

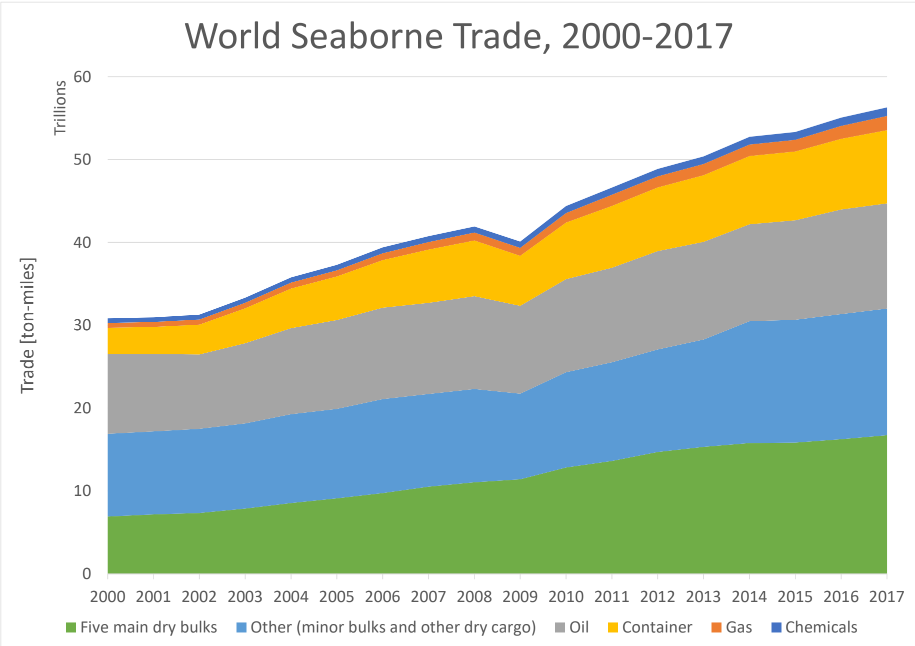



**Figure 2.9.:** World merchant trade by type over 2000-2017.
*Source:* UNCTAD [1]

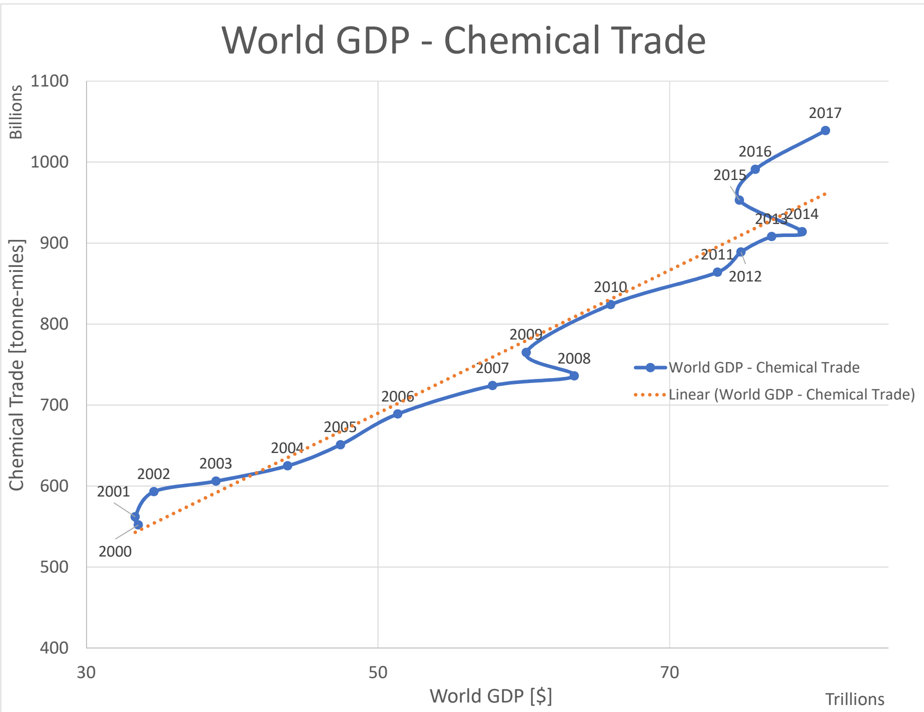



**Figure 2.10.:** Seaborne chemical trade vs world GDP.
*Source:* UNCTAD [1] and The World Bank [18]

chemicals, are derived from crude oil. Figure 2.11 shows the 12 month rolling average of the spot earnings for the product and crude oil spot market compared to the average of the Stolt Tankers and Odfjell freight indexes. In general, the chemical markets are less volatile compared to the crude and product markets. The chemical markets follow the oil markets with a delay of some days to weeks. This delay is caused by the price transfer of the crude as a resource in the crude oil-derived chemicals.

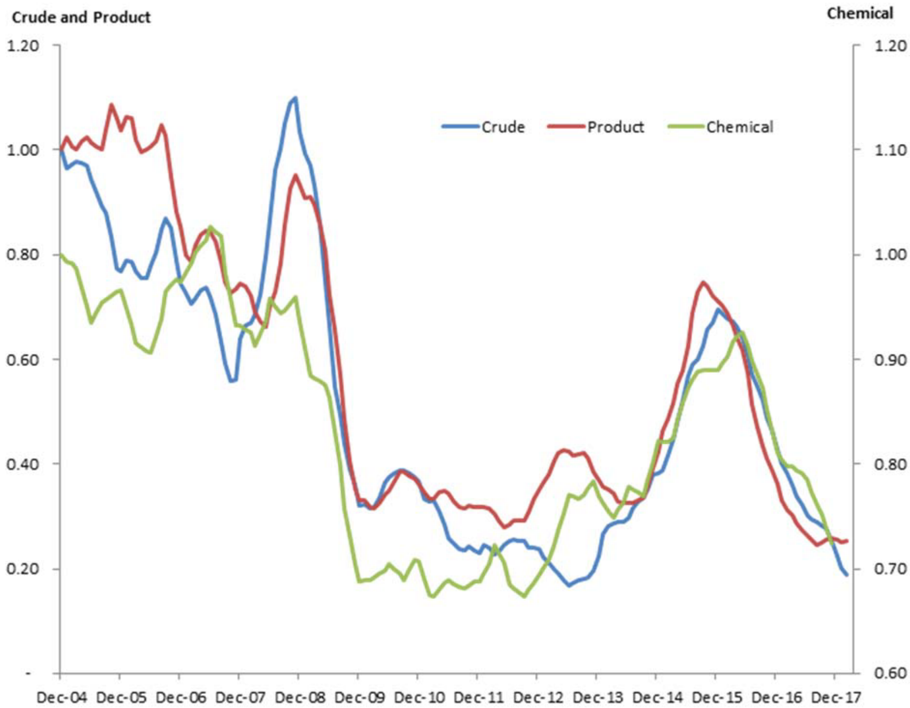



**Figure 2.11.:** Rolling Average of spot earnings for crude and product tankers and the combined average freight indexed from chemical majors Odfjell and Stolt Tanker.
*Source:* Stolt-Nielsen [2]

Organic chemical products count for 48% of the chemical trade (section 2.4), so it is not a surprise that there is a correlation between the chemical markets and the crude oil and oil product markets. However, this does not fully explain why the markets are so closely correlated, since 52% of the chemical trade is not organic. The following oil price-related variables affect the chemical markets: energy cost, price setting and commodities required for specialty chemicals [19, 20]. Many processes in the chemical industry have a high energy demand. In areas where the energy price is closely correlated to the oil price (oil powered energy plants) the correlation between the oil and chemical prices is close. Another factor is the price-setting that is used for easy chemicals by a marginal producer. A marginal producer is a company that produces a small volume, relative to the total market volume, of a product with a small profit margin and a price that depends highly on the production cost. This means that a shock in the oil price is directly affecting the price of these commodity chemicals. A change in the price of the commodity chemicals impacts the specialty chemicals downstream since commodity chemicals are often used in the production processes of specialty chemicals. A part of the change in the price of the commodity chemicals is passed on in the price of the specialty product. This implies that parcel tankers are less affected by the price volatility of the oil market, than the chemical tankers and chemical/product tankers which ship more commodity chemicals.

A shift in demand can be a factor in the longer term. When oil prices go up the spending patterns of consumers change when the price remains high for a longer term. An example, of this demand change is when people postpone expensive purchases such as cars or housing projects. These changes will trickle down to the producers of the goods and affect the demand for chemicals and other production materials. This is the main economic mechanic that creates the close correlation between the chemical shipping demand and the world consumption economy.

The conclusion is the world chemical demand is closely related to both the world economy and the oil markets.

### Trade Routes and Average Haul

Trade routes, or trade lanes, are the shipping routes that connect two ports. Deep sea trades are taking place between continents, for example between North-America and Europe or North-America and South-America or Asia and the Americas. Every trade route has its own characteristic cargo portfolio of cargoes that are shipped on that lane. Changes in global supply and demand for chemicals and importing and exporting countries make trade routes and their product portfolios change over time.

The main producers and exporters of chemicals are the United States, East Asia and the Middle East. Specialty chemicals are transported between the US Gulf and Asia. Also, between the US and Europe specialty and commodity chemicals are traded both east and west across the North Atlantic. Along the west coast of South America sulphuric acid is transported where it will be used in the (copper) mining industry. Phosphoric acid is transported from North Africa east to India where it is used to make fertilisers. Commodity chemicals with endless applications are traded both east and west between the Arabian Gulf to Europe and the US, Africa and to Asia. Brazilian ethanol, vegetable oils and petrochemicals flow east to South Africa and Asia with commodity and specialty chemicals and a trade flow of palm oils going to the west.

The demand is not only described by the sum of the quantities that are transported, but also the distance over which the cargo is transported is an important factor. Therefore the trade of goods is quantified in ton-miles. This metric quantifies the demand or trade by multiplying the volume of cargo moved in metric tonnes by the average distance travelled, the 'average haul', in nautical miles. An increase in average haul means that the location of the exporters and importers increased. This can be the case when prices of a product are increased to a level where it becomes more cost-effective to import the product from another exporter that is further away but offers a lower price. Often macroeconomic factors and the opening/closing of production plants cause changes in the average haul. The average haul of the total chemical trade in 2017 was 3745 nm. Figure 2.12 shows the average haul per product type. Changes over time are noticeable for some product groups, thus indicating an increase or decrease in demand. The average haul gives an indication of the dislocation of the supply and demand. For example, the organic chemicals have a shorter average haul than vegetable oils, because the industries that require organic chemicals are relatively close to the oil refining industries. Vegetable oil producers are more dependent on the area where the crop grows, therefore the distance the product has to travel from producer to consumer is larger. The group of 'Other' products in the the figure (yellow line) primarily consist of the sum of Ethanol, Molasses, and liquid fertiliser (UAN). This group shows a growth of average haul The last years have seen a declining average haul of some products (mostly organics). The economic and industrial development in China resulted in the opening of new chemical production facilities that supply the local Asian industries. This is considered a structural change since China develops to become self-sufficiency in the production of chemicals. Protectionism (anti-dumping duties) are expected to continue and will reduce the average haul of commodity organic chemicals such as styrene and paraxylene [10][5].

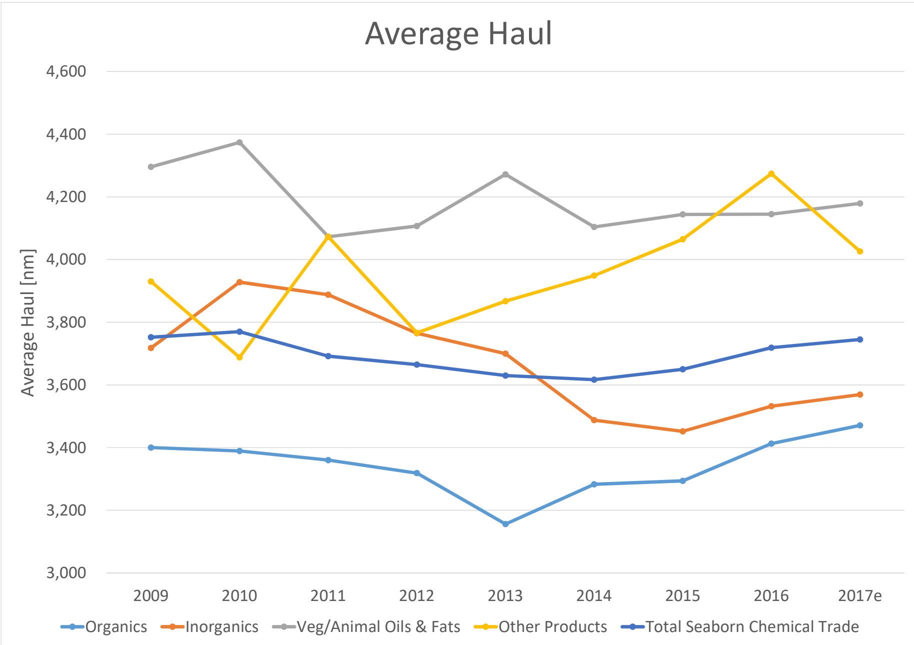



**Figure 2.12.:** Average haul per cargo group
*Source:* Drewry [10]

Fronthaul and backhaul are terms that are often used in shipping. Uneven demand for products between two places results in one trade route being in higher demand than the other. For the shipper this means that the profits are made on the fronthaul, while a loss (or a significantly lower profit) is made when travelling in the opposite direction, the backhaul. Having vessels operate in a liner service, or round service, will reduce the backhaul loss, since the service is designed to find the most profitable backhaul leg to return to the fronthaul port in respect to a direct line service between two ports or tramp shipping. The goal of a liner service is to maximise the total profit for a round voyage. Typical liner services for parcel tankers are a Trans-Atlantic round service (TAS), Pacific service (PACS) and a full range (FR) service that takes the ship around the world.

### Political and Regulatory Supply and Demand Risks

Political or regulatory decisions can have a major impact on the supply and demand dynamics of shipping markets. While some of the impacts happen suddenly, others are announced long before the effect is visible.

A regulatory event that is expected to have a large impact on the shipping markets in the near future is the global fuel oil sulphur limit that will come into effect the first of January 2020 [21]. Since the adoption of the regulation in 2008, there is a lot of speculation and uncertainty about the reaction of the shipping markets. The majority of the chemical tankers is expected to switch to the more expensive low sulphur fuel (Low Sulphur Fuel Oil (LSFO)), only a small part of the deep sea fleet is expected to invest in exhaust gas cleaning systems (scrubbers) or LNG. The expected increasing demand for Low Sulphur Fuel Oil (LSFO) and

[5] Ton-mile demand of styrene is expected to decline by 20.6% and of paraxylene by 5.6%

the expected oversupply in High Sulphur Fuel Oil (HSFO) will have an impact on the bunker prices. An increase in Marine Gas Oil (MGO) and Low Sulphur Fuel Oil (LSFO) prices is expected to start an increase in demolitions of older, inefficient tonnage and in the longer term increase orders for newbuild 'eco-ships'. Also, the CPP market could be picking up as the Low Sulphur Fuel Oil (LSFO)'s have to be transported to feed the demand. This, in turn, could free the chemical tanker markets of oversupply as vessels swing to CPP trades. The general expectation is that the parcel tanker business will benefit from the lower supply of chemical/product tankers trading chemicals. Since the swing tonnage mainly trades the commodity chemicals, the effects of the parcel tanker fleet will be smaller than the *type 2* chemical tanker fleet. However, the organic chemicals will likely increase in value due to the expected higher oil and oil products prices. Depending on the freight pricing strategy this could lead to an increased freight rate of organic chemicals[6]. While the 2020 sulphur cap is a short-term, concrete change in the longer term the regulatory bodies are focusing on sustainability-related items that potentially have an effect on trade, technical requirements or operating procedures.

Possible political impacts on the shipping markets can relate to conflict areas, boycotts, war treats or trade conventions or -wars. Two political conflicts that currently and in the future could have an effect on the global (chemical) freight markets are the U.S. threat of a trade war with China and Europe and the U.S. boycott on Iranian exports. Political and regulatory decisions do not necessarily have a negative impact on the freight markets. For instance, political trade conventions can rise freight rates on trade routes or open new markets.

### 2.6.2. Supply of Chemical Tankers

In chapter 2.2 the main tanker types that are able to carry liquid chemicals are grouped as product tankers, chemical tankers and parcel tankers. This chapter will look at the supply side of the chemical seaborne transportation market: the chemical tanker fleet. In the last twenty years several developments, phases and trends can be identified in the chemical tanker fleet. First the total chemical tanker fleet is analysed in terms of total growth, the orderbook, deliveries and demolitions. The effects of swing tonnage and the trends of increasing average tank capacity are discussed. After analysing the total chemical tanker fleet, the focus will zoom in to a smaller selection of the fleet that is considered the core competition for Stolt Tankers.

#### Growth of the World Chemical Tanker Fleet

The world fleet of sea-going vessels able to carry IMO 1, 2 or 3 type of cargoes consisted of 4,386 ships on the 31th of December 2017. Over the years the number of ships, the total tonnage and the number of parcels has changed, see figure 2.13. The total fleet doubled in numbers and in tonnage between 2004 and 2014. The growth over the last 13 years shows a linear trend with and annual average growth of 4.9 million DWT. This is an average yearly capacity growth of 7%. While the financial crisis has impacted the global markets, the chemical tanker fleet kept expanding.

[6] For example value-based pricing

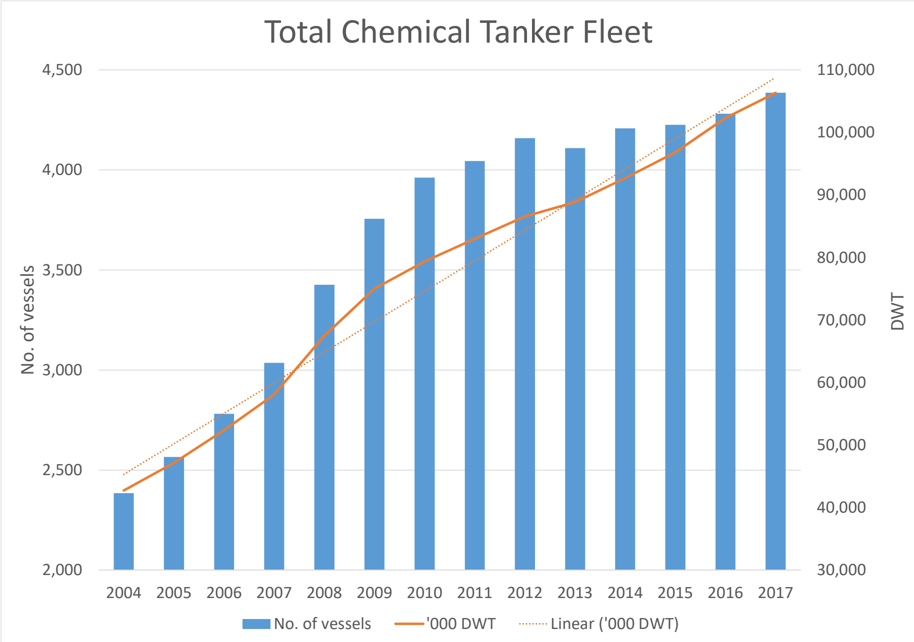



**Figure 2.13.:** Total chemical tanker fleet 2008-2017.
*Source:* Drewry [22, 10]

#### Chemical Tanker Orderbook, Newbuildings and Demolitions

The growth of the world fleet is determined by the difference between vessel deliveries and demolitions. When the orderbook and the deliveries/demolitions are analysed the impact of the global economic crisis becomes better visible, see figures 2.14 and 2.15. In the years before 2008/2009 the tonnage delivered increased yearly, while the demolition of vessels stayed constant. The slowdown of the world economy caused by the financial crisis in 2008-2009 the deliveries dropped rapidly, and more tonnage was removed from the market. From 2012 to 2015 negative tonnage delivered is growing again.

The orderbook of chemical tankers of the last 22 years, shows that periods of massive ordering are alternated by lows in the orderbook. A shipowner can have multiple reasons to order ships, to renew an ageing fleet, to take in a growing demand or to (aggressively) acquire market share. Different phased and reactions to economic effects can be noticed in the growth and decline of the orderbook in figure 2.15. In the period 1996-2001 the orderbook was relatively low. This was due to the effects of the Asian financial crisis in 1997 that caused weakened demand and low freight rates for multiple years. In 2002 the market started to recover and ships where ordered in greater numbers. The global economic growth and the boom in the Chinese economy resulted in an exponential growth in demand for bulk materials. This let to shortage of ships and increased freight rates. Ship owners where prosperous and ordered ships in large numbers to cope with the increasing demand. Also, Chinese shipyards where offering low newbuilding prices in order to enter into niche shipbuilding markets such as stainless steel chemical tankers. 2008 and 2009 mark the year that the global financial crisis hit the chemical shipping industry. This caused a drop in orders in the next years. In 2014-2017 more vessels where ordered again because of anti-cyclical ordering. Ships yards had bad years after the crisis, with less ships being built. The yards orderbooks were low and many were at the edge of bankruptcy. This meant that shipowners could order vessels

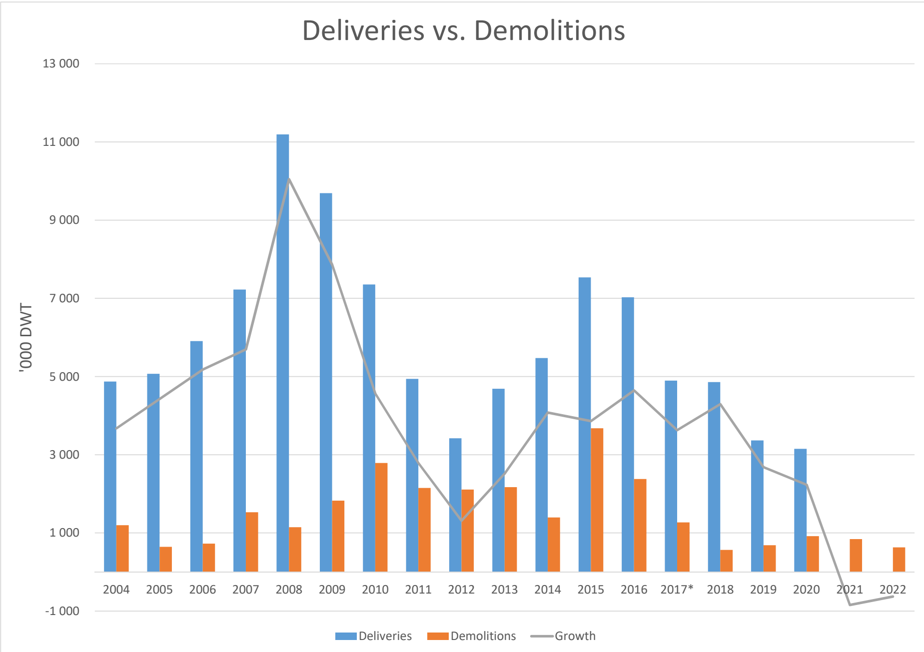



**Figure 2.14.:** Deliveries and Demolitions.
*Source:* Drewry [22, 10]

for low prices. At the same time it became harder to finance ships with a traditional bank loan, because of restricting rules and the restraint of the financial sector to lend money. This financing gap was filled by private equity and hedge funds who got interested in the chemical tanker business because of promising earning outlooks and the historic returns. This boosted the orderbooks, not because of a increase in demand of logistical services, but because of the overflow of capital in the market [23]. As already mentioned the last years the chemical tanker business is a consolidation phase caused by oversupply of vessels caused by the ordering wave before the economic crisis and in 2014-2017. Because of this the orderbook of vessels is back at a low level, consisting mainly of replacement orders.

A chemical tanker has a technical life expectancy of 25 to 30 years. However due to the market demand, implementation of new regulations or technical innovations the economical life expectancy changes over time. At the end of the ships life, the OPEX are high, while the CAPEX are low. In prosperous times ships where freight rates are high it is worthwhile for shipowners to keep old ships in service if they still can generate earnings. However in weak or depressed markets ships can be scrapped while they are still technically in a sound condition. In depressed times, such as the years after the financial crisis in 2009, the number of demolitions increases, see figure 2.14. During the prosperous years before the crisis vessels were ordered in large number and the total fleet capacity more than doubled as can be seen in figure 2.13. One of the current problems in the chemical tanker fleet is that the average age is relatively low. This means that the shipowners are very cautious to sent relatively new ships to the recycling yard since it would mean an incredible financial loss. A recovery of the supply of chemical tankers in general is therefore expected to be slow.

The second-hand market of chemical tankers mainly consists of MR tankers and 'simple' chemical tankers. Second-hand parcel tankers are rarely traded. Only in distressed situations, such as a immediate need of cash, do parcel tankers switch ownership. Since the number of operators of parcel tankers is low, trading second-hand ships directly affects the market share and the competitive position. Parcel tanker operators are therefore operating the majority

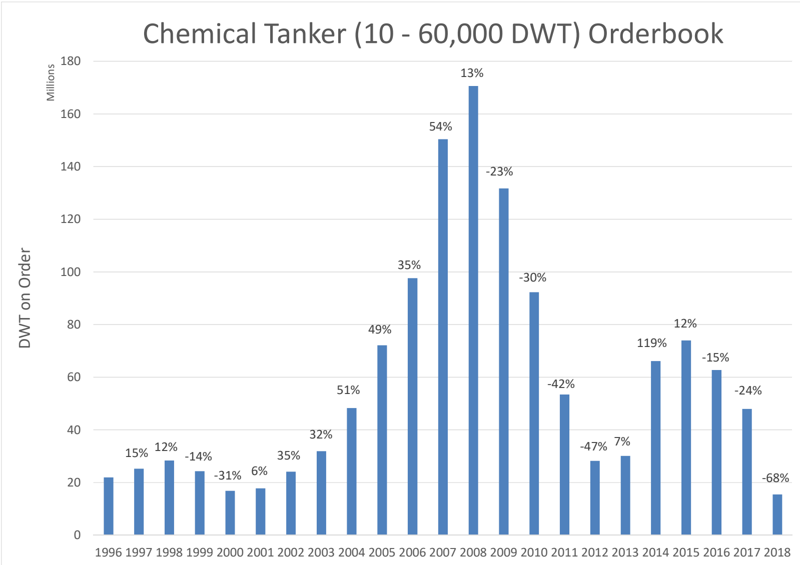



**Figure 2.15.:** Chemical tanker (10-60 kDWT) orderbook including percentage of change relative to previous year.
*Source:* Clarksons Research [9]

of their ships until they are scrapped. The lack of a second-hand market also creates barriers for new companies and speculative buyers.

### Trend in Size and Tank Capacity

Chemical tankers have a upper limit to the size of the vessels of about 50,000 DWT, while product and crude oil tankers go up to more than 300,000 DWT. The principle of economies of scale would suggest that larger chemical tankers could reduce the cost per parcel. There are a couple of reasons why the chemical tanker business has not experienced the explosive growth in tanker capacity such as in the container and bulk-carrier sectors. The first reason is that the cargoes transported are not traded in large volumes. Even though some chemicals are considered 'commodities' in the chemical sector, the volumes at which they are traded are still relatively small compared to the commodities as containers, crude oil and iron ore. So, while the chemical tanker has not expanded in size such as other vessel types, there are indications that suggest a trend towards scale growth.

The average ship size for the deep-sea world fleet has increased from 30,874 DWT in 2012 to 33,301 DWT in 2017. Figure 2.16 shows that the vessel size started to increase from year 2010 for the fleet larger than 10.000 DWT. For the total fleet this trend is noticeable from 2004, but the increase since 2010 is mainly due to the increase of the average size of deep-sea vessels.

Just like the trend in larger capacity vessels, the number of tank size is also increasing, see figure 2.17. Note that the graph shows only a selection of the total chemical fleet that is considered the core competition for Stolt, more about this in described in section 2.7.1. The average tank size (DWT/seg) has been increasing for the last 30 years. The driver of the increase in average tank size is not only the increase in vessel size, this is relatively small, but more so the number of tanks. Between the 1995 and 2014 these trends are very clear, however the last five years the average tank size has levelled out at around $1,200m^3$ and the

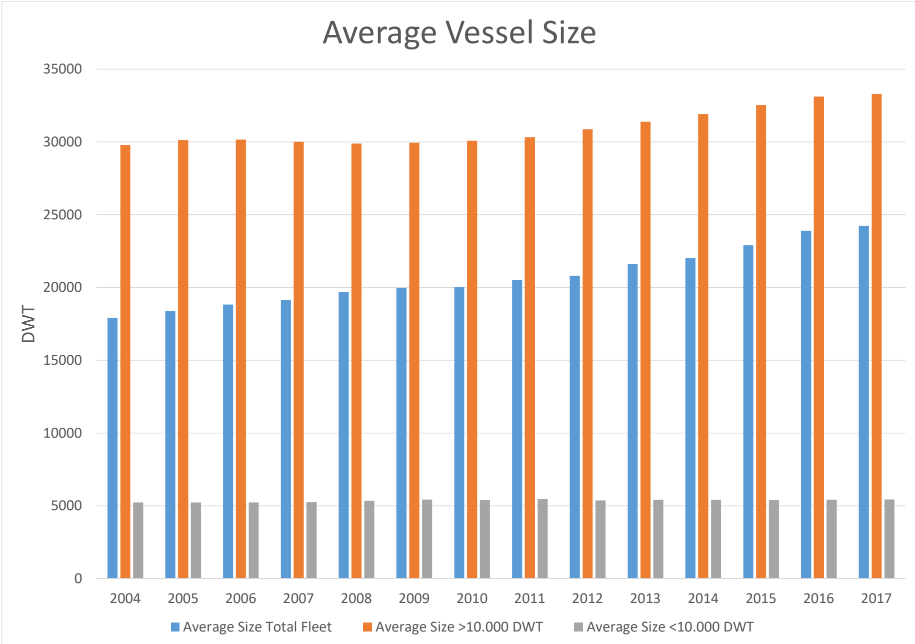



**Figure 2.16.:** Average DWT of deep-sea and total world fleet
*Source:* Drewry [10, 22]

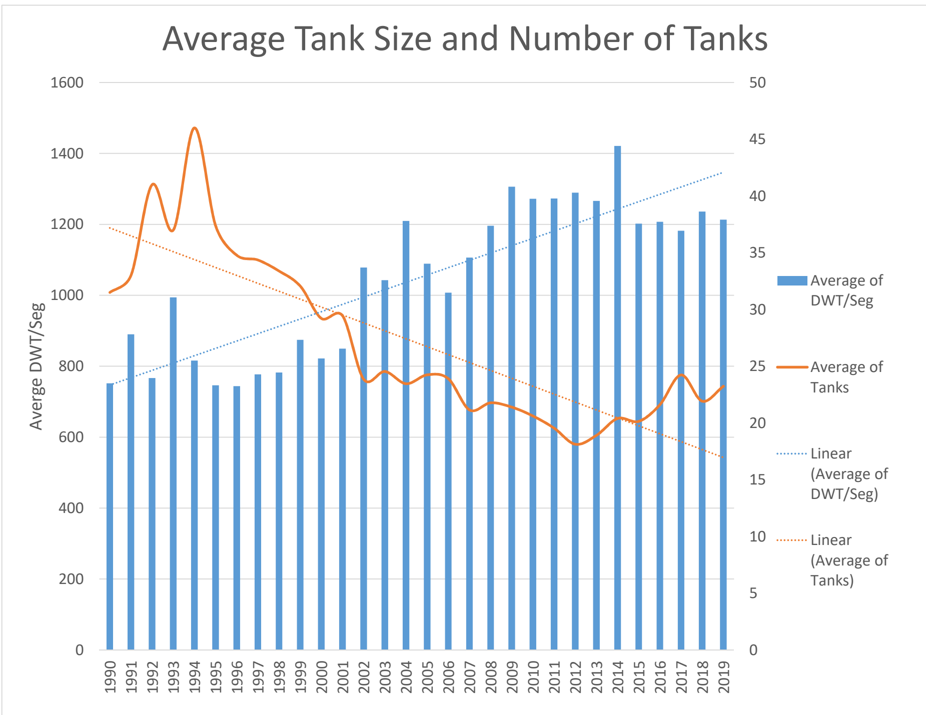



**Figure 2.17.:** The average tank size over the years
*Source:* data from core fleet, see section 2.7.1

average number of tanks is increasing again.

The increase in fuel prices in the last 20 resulted in ships reducing the service speed to reduce fuel consumption, i.e. slow steaming. Also, regulations such as the EEDI index resulted in less propulsion power installed in the ships. This has been a structural change that is reflected in the designs of new ships. The block coefficient of ships increased, allowing to maximise the ships cargo volume as speed and fuel consumption are reduced. An example are the Stolt D37 and the newly build C38 class. The D37 was designed for a service speed of 16.5 knots and has a block coefficient of 0.79, while the C38 is designed for a speed of 14 knots and has a block coefficient of 0.87. This trend is can be seen in both the Stolt and Odfjell parcel tanker fleets. The reduction in speed and increase in ship volume have had an impact on the supply of ships. While the resulting impact is not known. However, it can be argued that a reduction in speed of 12.5% (from 16 to 14 knots) increases the time of a ships voyage by 12.5%. This means that the transport capacity of the total fleet is reduced by this amount and more tonnage is required by either larger ships or more ships. It seems that both these things happened, larger capacity ships are build (figure 2.16) and the number of ships also increased (harder than the demand growth[12].

### Swing Tonnage

An interesting development in the chemical tanker market is the growth of the so called 'swing tonnage'. Swing ships are tankers with IBC ship type 2 or 3 notation, coated cargo tanks that are able to operate in the chemical market or in the CPP and DPP markets. This means that when one market is weak the ship can relatively easily change from transporting chemicals to oil products and vice versa. A small improvement in the oil products market can therefore mean a significant improvement for the chemical tanker market as a large part of the tankers swing over from chemicals to oil products. Typical swing products, chemicals that can be transported profitably by product tankers in weak CPP markets, are easy chemicals such as vegetable oils, liquid fertiliser (UAN), and methanol.

Swing ships exist for a long time in chemical shipping, however since 2007 swing ships entered the chemical shipping markets in increasing numbers. In that year the IMO reclassified many cargoes in MARPOL annex II [3]. Vegetable oils, methanol, and other products that are shipped in large quantities became listed as *type 2* (or *type 3* with double hull). At the same time the single hull tankers where phased out, requiring product tankers to be build with double hulls. It made sense for product tanker owners to make a small extra investment to build or modify their product tankers to also meet the ship type 2 or -3 requirements. While pre-2007 swing ships had mostly the *ship type 3* notation, the current designs are optimised to comply with the IBC *ship type 2* requirements. They are likely to be used more frequently in the chemical traded instead of CPP, since complying to the IBC code rules (type 2/3) the ship is designed better for chemicals than for CPP. Therefore these ships can be more permanent in the chemical trade than was the case with the old (pre-2007) swing ships.

Figure 2.18 shows the number of ships that classify as swing tonnage over time per trade. An increase of CPP tonnage is notable, while the number of ships trading chemicals is shows a decreasing trend since 2012. The expected number of ships over 2017 shows a opposite trend with a increased number of ships trading chemicals and decreasing for CPP. Note, no conclusion can be drawn based on this graph for the change of ships from CPP trade to chemical trade or vice versa. The changes in trade composition can be due to existing ships that change trade, by newbuildings entering the market or removal/scrapping of tonnage.

Interesting to see is the opposing trends in the tonnage growth of the swing fleet that

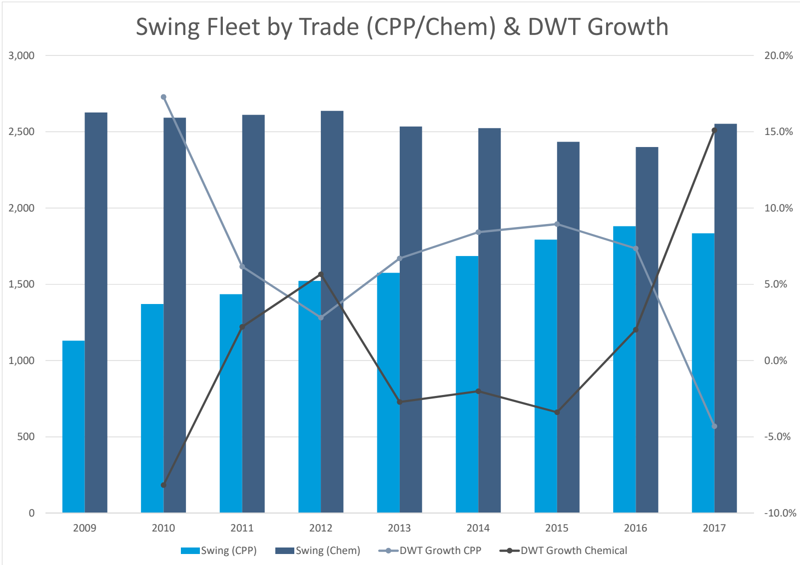



**Figure 2.18.:** Percentage of swing tonnage over time.
*Source:* Drewry [12]

trades CPP and the fleet that trades chemicals and vegetable oils. These trends show how shipowners react to changes in market conditions. By swinging or by ordering and scrapping ships to/from a market the supply side of the chemical and CPP markets are kept in an equilibrium. The point at which the ship operators decide to change trade depends on the spot freight rates of the chemical and CPP markets.

The majority of the swing product tankers have epoxy coated cargo tanks. Figure 2.19 shows the cargo capacity (in DWT) per size group, per coating type. Stainless steel tanks are used by pure chemical tankers and parcel tankers, sometimes in combination with zinc tanks. MarineLine and Interline are polymeric coatings that are developing in their effectiveness as coating, but they are not (yet) applied in great numbers. The figure shows that in the MR product tanker size range of 35.000-50.000 DWT significantly more vessels have epoxy coated cargo tanks. The majority of these vessels are swing product/chemical tankers. The product tankers in this size range directly compete with the large parcel and chemical tankers for cargoes in parcel sizes larger than 3,000 DWT/seg. These price competitive product tankers pose a treat to Stolt's parcel tankers, considering that 15% of the cargoes that Stolt parcel tankers traded the last 7 years is 3,000 tonnes or more and that these cargoes account for 55% of the total tonnes traded (see figure 2.8). Of these 55% at least 25% of the products can be considered as 'easy chemicals'[7]. The other part consists of specialised chemicals in larger parcel sizes which are most likely not in a product portfolio of a swing tanker. This means that at least 14% of Stolt's total traded volume is in the size range and type category to compete with MR product/chemical tankers.

**Example of the effect of swing tonnage on the Transatlantic Tradelane**
The transatlantic tradelane is an interesting area for the product and chemical trade. Comparing oil products against the main chemicals shipped on this tradelane shows how swing ships can target the chemical markets. Tradition-

[7]Counted the following products as 'easy chemicals': Benzene, Toluene, Xylene (BTX), CPP, DPP, ethanol, methanol, mineral oils/spirits, naphtha, liquid fertiliser and palm oil

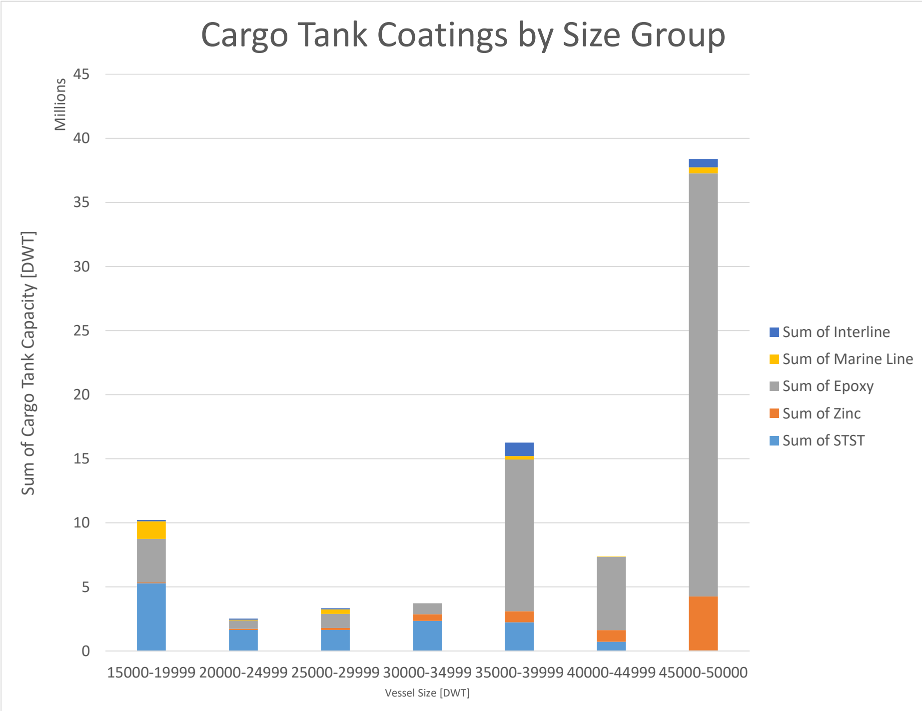



**Figure 2.19.:** Cargo tank coating used per vessel size as per January 2018. *Source:* Drewry [10]

ally the eastbound transatlantic trade (US to Europe) has been a backhaul for the ships trading in CPP and the westbound trade the fronthaul. For chemical tankers the front- and backhaul in the Atlantic are the opposite. The growth of the shale gas industry in the US resulted in a large growth of the export of swing products. For a charterer exporting these products the rates in the spot market for a product tanker on the backhaul are lower than those of a chemical tanker on the fronthaul. Therefore typical products that used to be transported in smaller volumes by chemical tankers are now being shipped in larger volumes in MR tankers (product tanker) at a lower freight rate. So, as long as the transport of these easy chemicals are offered in larger parcels the MR tanker are a charterers favourable choice. [24]

### 2.6.3. Deep-sea Chemical Trade

The shipping markets consist out of four markets: newbuilding market, the demolition market, sale and purchase S&P market and the freight market. The freight market is where the demand and supply meet and a price is negotiated for the transport of a cargo. The freight rates give a view on the interaction of the demand and the supply. When there is a low demand for shipments relative to the supply of ships, the freight rate will drop. While a lack of ships and a high demand, will let the freight rates go up. Different types of contracts are used to in order to fix the price of a cargo and the service that is required in return. In the chemical trade the three most used contracts are the contract of affreightment, the spot market and time charter.

### Freight Market Cycles

The shipping markets are well known for their cycles and is well explained by Stopford [6]. The cyclic nature of the markets are also valid for the chemical shipping markets. The market cycles express themselves in the freight rates. Short and long cycles can be identified. Long market cycles can span over multiple decades, while short cycles often have a period of days, weeks, months or years. Also seasonal effects can be identified, within a year. The four stages of a cycle, as explained by Stopford [6], are the trough, recovery, peak/plateau and collapse. The freight rates show the cyclic nature of the local supply and demand balance for (a group of) product for a specific area of trade route. Figure 2.20 shows an example of the freight rates from 1986 until 2017 for the Houston-Rotterdam trade of easy chemicals of 3,000 mt. The graph shows short term (5-10 year) business cycles in the periods 1988-1993,1993-1998 and shorter cycles of 3-4 years from 2002 onward. Currently the cycle is in a trough, coming from a peak in 2015.

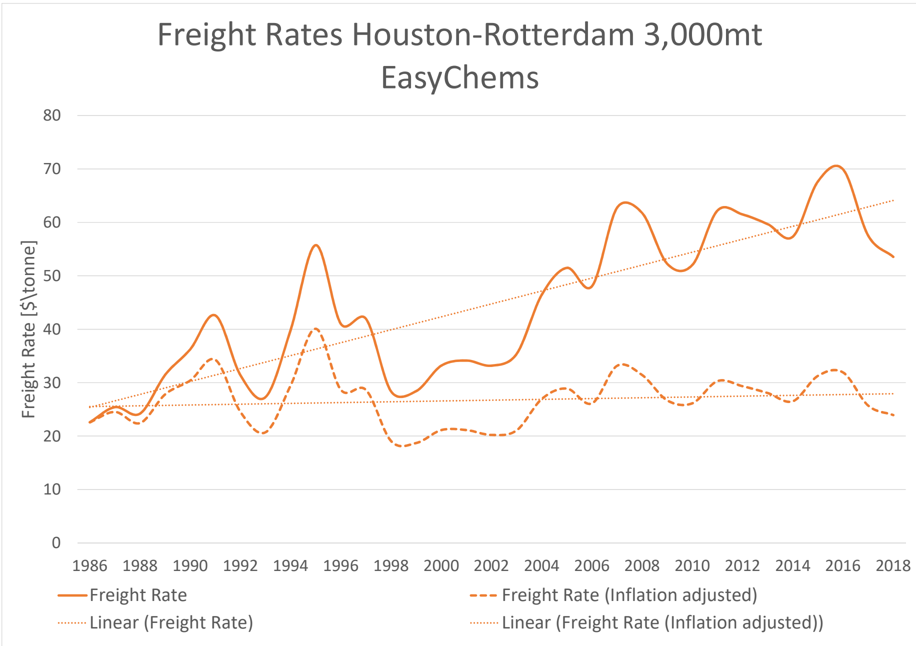



**Figure 2.20.:** Freight rates 1993-2017 Houston-Rotterdam 3,000mt Easy Chemicals, smoothed.
*Source:* Clarksons Research [9]

The figure also shows that the freight rate, corrected to the inflation, varies around a mean value. For the freight rates of the easy chemicals on the Houston-Rotterdam trade lane, that is presented in figure 2.20 the mean value is growing at about the same rate as inflation. Other freight indexes showed increasing or decreasing averages compared to the inflation. A comparison between the freight indexes of easy chemicals (i.e. commodity chemicals) and specialty chemicals showed that the averages for the commodity chemicals have hardly any increase, while the adjusted averages of the specialty chemical freight indexes showed a growth of 1%-3% per year. These long term trends trends show how the freight becomes more or less efficient. We can assume that over the long term the supply and demand will meet, thus long term freight rates are not influenced by long term (25+ years) over- or under supply. This means that a reduction in the long-run corrected freight rates is because of increasing (cost) efficiency by economies of scale and technical innovations.

The recession that is currently occurring in the chemical tanker industry is said to be mainly caused by the oversupply of vessels [25]. This statement becomes evident when looking at the capacity growth of the world fleet, compared with the growth of the traded volumes. In figure 2.21 the tonnage growth of the chemical tanker fleet is measured against the growth of shipped products (year on year percentage of ton-mile transported). It shows that the total fleet capacity was growing faster than the traded tonnes of chemicals in the years 2004-2009. The world economy was booming in these years and many newbuilding projects where started as shipowners saw opportunities in the expected growth of the world economy and chemical sector. The economic crisis ended the bright outlook abruptly. The figure shows that the growth of the fleet is one to two years being the trend of the trade. The reason is that new-building projects take usually around two years from signing a contract to completion.

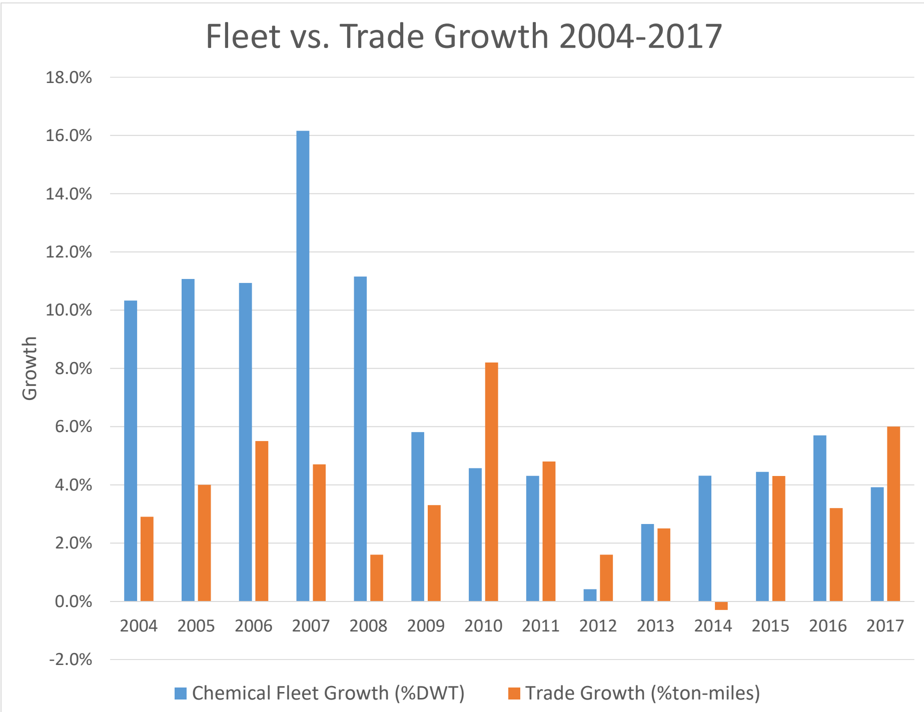



**Figure 2.21.:** Fleet Capacity growth vs. Trade growth.
*Source:* Drewry [10]

The oversupply was thus created after the crisis in 2009, when the market was soaked with newly build tonnage, while the demand for seaborne chemical transport declined. The next expected thing is that the freight rates (and the earnings for shipowners) drop and in the longer term the scrapping of older tonnage will increase. Figure 2.22 shows indeed a drop in 1 year time charter rates after 2008. The rates increased again from 2010 to 2016, but then dropped caused by a combination of low fuel prices, low demand, swing tonnage and high fleet growth. The current time charter rate is 35% lower than at the peak in 2008 and 20% lower than the peak in 2016.

### Charter Contracts

In the shipping markets different types of charter contracts are available. The main types used in the chemical trading markets are the time charter (TC), voyage charter (spot), bareboat charter. These contracts have properties that each have beneficial applications for different

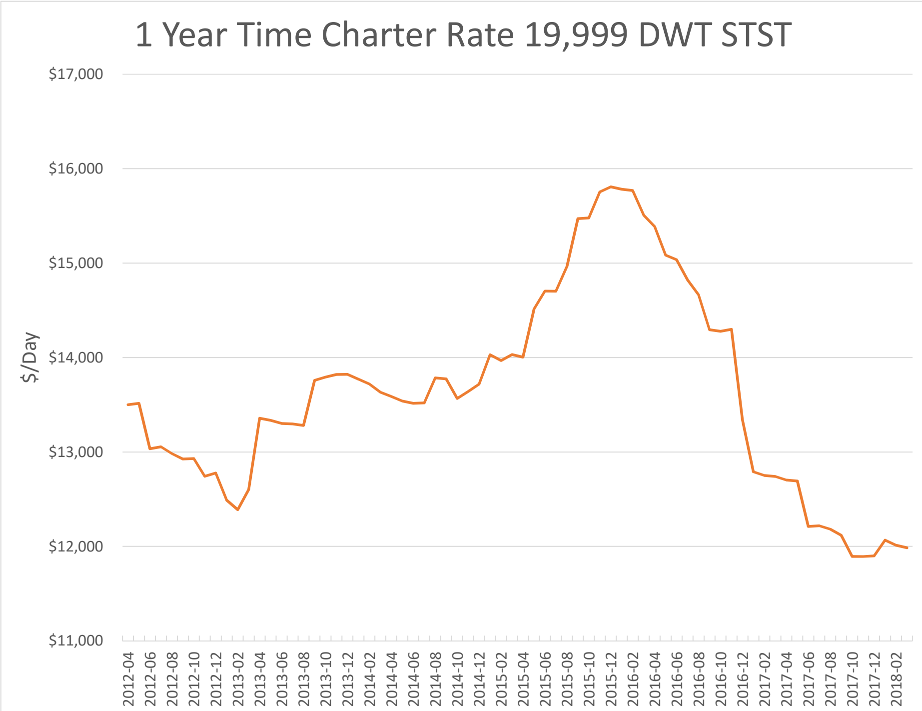



**Figure 2.22.:** 1-year time charter rates for 19,000 DWT stainless steel chemical tanker, inflation adjusted.
*Source:* Clarksons [26]

types of trading. The foremost item that is determined by the type of charter contract is which party is responsible for the cost types of the ship. Table 2.3 shows the cost types that are covered by the owner of the ship given the charter contract. In the contract also the reward for the shipment is agreed, either by a lumpsum payment, a rate per day or a rate per ton of transported good. The different cost structures of the charter contracts determine the incentives for a ship owner or charter party to reduce cost and increase efficiency and utilisation are different. For instance, the contract of affreightment and voyage charter, the most common contract types for deep-sea parcel tanker trading, require that all cost types are for the owners (i.e. Stolt Tankers') account. Since the owner has control over the ships operations it has the incentive to minimise costs and losses as these directly have effect on the profit margins.

**Table 2.3.:** Cost that are paid by the shipowner for different charter contracts
*Source:* Stopford [6] and Aalbers [27]

| Cost type | Bare Boat | Time Charter | Voyage Charter | Contract of Affreightment |
|---|---|---|---|---|
| Capital | X | X | X | X |
| Running | | X | X | X |
| Voyage | | | X | X |
| Loading | | | (X) | X |
| Discharge | | | | X |

Time charter contracts are generally long term contracts (1-5 years) that are considered to bring in steady revenues for the shipowner. Especially when markets are weak time charter contracts are in favour for ship operators. Spot freight rates fluctuate more and therefore have a higher profit potential in prosperous times.

A Contract of Affreightment is a commitment of a ship-owner to a charterer to carry cargo(es) in a specific time period. A certain amount of cargo space is reserved for the charterer, but the ship owner is usually free to ship other cargoes, as long a the cargo of the charterer are loaded and discharged within the agreed periods. A freight rate is agreed for the agreed amounts and the shipowner will pay all the cost [6]. Contract of affreightments are common freight contract used in the chemical tanker sector. Especially for specialised, high value products, charterers opt for contract of affreightments with shipowners with a good reputation to handle their shipments. The ratio of COA and spot is an important characteristic for the method of operating a fleet of ships. A COA does not specify the details of each voyage, so each ship in the fleet that fulfils the basic requirements stated in the contract (related to safety, cargo handling equipment etc.) can take the cargo. This creates flexibility for the shipowner in utilising the fleet of ships. Historically the COA formed the basis of the trade contracts and income for Stolt Tankers. About 70% of the cargoes that Stolt Tankers ships has a COA contract. The other 30% are primarily spot cargoes. A high COA coverage provides certainty of income, but it requires a lot of logistical planning and fleet management to not miss loading and discharge windows. A high COA coverage favours the use of round services since this provides a structured and regular cargo loading/discharging intervals.

### Commoditisation in Cargoes and Tankers

In section 2.2 and 2.7.2 we showed that the chemical shipping industry is relatively small and complex with high entry barriers due to the complexity and the required knowledge of the business. The trade of chemicals is still considered a specialised market, however the markets are changing towards a more commoditised market model. In the context of this thesis 'commoditisation' is defined as '*The process by which goods that have economic value and are distinguished in terms of attributes (uniqueness or brand) end up becoming simple commodities in the eyes of the market or consumers* [28]. It must be noted that when speaking about commoditisation, different things can be commoditised. First the commoditisation of the chemical carrier and secondly the commoditisation of the products that these carriers transport. While it is likely that the commoditisation of the chemical products have an effect on the commoditisation of the chemical carrier, it is not considered a rule.

The indicators of potential commoditisation according to Holmes [29] are:

- Increased competition
- Prevalence of me-too products[8]and services
- A belief that suppliers are fundamentally the same
- The decrease on the customers part to look at new options or features
- An increasing preference for customers to select on the basis of price and little else
- A reluctance for customers to pay for anything they consider unnecessary
- Increasing pressures on margins

Research reports and news articles have discussed the topic of commoditisation in the chemical industry [30, 31]. Commoditisation in the chemical production industry has automatically has an impact on the chemical transport industry as well. A commodity chemical will be considered a commodity in the total chemical industry and will be traded like a commodity.

[8]a 'me-too product' is a product that is similar to the competitor's product in order to prevent that competitor from maximising its market share.

So, what does commoditisation mean for the parcel tanker? In commoditised chemical tanker markets niches are expected to stay. Where a parcel tanker benefits from the small, specialised cargoes it still is dependent on the larger volume (often commodity) cargoes for a optimal utilisation of its cargo space. This means that the parcel tanker stands with one leg in the commodity trade, while it other leg is in the specialised trade. For parcel tankers the threat lies in the the overlapping trades with the these lower priced commodities. As was shown in section 2.5, the majority of the revenue of a chemical tanker is coming from large parcels, which are mainly bulk (commodity) chemicals. If the price of this type of freight declines, the parcel tanker income declines as well. A simple MR- or commodity chemical tanker will still be profitable trading commodities, while the parcel tanker has to rely more on the specialised cargoes. Commoditisation will have an effect on the operational and technical needs of a parcel tanker. The charterers required different levels of service. On a company level, commoditisation is considered a threat for a established, long-term market leader as commoditisation allows lower entry barriers to the market.

### 2.6.4. Conclusions of the Current Status, Developments and Outlook of the Seaborne Chemical Transport Markets

The chemical sector is relatively small in the world seaborne trade, but it is very diverse in the number of cargoes that are transported. The chemical shipping sector has a strong correlation with the growth of the world economy and with the crude oil and oil product markets. It is however less volatile compared to the oil and other bulk markets. The chemical seaborne tonne mile demand is expected to grow around 4% per year for the coming years. For the last years, while demand growth was steady, the supply has been growing disproportionately harder. The current status is the chemical seaborne trade is that it is at the bottom of the cycle. This current status can persist for the next 1 to 2 years and, if no unexpected shocks happen, the market will start to recover. Some of the latest developments could be seen as structural, not developing in line with the market cycle. One of these structural developments is the 'commoditsation' of some chemical products, being shipped in larger volumes in standard quantities. The growth of product/chemical tankers with optimised designs for these chemical trades can be seen as a structural consequence.

## 2.7. Competition

In this section the competitive factors are analysed and the competition of Stolt Tankers is determined. Competition takes place among ships and shipping companies that are aimed at the same business. In order to determine the competitors for Stolt Tankers the business of the Stolt parcel tankers need to be known. The first sections of this section will elaborate on this, by identifying the type of ships Stolt operates for the specific products. The second part of the section will focus on the competitors of Stolt's parcel tankers. The direct competition is analysed in section 2.7.1. These are the shipping companies that operate the same way Stolt does. The competition between these players is the fiercest. For Stolt a direct competitor is, for example, Odfjell. The analysis also analyses the competition structure and its consequences for the business of Stolt in section 2.7.2. The parcel chemical tanker sector is competing with different modes of transport. The tank container sector is competing on some levels with the parcel tanker. This competition is analysed in section 2.7.3.

### 2.7.1. Direct Competitors

In the previous the overall market conditions for the deep sea chemical tanker business have been analysed. In this section Stolt will be compared with it competitors in order to see differences in strategies used and the results that come from that. Since the details on who is trading what cargoes is not available it is impossible to compare companies that directly compete with Stolt. The data that is available are the fleets that are operated by the chemical shipping companies. Analysis and comparison is mainly based on the fleets of Stolt and its competitors.

From the more than 4000 ships that classify as chemical tankers, a selection is made that represents ships that are, including Stolt Tankers, competing in the same markets with similar types of vessels. The following criteria are used to select the 'core competition' for the deep-sea specialised chemical transportation markets:

- Vessel of traditional owners:
  - $15.000 \leq DWT < 50,000$
  - $\frac{DWT}{Segs} \leq 3,000$
  - Exclude ships with only *type 3* notation
- Stainless Steel vessels that comply to above three criteria operated by NTO

Using these criteria the list of vessels is reduced from more than 4,000 to almost 700, see list of core traditional owners in appendix A. A distinction is made between traditional and non-traditional owners and operators. Traditional owners have larger fleets of ships and have proven to be able to maintain in the chemical tanker business for a longer period due to their market share, knowledge of the sector and sound business structure. No hard criteria are used for the selection of these companies. Navig8 is different from the companies in the figure, because of their relatively large fleet of simple product/chemical tankers.

#### Top 5 Competitors

Figure 2.23 shows the top 20 of the 'core' chemical tanker owners in terms of deadweight and the number of ships in their fleet plus newbuildings as of the first of January 2018. The top five in terms of market share based on tonnage, Odfjell (14%), Stolt Tankers (14%), Fairfield/Lino (10%), Navig8 (10%) and MOL (8%) control a total of 56.4% of the pure chemical tanker market. In the history of chemical tanker shipping the top 2, Stolt Tankers and Odfjell, has not seen changes. The follow up companies in the top 5 are relatively new, so a brief overview will be given of the currently five most influential companies in the deep-sea core chemical tanker sector.

Traditionally Stolt Tankers and Odfjell have been in the chemical tanker business from the early days of chemical shipping. Both companies pioneered and innovated the industry since the mid-1950s. Stolt Tankers was the first to use deep-well pumps in 1955 to reduce the risk of contaminating cargoes, while Odfjell pioneered with stainless steel tanks. Currently the deep-sea fleet of Stolt Tankers consist of 75 ships against a fleet of 80 owned and chartered by Odfjell. Stolt Tankers and Odfjell operate the most sophisticated chemical tankers, many having the *ship type 1* notation, cargo cooling and heating and the highest number of segregations per ship. Both companies have a similar business profile; traditional family owned, focus on innovation, and offering a reliable and flexible worldwide service.

Fairfield Chemical Carriers (FCC) and Lino Kaiun Kaisha Ltd are two independent traditional chemical tankers owner and operators. The two companies decided in to pool their

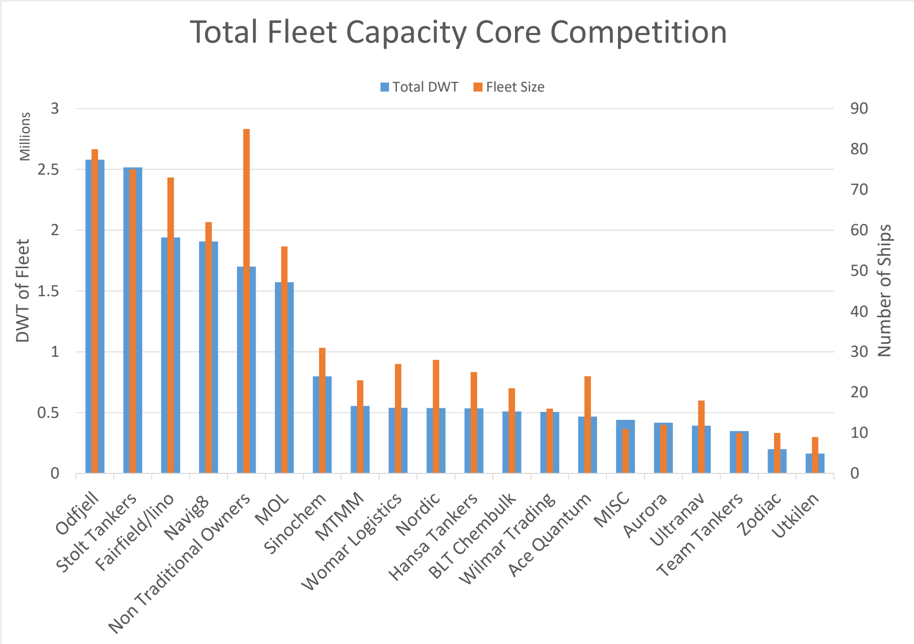



**Figure 2.23.:** Market share of core competition
*Source:* Compiled by Julius Jansen from fleet list by Drewry [12]

ships and created a pooling joint venture Allied Chemical Carriers Inc. (ACCI). The combined fleet of owned, time chartered and bareboat chartered ships consists at august 2018 of 53 stainless steel *type 2* ships. The companies furthermore have a combined orderbook of 20 ships that are expected to enter the market in 2018 and 2019.

Navig8 Chemicals is one of the newcomers in the core deep-sea chemical sector. The company started in 2013 from as a joint venture between Oaktree Capital Management and the Navig8 group, that already participated in the product- and crude tanker sectors. Navig8 stormed the chemical tanker markets in 2013 with an attempt to aggressively capture market share by placing large orders for large, fuel efficient 'eco'-tankers. With Oaktree Capital providing the capital to quickly invest in new tankers, Navi8 Chemicals fleets has expanded in a very short period to a fleet of currently 67 owned and chartered ships. Halfway 2018 Navig8 holds the largest deep-sea coated chemical tanker fleet. Opposed to the traditional chemical shipping companies, such as Stolt and Odfjell, Navig8 is not a family owned business. While more companies tried to enter the chemical tanker markets with funding from private equity, only a small number was able to survive. Consolidation in recent years has seen multiple smaller operators merged, taken over by the larger companies or teamed up in pools [9].

MOL Chemical Tankers was established in 1972 under the name Tokyo Marine. In 1996 Tokyo Marine joint the Mitsui O.S.K. Line (MOL) Group in 1996. As of January 2017, the company amalgamated with Milestone Chemical Tankers Pte. Ltd after the joint venture partner JO Tankers was taken over by Stolt Tankers. The new company changed its name

[9] Examples are the JO tankers take over by Stolt Tankers (2017), Crystal Nordic taken over by Essberger Tankers (2018), Odfjell and Sinochem Pooling Joint Venture (2017) and Stolt Tankers – Sinochem Pool Joint Venture (2003)

from Tokyo Marine to MOL Chemical Tankers. MOL Chemical Tankers owns a fleet of 58 deep-sea, stainless steel, *type 2* chemical tankers. The all ships in the MOL fleet are built by Japanese yards, known for their standardised, basic chemical tanker designs and outfitting.

The top six chemical tanker companies show two types of companies, first the traditional companies that are for the large part family owned and controlled, and secondly the backed public companies that are backed by private equity groups (PEG). While traditional companies are nowadays being publicly traded on the stock markets, the majority of the shares is still within the founding families. The business motivation and mentality for these two types of companies differ. The private equity companies that own the private shipping companies have the main focus to maximise profits for their shareholders. This means that sometimes these companies are driven by opportunities for short term gains, rather than focusing on long term continuity. The traditional, family owned companies generally have their focus on long term gains and stability.

These four companies that are ranked 3 to 6 in the figure, are potential threats to the market leader positions that are currently held by Stolt Tankers and Odfjell. An acquisition or merger of these companies with one of the smaller companies will add them right next to the two established market leaders (in terms of tonnage). The next section looks at this structure of the the companies operating in the market and their competition.

### 2.7.2. Oligopoly in the Deep-Sea Chemical Shipping Sector

This section takes a closer look at the deep-sea chemical tanker market structure and it will show that the sector has strong characteristics of an oligopoly. An oligopoly is a market structure that, according to neoclassical theory, has (1) few firms, (2) relatively high barriers for new companies to enter the sector and (3) some product differentiation [32]. The first two characteristics of an oligopoly are investigated in this chapter. The product differentiation of a parcel tanker in the chemical tanker is anlready discusses, and will be further studied in the next chapters. The question that will be answered is if the chemical shipping sector is moving toward or away from the oligopoly character. This question is relevant to the study since the parcel tanker as it has been part part of the growth and presence of the two largest chemical tanker operators Stolt Tankers and Odfjell. The hypothesis is that developments in the market form impact the position of the parcel tanker business.

#### Market Concentration

The chemical tanker market is relatively concentrated compared to other shipping sectors. The concentration of a market sector can be indicated and compared with other sectors using the Herfindahl-Hirschman Index (HHI) and the Concentration Ratio $CR_x$. This HHI is a measure to compare market concentration by taking the sum of the squares of the market shares, see Equation 2.1.

$$HHI = \sum_{i=1}^{N} {s_i}^2 \tag{2.1}$$

Where $s_i$ is the market share of company $i$ in whole percentages, $N$ is the number of companies in the sector. A small index indicates a market with many companies all having a small market share, thus a low market concentration. The closer the index is to $10,000(100\%^2)$ the more concentrated the market is (with 10,000 being a monopoly and 5,000 a duopoly). The concentration ratio is more basic as is does not consider the total number of players in the market. The $CR_x$ sums the top x companies market shares, see Equation 2.2.

$$CR_x = \sum_{i=1}^{x} s_i \tag{2.2}$$

So, for example, $CR_4$ is the sum of the four largest companies in the market. A concentration ratio ($CR_4$) larger than 50% is generally considered a tight oligopoly. A ($CR_4$) between 25 and 50% generally considered a loose oligopoly. For the case of a monopolistic market $CR_1$ is equal to 100%. The drawback of the concentration ratio measure is that the relative size of the top companies is not considered. For example, for a $CR_3$ of 80%, it is possible that the four companies have each have a market share of 20% or that there is one with 50% market share and the other three 10%. Therefore, the combination of the concentration ratio and the Herfindahl-Hirschman Index are often used both.

There are many methods to measure market share. The sum of the deadweight of a companies fleet is used to define the market share of the company in the specific sector. The deadweight of the fleet is used as a proxy for the capital deployed by the companies. It reflects the capacity a company has to move cargo and generally the scale of the fleet. It does not exactly reflect the capital deployed, since a fleet of parcel tankers have a different value than a same size fleet of MR product tankers. For the chemical tanker fleet the concentration is calculated twice, one for only the core deep-sea chemical sector, and secondly for the total chemical shipping sector. The difference is that the total fleet consists largely of product/chemical tankers that operate in the commodity markets only, while the core chemical fleet consists of the direct competitors to Stolt Tankers.

The core chemical tanker sector has a HHI of 836 which is considered an low concentrated industry by the US federal Trade Commission (U.S. Department of Justice and the Federal Trade Commission, 2010). Table 2.4 shows the HHI and indices for different shipping sectors. The core deep-sea chemical sector has high degree of concentration compared to the other sectors. However, this is partially due to pre-selection in the definition of the core fleet. The total chemical shipping sector (so including regional and coated ships) the concentration measures are in between the values for the other sectors.

**Table 2.4.:** Concentration ratios for different shipping sectors
*Source:* Compiled by Julius Jansen from various sources

| Sector | HHI | $CR_4$ |
|---|---|---|
| Deep-sea Chemicals, core | 836 | 56.4% |
| Chemicals, total [10] | 416 | 41.4% |
| Dry Bulk [10] | 314 | 34.2% |
| Gas [10] | 383 | 35.5% |
| Container[11] | 775 | 53.1% |
| Crude and Oil Products [12] | 538 | 28.2% |

Although the current deep-sea core chemical market concentration can be considered high compared to other shipping sectors, year reports from Odfjell show that the market share of the top four owners has decreased in the last 15 years. The top four had a combined

[10] Calculated with data from 2018 retrieved from Clarksons Research [9]
[11] Calculated with data from 2017 presented in UNCTAD [1] and Sys [33]
[12] Calculated with data retrieved from (Tanker Operator Magazine, 2017)

market share of 57%, 48%, 41% respectively in 2005, 2010 and 2015 [34, 35, 36][13]. The top chemical shipping companies seem to lose market share in the market. In a span of 10 years the market share of the top four has declined by 16%. This is a alarming trend for Stolt Tankers, one of the top four, since it means that its market domination is declining. A declining market domination has a negative influence on the top companies as profit margins generally drop with increasing competition. As the economies of scale of the top companies decline relative to the other companies, the average cost difference between the top and rest of the sector is decreasing, thus reducing the margin gap between the top companies and rest. The consolidation in the chemical tanker markets, including the mergers and acquisitions in the period after 2015[9] could have been an attempt of the top companies to reverse the trend of the $CR_4$.

#### Entry Barriers

The second characteristic of an oligopoly analysed are the high entry barriers to the market. The oligopolies protect their market from entries in the market by setting high entry barriers that should deter and make it difficult for entrants to start in the sector. The story of Navig8 Chemicals shows that it is possible for a newcomer to break through the barriers and become a one of the 'top dogs'. Common barriers for new entries in the chemical tanker sector are described here, as well as the role of the parcel tanker.

The highly dangerous nature of the cargoes and the environmental sensitivity of the customers (oil majors) make that the vessels and chemical companies are subject to stringent vetting requirements. This means that a long history of third-party inspections is necessary to access markets for many of the cargoes.

The spectrum of chemical oil products is large and they come in small parcel sizes. The parcel nature of cargoes requires an logistics and planning expertise to optimise earnings for voyages for multiple cargoes. This also makes the chemical tanker stand out compared to product tankers in technical complexity.

The number of ship yards that have the experience to build sophisticated chemical tankers is limited. The main chemical tanker operators keep control of the second-hand market and are very cautious to sell assets to a new entry. This means that there is a limited availability of assets for new entries. Also, the price of new ships is high, so sufficient capital as well as solvency is required to finance a newbuild. The capital of private equity firms could have been a factor that lowered this barrier to enter or grow in the sector for some newcomers.

The commercial, operational and technical expertise that is required by the crew of a parcel tanker is unique. A specialised crew is required with extensive knowledge of efficient (and safe) operation of the ship. The availability of these quality and qualified people is limited. Building this base of knowledge and operating structure is difficult for new companies. The top companies have a relatively high overhead that is able to efficiently operate the ships. For small companies this is difficult to beat. However newcomers can get around these barriers by enter into pooling arrangements and technical management companies.

Research done by [37] describes the entry barriers in the chemical tanker sector and strategies for entrants and incumbents for entering/protecting the market. The research gives suggestions of possible strategies of entrants and incumbents for entry in the chemical markets and tests by observations if these strategies are used in the deep-sea chemical sector. It however does not prove that the strategies are used, because of "inconsistent sources" and a "complex market with lack of testable data".

[13] Numbers presented by Odfjell differ to the values in table 2.4 because Odfjell uses different criteria to define the core fleet.

### 2.7.3. Tank Containers

Shipping chemicals over sea by means of chemical tankers is not the only method that is used to transport chemicals. Tank containers and inland transportation, such as tank barges or train wagons, can in some cases be competitive alternatives to tankers. This is mainly the case when small volumes of chemicals are to be transported. Tank barges and trains have a smaller range than the deep sea tankers, so they compete with regional tankers. Tank containers are transported by container vessels between continents. A benefit of a tank container compared to transport by tanker, is a reduced logistics chain. Storage of a product in a load and discharge terminal is not required making transshipments easier, quicker and cheaper.

The use of tank container has seen a fast growth in the last decade. Figure 2.24 shows the development of the total supply of tank containers and the number of yearly produced units. Between 1998 and 2008 world supply grew with 69% (5.4% average per year) and between 2008 and 2018 with 168% (10.3% per year). The reason for the accelerated growth after 2008 is not exactly known,

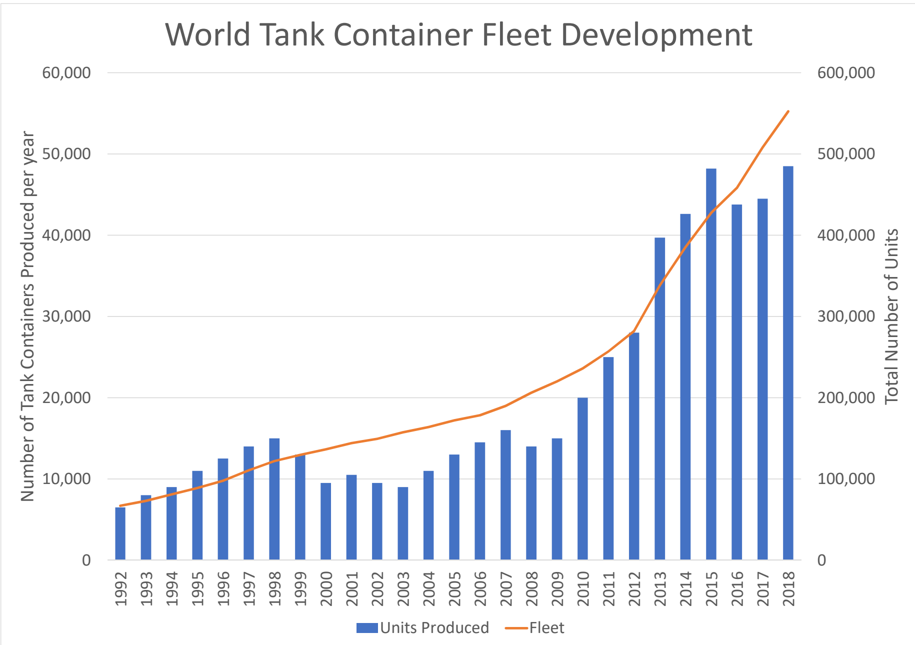



**Figure 2.24.:** Development of the world tank container fleet
*Source:* Song [38]

The tank container is not directly competing with the parcel tanker, however it becomes a substitute of the parcel tanker in the supply chain of shipments of small volumes. Shippers see a couple of benefits of tank containers over the use of a parcel tanker[14]. First benefit of a tank container is that the supply chain is better 'aligned' for specialised producers by shipping smaller quantities more frequently with a higher reliability regarding lead times. Producers are developing their supply chains according to the Just-In-Time principle in order to minimise the required storage at the production plant or at a terminal. Secondly, shippers reduce the risk of losing product due to contamination and factors by shipments in smaller

[14]the arguments from interviews with a commercial manager and a ship broker at Stolt Tankers

batches. Another benefit or containerised transport is its reliability. The liner services of container liners are very accurate, while parcel tankers more often experience delays due to terminal congestion. For some cases, depending on the voyage distance, cargo quantity and other parts of the supply chain, the tank container is a cheaper alternative than the chemical/parcel tanker[15]. However, these other beneficial factors of the transport of chemicals by tank container also add value for the shipper.

The growth of the tank container industry could explain the declining number of small parcels shipped by Stolt[16]. It also is in line with the commoditisation trends that were identified in section 2.6.3. While there looks to be a strong correlation, more investigation should be undertaken to determine the effect of the growth of tank containers on the parcel tanker trade.

The following is concluded on the review of the competition and competitors in the chemical tanker sector. The chemical market share of the chemical tanker sector is relatively concentrated, and clearly shows indications of an oligopoly. The trend in the sector is that the market concentration of the top companies is declining, moving to a less concentrated and more competitive form. Other research of the entry barriers of the deep-sea chemical tanker market concluded that there are indeed entry barriers in the chemical tanker market. While these entry barriers are present, newcomers have some possibilities to mitigate them as has some newcomers successfully showed. An other form of competition to the parcel tanker that is likely to pose a threat is the tank container. While it has not be verified that tank containers are directly competing for cargo with parcel tankers, the mode of transport has a strong correlation with the shipment of small cargoes. The strong increase in the number of tank containers is a threat to the parcel tanker.

[15] A showcased in study done by Knops [39]

[16] between 2012 and 2017 the number of shipments of cargoes smaller than $500m^3$ declined with 32%

## 2.8. SWOT Analysis

This section presents the strengths, weaknesses, opportunities and threats (SWOT) analysis of Stolt Tankers, in particular its parcel tanker business, in its operating market. The analysis is based on the findings from previous sections that analysed the supply, demand, trade and competition of the chemical tanker markets. The SWOT analysis is a method used to determine the negative and positive factors that need to be addresses or exploited in a business case, project or operation. The purpose of the SWOT analysis in the context of this study is to determine how the current parcel tanker business of Stolt Tankers is coping in the market and where future opportunities and losses could be made. The results of the SWOT analysis are part of the output for the study's discussion and considerations in the analysis of the features of the next chapter.

| | Helpful | Harmful |
|---|---|---|
| Internal Origin | **Strengths**<br>- Market share<br>- Flexibility to adjust to market demand<br>- Lower volatility of earnings due to CoA's portfolio | **Weaknesses**<br>- Decreasing Market Share<br>- Oversupply and decreased earnings<br>- No second-hand market<br>- Ageing tonnage |
| External Origin | **Opportunities**<br>- Expand in current and to new niches<br>- Long term growth of chemical trade | **Threats**<br>- Containerisation of smaller parcels<br>- Regulatory changes<br>- Pooling of smaller companies<br>- Commoditisation: Reducing profit margins and increasing competition<br>- (Structural) swing tonnage<br>- Protectionism |

**Figure 2.25.:** SWOT Matrix
*Source:* Julius Jansen

### 2.8.1. Strengths

In this section the strengths of Stolt's deep-sea parcel tanker fleet are evaluated. The strengths are the properties of the composition and the operations of the Stolt deep-sea fleet that make them positively and strategically standout.

First strength that has come forward from the market analysis is that Stolt Tankers is benefiting from its market share in terms of tonnage and the number of ships. The large market share on a number of trade areas adds to the competitive strength. Especially in a market that is subject to decreasing margins caused by oversupply in the short term and commoditisation in the long term. Large number of ships in the Stolt fleet also means that the fleet is diversified over different areas and trade routes. This diversification and the flexibility of a chemical tanker itself creates a high availability of ships anywhere in the world for the customer needs.

Secondly, the strength of the parcel tanker concept is that the vessel is flexible to trade since it is not bound to only a small number of products that it can carry and the many stowage possibilities. Together with the strength of a large market share and the liner service, the flexibility of a parcel tanker has a competitive advantage as contracts for carriage of more than one cargo are frequently bundled in one contract of affreightment. Being able to provide the tonnage, flexibility and reliability strengthens the position to win those contracts.

Thirdly, is the high COA ratio of the Stolt parcel tanker portfolio. The parcel tanker contract portfolio consist for the majority of contracts of affreightment. The risk of freight and freight rate volatility is therefore reduced as long as COA renewals continue and their rates are competitive.

### 2.8.2. Weaknesses

A weakness of the parcel tanker is that, because of its high operating and capital cost, its undercut in price by chemical and chemical/product tankers for competition of commodity cargoes.

Another weakness of the parcel tanker is that, in the philosophy of Stolt, are operated until the end of their life. Since there is no secondhand market parcel tankers cannot be traded on the second hand market. Therefore, there is not the possibility to sell and buy depending on the supply and demand. In short periods with low demand it is not possible to easily sell a parcel tanker, and in times of high demand it is not possible to quickly acquire parcel tanker tonnage, since newbuilding is the only option.

### 2.8.3. Opportunities

The versatility of a parcel tanker as well as the variation of

Opportunities for parcel tankers will arise when new specialised chemical production processes start up and new specialised chemicals are produced. This will expand the range of specialised products and require special equipment to handle and transport these products.

A short term opportunity in the near future will be the impact of the 2020 sulphur limit for marine fuels is expected to cause an positive impact on the oil products market and the oil product shipping markets. As effect on this impact it is expected that the chemical shipping industry will also benefit from the reduced swing tonnage that will operate in the chemical trade as well as the increase in prices of the organic chemicals (as result of the price hike in oil products). While this itself is not an opportunity, the shock in the market will present new opportunities and preparations to be well positioned in advance of 2020 could result in the best outcome.

### 2.8.4. Threats

The threats that external sources have on Stolt's parcel tanker business are concluded in this section. A threat is defined as anything that can do harm to- or exploit a weakness in the company's business model. A threat that always been present to the chemical and parcel tanker market is the swing tonnage. This threat has gone from a periodical negative event to a potentially more structural one as Drewry [12] expects a more structural presence of MR/Product tankers in the chemical markets due to the improved design are new product tankers better adapted for chemical trades. The blending of CPP and easy chemical market can also be seen as a sign of the commoditisation of the chemical market, bringing it closer to the commoditised CPP markets.

Competitors with smaller market share are gathering in pooling arrangements and operational management companies to benefit from the scale benefits that can be achieved in operating in groups. So even though, Stolt Tankers is on paper one of the largest companies in tonnage market share, pool arrangements are forming a counter balance to the oligopoly that the market was used to. This is considered one of the threats to the business model of Stolt, since the pooling arrangements often are operationally managed by one party that can operate the pool as if it is one fleet, using the benefits of deploying the ships in round services and offering flexibility to the charterer.

Due to the oversupply of ships the number of COA's are expected to decline and a larger part will be traded on the spot market. This is an negative trend for Stolt since they rely heavily on COA's and are vulnerable on the spot market for easy chemicals. The last 7 year the COA/spot ratio varied around 80%/20% with the biggest change in 2017 to 77%/23%.

A threat (or opportunity) to both the commodity and specialty chemicals market are the tensions of a trade war between the U.S.A. and China. At the time of writing it is not clear how the import tariffs affected the chemical trade. Import fees on bulk liquid chemicals could both hurt the Chinese and U.S. ex- and imports of chemicals and therefore the seaborne trade. It could also be considered an opportunity as trade is partially diverted to other trade routes[17]. This create demand on other trade routes and, if the fleets have flexibility in rearranging the round services one could benefit from the change in demand. .

A development that is both a threat as it is an opportunity is the change of the global economies toward a more sustainable future. Many (western) countries are in the transition of using more renewable energy sources and a circular economy. It is not expected that the flows of materials are majorly impacted in the short future. However, in the long term the change to a sustainable future poses threats and challenges to the current business model of many oil majors and all the derivative services, such as shipping. Also, the IMO has set the target to reduce the carbon footprint of shipping by 50% in 2050. This means that significant (regulatory) changes can be expected in the next 30 years. While these developments can be seen as a threat due to the uncertainty, they also create opportunities as reduction in fuel consumption and efficiency improvements generally lead to higher margins.

[17] Examples of this are plentiful in the shipping history. A recent example is the trade of soybeans between US and China that due to the China's import tariffs has diverted to South-America, creating new demand for ships on that route while restricting the US-China trade route [40]

# 3. Parcel Tanker Features

In this chapter the features that differentiate a parcel tanker from other chemical tanker types are analysed for their contribution to the operation and profitability of the parcel tanker. First, the definition of a feature is given, followed by some examples of features that are unique to a parcel tanker. In section 3.2 the case study is introduced that will be the subject of this research; the evaluation of features for the replacement of the D37 class ships. The sections 3.4 to 3.7 analyse the individual features in more detail.

## 3.1. Features of Parcel Tankers

In this section the features of a parcel tanker are introduced. In previous chapter some features have already be mentioned, this section will define the features and the technical characteristics that that differentiate the parcel tanker from a chemical and MR product tanker. In section 3.1.1 the definition of a feature is given and the factors that add value the features that are considered typical for a parcel tanker are further explained.

### 3.1.1. Defining Features

The word 'feature' is defined in the context of this thesis as *something that makes a product, machine, or system different, and usually better, than others of a similar type*. From this definition there are three elements that are important for the definition of features for tankers. First, it is about a product, machine or system, this means that it is relates to a physical element of a ship that adds an additional functionality or capability to the ship or improves a basic function. Secondly, this system will make the tanker stand out, or differentiate itself, in a fleet of similar tankers. This means that that ships are to be compared and, if the feature is successful, the ship with the feature will have better results. A feature can also be seen as a way to enter or create a niche market. A niche market is a small, specialised part of the market with a small number of players and less competition. A niche market can be very cost-effective due to the select targeted products and/or manufacturers and few competitors.

### 3.1.2. Cargo Features of Tankers

The features that are subject of the scope of this research are regarding the cargo related systems and equipment and are the items that make the parcel tanker stand out compared to the 'average' chemical tanker. The following categories and features are identified after studying the cargo systems of parcel tankers, chemical tankers and product tankers, see table 3.1. Some of the features listed are considered to target a small product group, such is the case for cargo cooling for example. Other features, such as tank inerting, are more common on tankers and are required for many cargoes. However, the cargo specification can require a feature that is targeted for a niche. An example of this is the purity of the inerting plant. A high purity inerting plant is required for a small number of cargoes, while less sophisticated systems can handle the bulk of the cargoes that require inerting.

**Table 3.1.:** Cargo related features
*Source:* Own contribution

| Group | Features |
|---|---|
| Cargo Tanks | IBC ship type |
| | Number of parcels |
| | Size of parcels |
| | Max. specific gravity (tank strength) |
| | Cargo tank coating and material |
| | Cargo pump capacity |
| Cargo Cooling | Cooling capacity (in $m^3$ and °$C$) |
| Cargo Pressurisation | Tank design pressure |
| Cargo Heating | Thermal Oil Heating (TO) |
| | Max Heating Temperature |
| | No. and capacity of TO heated tanks |
| Tank Inerting | Inerting method |
| | Inerting purity and capacity |

### Cargo Tank Features

The cargo tanks are a fixed characteristic of a ship. After the design and building of the ship will have to do with the number of cargo tanks and the distribution of total carrying capacity over the number of tanks. The tank layout and capacities will at a large extent determine the trading of the ship. Factors that are in this context seen as features related to the cargo tank layout and construction are the number and capacity of the tanks, the coating and construction material, IBC ship type and maximum allowed specific gravity to be loaded (loading factor). A feature that can be identified on deep-sea parcel tankers are the small sized cargo tanks. For product tankers and most chemical tankers, the cargo tanks capacity range between $1,000m^3$ and $3,000m^3$. Parcel tankers feature tanks that have smaller capacities as low as $350m^3$. The feature of small capacity tanks aims a niche market of small parcel sizes.

### Tank Material and Coatings

As mentioned in section 2.6.2 chemical tankers have different options when it comes to cargo tank arrangements and coatings. Depending on the products that are to be transported a ship owner can opt for different types of cargo tank coatings or stainless steel types. Important for the a cargo tanks surface material is to have the right protective properties against the product that are transported, such as corrosion resistance. The cargo tanks surface should have a low roughness, making cleaning easier and reduce residues sticking to the surface. This will reduce tank cleaning times and the risk of cargo contamination. The most common types of coatings are phenolic epoxy, zinc or polymer based products, such as MarineLine® and Interline. The coating products and stainless steel types have different properties of which chemical resistance is one of the main factors. The chemical resistance determines for a large extent the types of cargoes that the ship is technically capable of carrying. It also has an influence on the tank cleaning method and maintenance schedules. For example, coatings such a MarineLine need a new coating twice in the 25 year life of the ship and it needs care/maintenance after discharging aggressive cargoes. Stainless steels have the highest chemical resistance compared to coatings, but is is not completely maintenance free and is has weaknesses. Figure 3.1 shows the percentage of tank coatings used in the deep sea chemical tanker fleet per ship type.

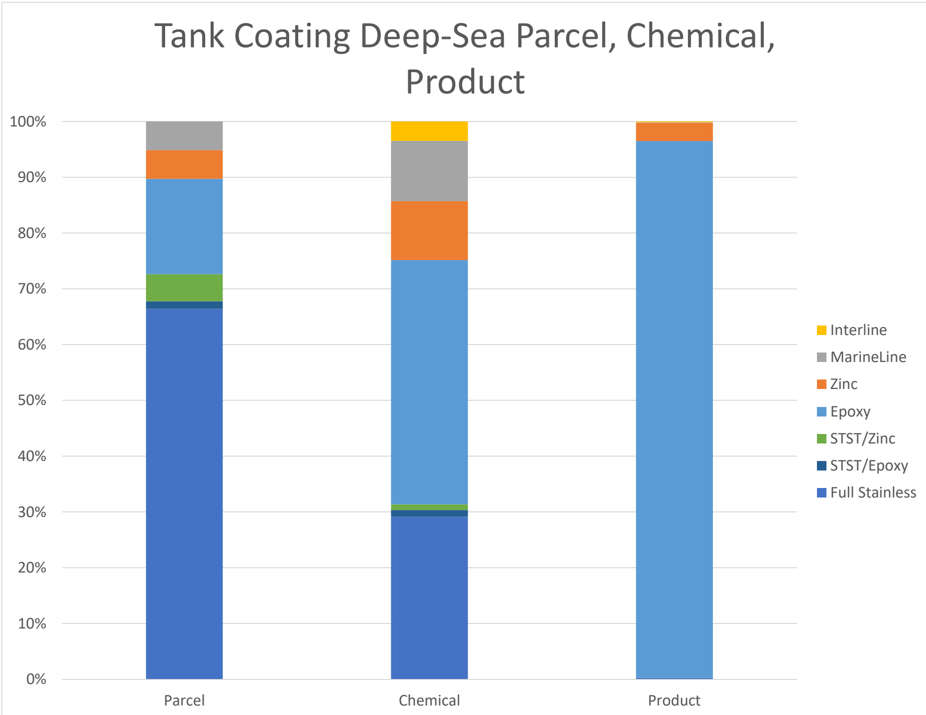



**Figure 3.1.:** Cargo tank coatings used in deep-sea fleet per ship type (as per January 2018)
*Source:* Compiled by Julius Jansen from Drewry fleet list [5].

The figure shows that 71% of the deep-sea parcel tanker fleet has stainless steel tanks. This makes sense since the stainless steel is considered the material having best chemical resistance characteristics for a wide range of products. The tank coating of choice for product tankers is epoxy coating. The other 3% is zinc coated. The group of 'normal' chemical tankers shows a wider variety of cargo tank coatings used. Of the fleet 45% has epoxy coated cargo tanks and 27% has full stainless steel tanks. While stainless steel has a higher purchase price than the combination of steel and coating, however, the benefits of stainless steel for Stolt do not weigh up against the lower cost. Since the benefits of stainless steel over coated ships are clear and profound, it will not be evaluated in the further analysis of the features.

### Cargo Cooling, Pressurisation and Heating Features

A feature that has been identified to make a difference between a parcel and a general chemical tanker is the system used to carry cooled cargoes such as Isoprene (IP) and Propylene Oxide (PO) by means of actively cooling the cargo or transporting it under pressure. Cargo cooling equipment and pressure rating are present on only a small number of parcel tankers. This feature is investigated in further detail in section 3.4 as it is one of the clear features of a parcel tanker. The third feature that has been identified is the heating of cargo using thermal oil and/or heated water. While cargo heating with either thermal oil or hot water is common on most parcel-, chemical- and product tankers, a combination of both methods is only seen on parcel tankers and a number of chemical tankers chemical tankers[1]. The thermal oil heating feature will be further investigated in section 3.5.

[1]the exact number and distribution of ships with thermal- and/or hot water heating is not recorded

#### Cargo Tank Inerting

Inerting is the process of lowering the concentration of combustible (or flammable) gasses (dioxide) from a cargo tank by replacing the air with an inert gas in order to either or (1) reduce fire hazard, and (2) guarantee the quality of the cargo. For all tankers that trade combustible cargoes the inerting system is required. It is therefore not considered a feature as such. The majority of flammable cargoes, such as oil products, a basic inerting requirement is required. The most basic option is a flue gas inerting system that is connected to the exhaust of the boilers and provides cleaned exhaust gas with a lower oxygen content ($< 5\%$) than in air (21%). However, for specialised cargoes that require a high quality (no impurities) or cargoes that can react with elements in the air (oxygen, carbon dioxide or water vapour) require high purity nitrogen inerting. Special technical needs are required to inert with a higher purity nitrogen. The common methods to provide high purity nitrogen are a nitrogen production plant ($95 - 99.9\%$ purity), liquid nitrogen storage tanks (99.999% purity), or compressed nitrogen in bottles (99.999% purity). While most chemical tankers have a nitrogen generating plant the parcel tankers differentiate by having liquid nitrogen storage. Again, this shows the aim of a parcel tanker for niche markets. Tank inerting will not be further investigated in this study.

### 3.1.3. Considerations of Features for Ship Types

As explained in the previous sections there are different types of chemical tankers, and even within these types of tankers there are variations in the layout, equipment and outfitting levels. We have seen that each chemical tanker company has its own ideas about the composition of their fleet regarding the types of vessel and their designs. Many of these technical characteristics in the different fleets are the result of the trading portfolio and operating area and the type of trading (spot, COA or time charter). Chemical shipping companies, including Stolt Tankers, that trade (partially) in the niches of the market design their ships with features to aim at a position in (or create) a niche market.

#### Flexibility and Interchangeability of Features and Ships

When a chemical tanker is designed, and the features are chosen and dimensions are determined according to the (future) market needs. The market may be at a point in the shipping cycle where demand for a certain feature or product is high and it would therefor validate the investment in a type of ship that is fit for the needs at that moment. While the demand changes over the months, years or decades, the chemical tanker design will remain the same as when it was designed and built. And it is likely that the opportunities at the moment of building the ship will not persist for the rest of the ship's lifetime and that during the life other opportunities will arise. The dilemma for the shipping company in terms of the design of a tanker is thus how to deal with short term opportunities and maximising long term gains. Having ships that are interchangeable and can function in multiple markets creates the ability to adapt for future changes. This is exactly what is the case for product tankers, as well as chemical tankers that can transport multiple different products. For Stolt also another factor is closely related to this topic, that is the number of different ship classes in the deep-sea fleet. There is a trade-off in fleet variety and operational performance. A fleet with a lot of different vessels can be a pain from a maintenance- and technical management point of view, but it gives freedom and flexibility to play with the fleet composition to optimise round services for the given demand needs and utilise the ships to a high degree.

The interchangeability of ships in different trades, geographical areas and fleets is therefore an important feature that is required for a chemical tanker. This section will investigate the operational and technical parameters of chemical tankers that define the interchangeability and how these can be used effectively in a fleet of chemical tankers.

In the context of this research interchangeability is defined as the technical and operational ability of a chemical tanker to replace another ship in trades and trading area. In order to measure the technical interchangeability between ships the factors that play are defined: Required equipment and function for the trading operation of both ships

Also interesting is to define a factor for a fleet of ships that describes the extent of which the fleet can adapt (interchange) to changes (more like a flexibility factor maybe) The parcel tankers ships within the Stolt fleet are fully technical interchangeable with the other large ships in the chemical tanker fleet (LC, LScoat, LSstst). For the smaller vessels there can be some limiting factor for which the parcel tanker is not interchangeable. For example, the size of vessels can limit the ability to enter a port (draft) or moor to a terminal (length or draft restriction). If these ships are commercially interchangeable is another question. The high operating cost of a parcel tanker compared to a LS coated ships is much more, so trading only easy chemicals with a LVC will not be profitable.

While ships can be technically interchangeable, there remains always the question to whether they are also commercially or economically interchangeable. When one ships is more expensive to operate, it can be economically unfeasible to interchange them. The following two measures to increase the interchangeability within a fleet are proposed.
**Standardisation**: when equipment is standardised fleet wide the differences between ships will reduce and less effort is required to prepare or refit ships to replace of interchange them. Items such as piping connections (sizes, materials etc.) are standardised to the most commons specification as well as safety equipment and pumping systems. On of the disadvantages is that standardisation can be more expensive than unique designed equipment when not applied in large scale. Examples of successful implementation of standardisation in ship designs are the Damen vessels (add source). Within the chemical tanker industry the Japanese built chemical tankers can also be seen as a highly standardised. The Japanese yards use proven designs and with little freedom for the owner to define specifications and additional options.
**Modularisation**: A fleet of basic, identical ships is interchangeable per definition. By designing the ships for the basic trading needs and outfitting them with preparations for modules for specific features the fleet remains interchangeable while at the same time flexible. For the feature modules one could think for example of a container-like construction that houses cargo cooling equipment (compressors, condensers, hoses and cooler) that can easily be stored on deck in a pre-designed area with power connections etc in place. The same concept could also be used for heating with thermal oil or other equipment that is specific for a small number of cargoes.

## 3.2. Case Study: D37 Class

For the case study of the features of the Stolt ships, the Stolt D37 class ships are used as a reference. Based on this data the trading needs for a new replacement tanker will be derived. In this chapter the specifications of the D37 class are presented as well as the objective and assumptions of the case study.

### 3.2.1. Goal of Case Study

The goal of the case study is to identify the need for the parcel tanker features for a new parcel tanker. The subject of the analysis is the D37 class of parcel tankers that have the potential to be replaced in the near future.

### 3.2.2. The D37 Class

The D37 class ships, also known as the 'Innovation Class', is a series of nine sophisticated parcel tankers built for Stolt Tankers between 1995 and 1999 by Danyard A/S in Denmark. These ships were at the time of delivery considered the most sophisticated parcel tankers in the industry equipped with many features such as diesel electric propulsion, cargo cooling, -heating and -inerting and a high level of automation of cargo equipment and machinery. The main dimensions and characteristics are listed in Table C.1 which can be found in appendix C and the average freight rates in appendix J.

The reason to use the D37 as a reference is that this group of nine D37 parcel tankers represent a large part of the Stolt parcel tanker fleet. Secondly, the ships are reaching the 25 year mark in the next five years, which brings them in the picture for replacement. And thirdly, a large set of trade data of these ships, covering at least the last 5 years of operations, has been made available by Stolt Tankers to use for analysis. This data is used to get a view of the trading and operations of a parcel tanker.

The main trading and voyage data is presented in table 3.2.

**Table 3.2.:** D37 operating profile and average freight rates of 'normal' cargoes.
*Source:* Compiled by Julius Jansen form Stolt Tankers historic data 2012-2017.

| Round Service | Trade Lane | Voyage Trade Qty Distribution | Avg. Voyage Distance/Duration [nm / days] | Number of Voyages [#/year] | Freight Rate Avg. Average [USD/tonne][2] | Freight Rate St.Deviation [USD/tonne] |
|---|---|---|---|---|---|---|
| Pacific | TAE | 39% | 5,493 / 16.8 | 6 | 77 | 36 |
| | TAW | 6% | 5,324 / 16.7 | 6 | 85 | 30 |
| Atlantic | HBR-U | 18% | 14,630 / 43.6 | 3 | 106 | 36 |
| | TPW | 30% | 13,218 / 41.0 | 3 | 118 | 30 |
| Total | 93% | | | | 96 | 38 |

As mentioned in the introduction chapter of the thesis in section 1.1 a significant part of the parcel tanker fleet is reaching the end of their 25 year life time and the D37's (%) are a big portion of this tonnage. Thus, the reason that this type of parcel tanker is chosen is twofold, there is considerable amount of historical trading data available (in contrast to the recently delivered C38 class) and the class of ships are likely being removed or replaced in the near future.

The main dimensions of the D37 are a common standard for chemical tankers. Limiting factors prohibit the ships to grow in size. The length overall, beam and maximum freeboard are limited. The typical deep-sea chemical tanker has a maximum length overall of 185m. The length is limited to the berth layout in many ports that do not facilitate longer ships. The beam of most deep-sea chemical tankers is 32.2m, the maximum size possible for the old Panama canal locks. The new locks (Neo-Panamax) accept a wider beam up to 51m, but this also increases the canal toll. The draft of the chemical tankers is primarily restricted by the rivers and canals that the ship has to navigate to reach terminals. Examples are the Mississippi river, Houston Ship Channel (max. depth 14m), Scheldt River (max. depth 15.2 m). Optimising ship dimensions for fuel consumption results in drafts below these values.

### 3.2.3. Assumptions

For the replacement study the following assumptions are taken in to account to stay within the scope of the project.

#### Technical

The focus of the case study lies on the cargo area and the cargo systems, therefore other design points of the ship are disregarded in the analysis. First the assumption is that the successor of the D37 class has the same cargo area dimensions: $V_{cargo} = 40,000m^3$, $L_{cargo} = 125m$, $B_{cargo} = 27m$ and $H_{cargo} = 14m$

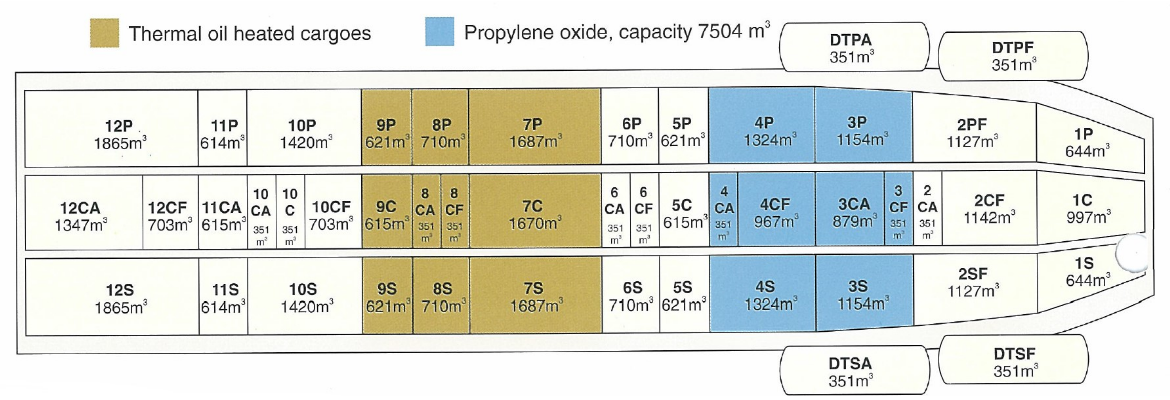



**Figure 3.2.:** D37 cargo tank layout including heating- and cooling capacities
*Source:* Stolt Tankers

#### Trading and Operational

Two trading areas are defined that form the basis of the trading analysis. The North Atlantic (TPW, HBR-U) and the North Pacific (TAW, TAE) trade lanes are used. These four trade lanes are chosen because they represent 93% of the D37 trade routes. Also, the four routes represent two fronthaul routes (TAE and TPW) and two backhaul routes (TAW and HBR-U). Currently four of the nine D37 ships are doing a pacific round service (TPW ⟷ HBR-U) and five ships are trading on the Atlantic round service (TAE ⟷ TAW). Since both the round services have the US gulf in common number of ships on a service can be interchanged according to demand. Table 3.2 shows the percentage of voyages spend on each trade lane and the average freight rates. It is assumed that this average represents the average of the freight rates in the near future, when corrected for inflation. In section 2.6.3 it was shown that inflation adjusted freight rates fluctuate over time around a constant mean value.

The D37, and every parcel tanker for that matter, have a high port-sea time ratio relative to other ship types. For the case study a port-sea ratio of 43% is assumed, based on the long term average of the Stolt parcel tanker fleet. The year for a parcel tanker has 362 operating days and 3 off hire days [3]. Based on the port-sea ratio the time spend at sea is assumed to be 206 days per year, the operating days in port is assumed to be 147 days a year. These assumptions are based on the long term averages for the D37 ships.

[2] The average freight rate is compiled from the all freights rates of the transported cargoes in the last 5 years, excluding the feature related cargoes (PO, IP, MDI & TDI)

[3] Budgeted off hire days by Stolt

### Economic and Financial

Features are assumed to be included in the newbuilding price of the ship and will therefore be subject to financing. Table 3.3 presents the financial parameters used in the valuation calculations. The ship and the features are assumed to be financed with a 60% loan-to-asset ratio, an interest rate of 5.0% and a quarterly repayment schedule over a period of 15 years. Also bank fees worth 1% of the purchase price are assumed. For the profitability calculations and net present value calculations the net cash flows are discounted for inflation as well as the weighted average cost of capital that is commonly used in investment evaluations. The $WACC$ that is as discount factor and is 7.5%. This value is used by Stolt. The scrap value after 25 year of life is assumed 7% of the purchase price of the feature, unless stated otherwise.These numbers are according common business practices for parcel tankers.

**Table 3.3.:** Financial Assumptions
*Source:* Julius Jansen

| | |
|---|---|
| Loan-to-Asset ratio, % | 60 |
| Maturity annuity loan, years | 15 |
| Discount Rate (WACC), % | 7.5 |
| Interest rate, % | 5.0 |
| Service life of ship, years | 25 |

The profitability of the investment of the feature is evaluated as part of the investment of the whole ship. This means that differences introduced by the features are measured against a base case of a virtual parcel tanker without these features. The value of the of the

## 3.3. Method of Prioritising Features for a Newbuilding Functional Specification

This section describes the methodology that is used to set up a framework that has the goal to structure the process of determining the functional specifications regarding the features for a new ship. This section elaborates first on the factors that a shipowner will consider when making a functional specification for a new ship. Secondly, the MoSCoW method of prioritising requirements is introduced that will be used to prioritise the features of this study to support the requirements for new parcel tankers.

### 3.3.1. Functional Specification

The functional specification is the standard way for the shop owner to communicate to the ship- designers and yards the requirements that it has for a new ship. When a design company and yard have been decided, based on the basic design, and price offer and the specification is worked out in detail by the The specification together with the shipbuilding contract form the most important documents in a newbuilding project. The shipbuilding contract mainly defines the prices, payments, guaranties and the the legal matters. The specification is about the technical requirements.

Making a functional specification for a new parcel tanker is generally a process that requires multiple divisions of a shipping company to work together and has an iterative nature. The following three factors (see figure 3.3) are the fundamental topics that work together to create the specification for a new ship. The first fundamental that required analysing are the shipping markets. The shipping markets analysis defines input to the specification on the

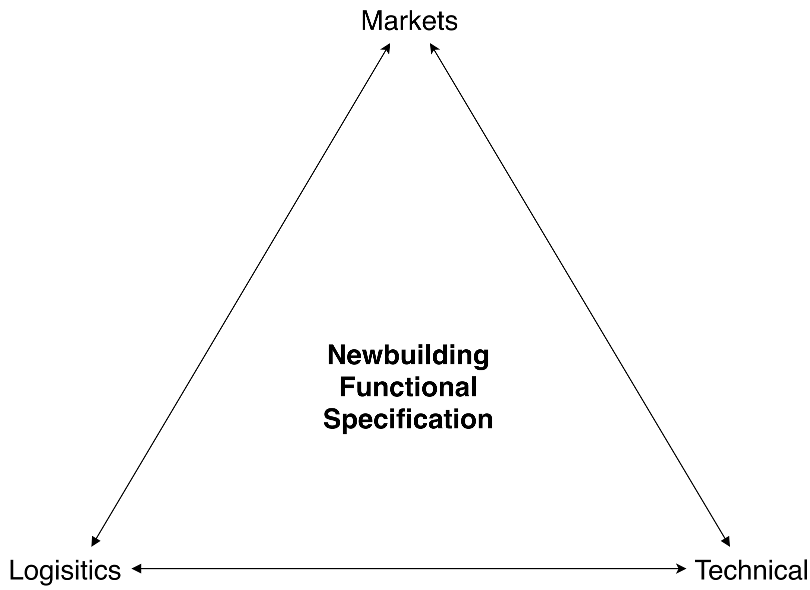



**Figure 3.3.:** Fundamental factors for input for a newbuilding functional specification from a shipowners perspective
*Source:* Own contribution

topics of the demand for ships, the competition, and the pricing of building a new ship. The second fundamental input that determines the requirements in the newbuilding specification come from the logistics and operations analysis. Design parameters are analysed from an logistics point of view. The third fundamental is the technical aspect. Topics related to this are considering the cost of equipment, the regulations and dimensional limitations. It must be clear that the technical requirements in the context of a newbuilding specifications can be specific on some parts, while others can be defined vaguely and are open for the ideas of the ship designer. The newbuilding specification has to be in line with the long term strategy of the company and the available budget. So, the three topic of the pyramid in figure 3.3 are subject to the goals and long term strategy of the company.

The three fundamental topics are depended on each other, concluding on a requirement in one field can have implications on the others. Therefore the process of determining the requirements has a iterative character. The process of determining the the functional requirements for a new ship, or a series of ships, starts generally with the analysis of the of the markets. Objectives can be derived as the picture of the market need gets clear. The the operational and technical requirements will also take shape. This process will iterate and, like the process of designing a ship [41], the technical and operational requirements will take shape.

Figure 3.4 shows the process overview of coming to a ships specification.

### 3.3.2. MoSCoW Prioritising

The MoSCoW method is a prioritising method that is used to order requirements on importance and focus decisions-making on the requirements that have large impact on the project/design. The MoSCoW prioritising method will qualitatively prioritise the items for the functional specification on a high level. Later steps in the actual design process will determine the design details in more detail. The goal of this way of prioritising is to have a more abstract list of requirements that can give the outline requirements, but also leave freedom

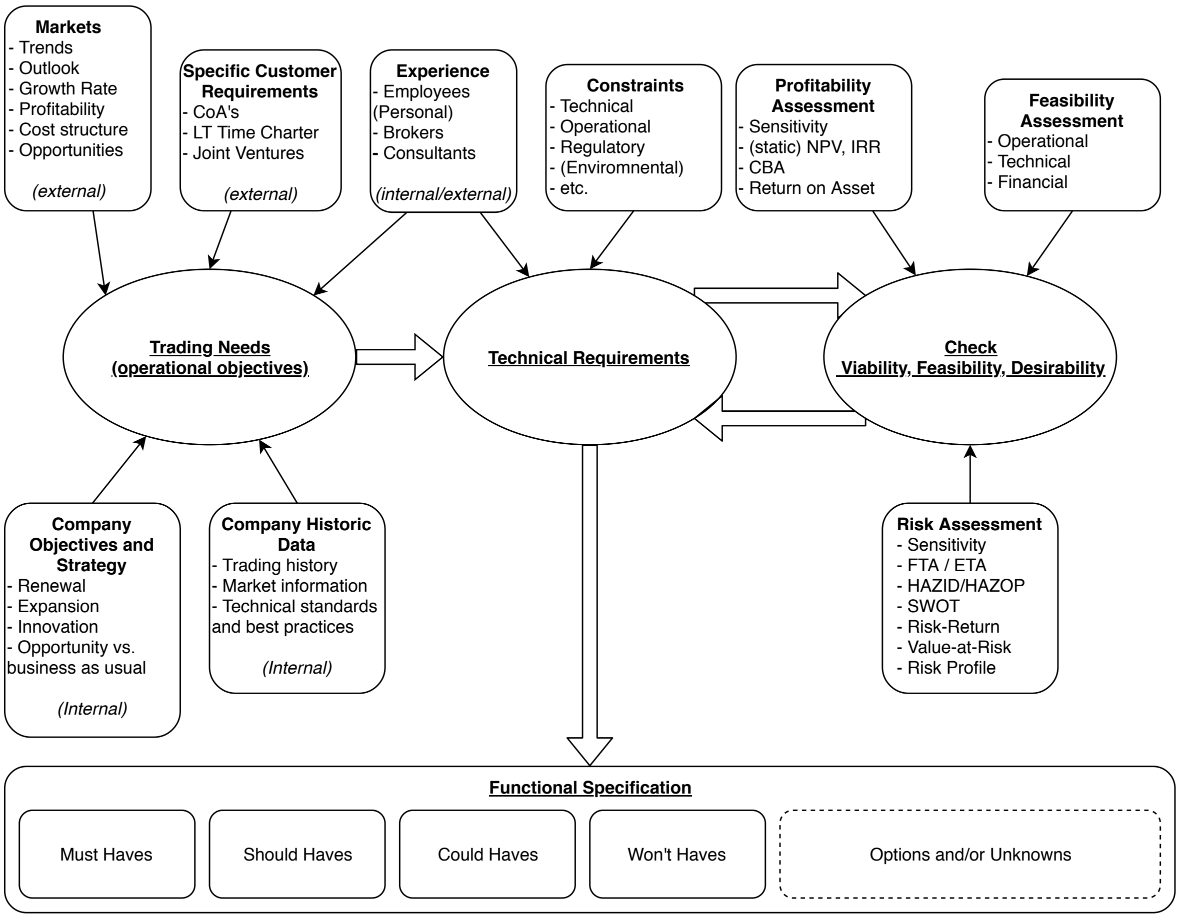



**Figure 3.4.:** High level overview of functional specification drafting process
*Source:* Own contribution

for the shipping company, design office and shipyard for their design input and optimisation.

**Must Have (M):** Items that are critical and cannot be omitted in the functional specification. These 'hard' requirements can, for instance, be related to rules and laws that must be followed or requirements that define the essence of the ships goal.

**Should Have (S):** Requirement items that are important but not vital. This category of items should be included in a final design, but if items are not included the project is still viable as opposed to the must have requirements that will cancel the project if the requirement is not met.

**Could Have (C):** Requirements that are desirable but not necessary. Requirement items in this category could improve the function or add costumer satisfaction at a relatively low cost. These items thus do add value so they could be added if resources (money, time, etc.) permit.

**Won't Have (W):** Items that have the lowest priority, or least suitable within the scope of the requirements. Items with this priority are not strictly necessary, and to do add little value to the requirements. Won't have is often used in common with the categories 'Wish to have' and 'Would like to have' although these are, strictly speaking, refer to items that are outside the scope of the technical requirements, or else it would be prioritised as a 'could have'.

There are some critics related to the MoSCoW method of prioritising. Since it the method used qualitative arguments to prioritise items in one of the four groups there can be a lack of rationale to prioritise an item in one or the other group. Depending on the view or approach when evaluating an item can been given a different priority. The threat of the the MoSCoW thus that the prioritisation will for the large part be based on 'expert' opinions in stead of quantifiable input. Therefore, the MoSCoW method is used in the part of the process after the feasibility, viability and desirability check where quantifiable analysis is gathered to substantiate the prioritisation.

A limitation using this technique is that prioritised options could have a different outcome when approached differently. For example, approaching the prioritising on a 'per ship' basis, a feature could be prioritised as a must have, however since ships are often built in series the prioritisation could have a different outcome when looking at the ship in the series context. So, for one single ship the feature could be a must, but in a fleet not all ships should have that feature as the profitability or the risk of losing profitability over the fleet will result in a lower priority. The right scope is therefore essential for a satisfactory outcome of the MoSCoW process.

## 3.4. Cargo Cooling

In this chapter, the cargo cooling feature of parcel tankers is analysed evaluated with respect to the markets, operations and profitability in the Stolt fleet. The first section will introduce the operating method and function of the cargo cooling system. In the second section, the trading needs for the seaborne trade of cooled chemicals are studied, looking at the demand, supply and growth in the last and for coming years. In the third section Stolt tankers cooled cargo trade and ships are analysed. In the section 3.4.4 the value of cargo cooling is evaluated. In sections 3.4.5 and 3.4.6 strategic considerations regarding cargo cooling features and the conclusion are presented respectively.

### 3.4.1. Introduction to Cargo Cooling

One of the features found on the parcel tankers is the ability to cool and maintain specific cargoes to a certain temperature. There are three products carried by Stolt that require cooling: isoprene, isoprene feedstock (IP) and propylene oxide (PO). These three hazardous products need to be kept at a temperature below 16, 25 and 25 degrees Celsius respectively to maintain the cargo as a liquid (below boiling point). The cargoes are cooled by inserting one or two of the portable cooling units through a deck opening in a tank, see 3.5, and connect the unit to the chilled water plant located in the deckhouse. The cooled water (or water/glycol mixture) is circulated through the coolers to cool the cargo. The coolers are 8 meters long, this means that they do not reach all the way to the bottom of the tank. In order to cool the cargo efficiently the space above the liquid (i.e. ullage) should be as small as possible so the cooler is as much submerged as possible.

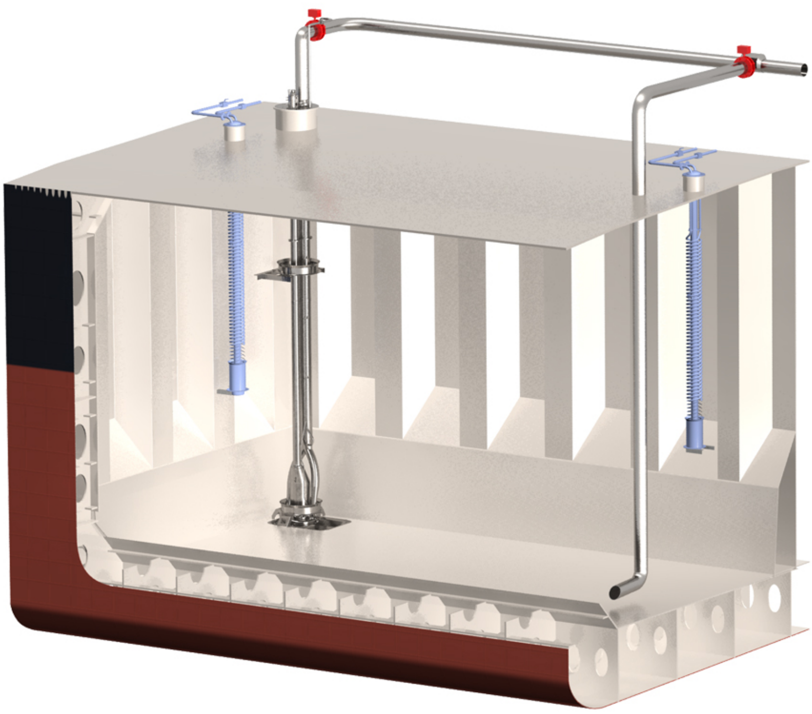


**Figure 3.5.:** Cargo coolers (in blue).
*Source:* FRAMO [42]

### 3.4.2. Trading Needs

This section will determine the trading needs regarding cargo cooling. Starting with the market analysis looking at the supply, and demand of cooled chemicals and chemical tankers. Followed up with the insights from Stolt's historical trading- and fleet data. Since the assumption for this case is to find a replacement of the D37 ships no specific customer requirements are considered other than the requirements in the freight contracts in the historical trade and freight data (i.e. the previous cargoes, freight rates and trade routes).

#### Demand of Cooled Cargo Transport

The three cooled products are intermediates needed for chemical production processes. The supply and demand for the isoprene and IP feed are closely related to each other as the IP feed is an extraction product from the isoprene production. Isoprene and IP feed are used in the production process of many other chemical products. The main use of PO is in the production of polyether polyols (60%) and propylene glycol (21%) [43].

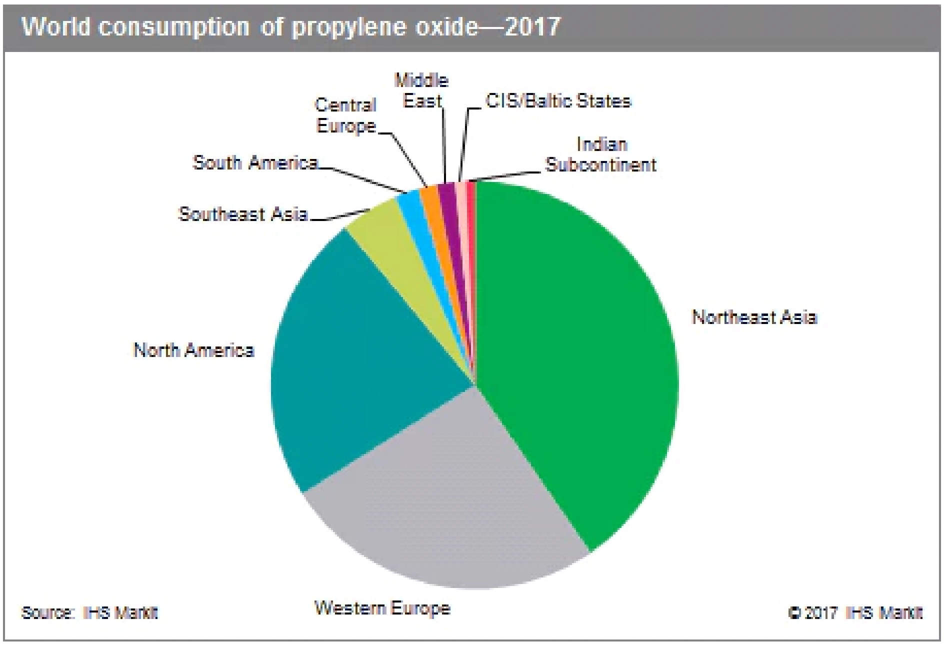
Figure 3.6 shows the world production and consumption of PO and isoprene in 2017. Figure 3.6a shows that Europe, with Russia in specific, is the largest consumer of isoprene. Russia, however, is also the largest producer of isoprene, the seaborne trade between Russia and the world is therefore relatively small. Isoprene is mainly produced in Asia and transported to the largest importer, the United States. The number of producers of PO is relatively low, the top 3 is controlling a significant part of the market, however, the exact numbers are unknown. The top PO manufacturers are DOW, Lyondell, Shell and BASF. The main manufacturer of isoprene and IP feed are Exxon, Shell and Jinshan [45, 44]. Both the Isoprene, IP feed and PO producing can, therefore, be considered a strong oligopoly with monopolistic characteristics.

The production of isoprene expected to grow at an average annual rate of 2.5% between 2016 and 2021 [45]. The total consumption of PO is expected to grow around 4% per year, with faster growth rates in China (6%). The Middle East and the Indian Subcontinent are also expected to grow faster, but with smaller production quantities [44]. It is unknown if for both products this production growth will translate to an equal growth of the seaborne transportation of in these areas, or that the consumption will largely be domestic. In this case, it is assumed that the seaborne trade will experience the same growth rates.

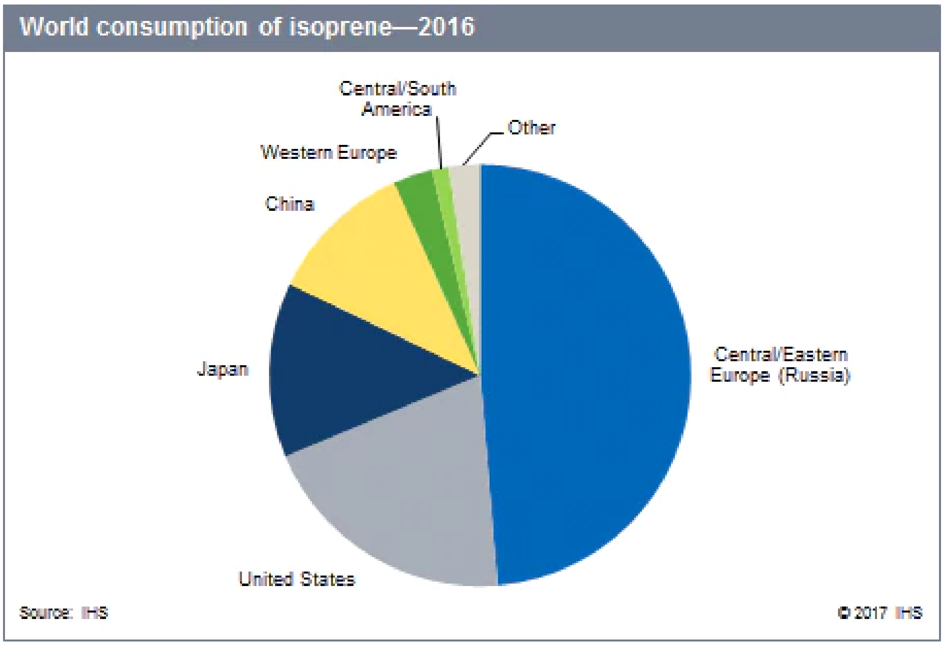
#### Supply of Cooling Capacity

Stolt Tankers and Odfjell are the two major companies owning and operating chemical tankers with cooled cargo capacity, see Figure 3.7. The total cooled cargo capacity for deep-sea ships is estimated at $516,000m^3$ tank volume and a fleet of 65 ships. To put this in context, 2.7% of the world deep-sea fleet is able to trade cooled cargoes and the total tank capacity of the world deep-sea fleet is estimated to be 0.5% of the total fleet cargo capacity. Based on this, cooling on chemical tankers is considered to be a niche in the world chemical tanker business. Of cargo cooling capable ships, 21 (36%) are reaching their 25 years mark between 2020 and 2025, including the nine D37s[4]. The figure shows that a significant part of the cargo cooling fleet of ships is older than 20 years. This will promote the argument to invest in cargo cooling for the next generation parcel tankers. There are 32 ships in the Stolt fleet that are PO/IP capable with a total cooled cargo capacity of $314,416m^3$ over a total of 268 tanks. Table D.1 in appendix D presents the cargo cooling capacities of the ships in the Stolt fleet. The removal of the D37 ships from the fleet will have an impact on the cooling capacity in the

[4]Data composed from Stolt ship particulars and Odfjell fleet webpage: https://www.odfjell.com/tankers/fleet/




**(a)**




**(b)**

**Figure 3.6.:** World consumption of (a) propylene oxide and (b) isoprene in 2017 and 2016 respectively.
*Source:* IHS Markit [44, 45]

Stolt fleet, but also on the world fleet. The nine D37's have a combined cooling capacity of approximately $5 \cdot 7,500 + 4 \cdot 13,300 = 90,700m^3$. This counts for 41% of the cooling capacity within the Stolt fleet and 18% of the estimated capacity of the deep-sea world chemical fleet. Eight newbuildings for Odfjell are scheduled to be delivered between 2019-2020 and four of these will have PO carrying capability. These ships will add a total of $74,000m^3$ cooled cargo capacity to the market, which is 5% more than the capacity by the older Odfjell fleet that is expected to be removed from the fleet[46]. This supports that the competition (Odfjell) is consolidating its current share of the cooled cargo market for the future.

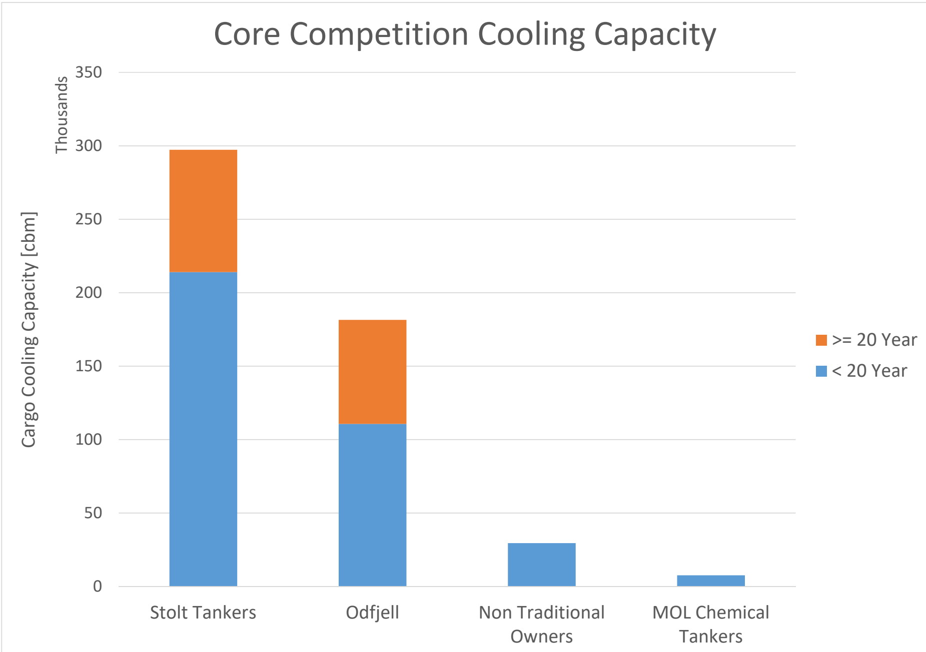



**Figure 3.7.:** Estimated deep-sea cooling capacity from core competitors with 'old' tonnage distinction (as per January 2018)
*Source:* Compiled by Julius Jansen from various sources.

Propylene oxide can also be transported without cooling, in that case it must be transported under pressure or, for special cases and conditions[5], could be waived by the flag state administration [8]. For ships that transport the cargoes under pressure strengthened pressure tanks are required. In the industry, the cooling of PO is preferred over the pressurised transport because some receiving terminals cannot receive pressurised cargoes or only have cooling capacity to maintain a certain temperature and are not able to cool down a cargo above a certain temperature. Gas tankers are the preferred type of ship to carry PO in bulk, however, for deep-sea traded the quantities of PO are generally too small for the large volume tanks of oceangoing gas tankers. Parcel tankers occupy the market in the deep-sea cooled cargo trade for parcel sizes smaller than $10,000m^3$. For regional shipping smaller gas tankers are better suited to carry PO in the smaller tanks, therefore the number of regional chemical carriers with cargo cooling features is low. Gas tankers will be left out of considerations in this analysis, on the assumption that these do not interfere with the deep-sea chemical tanker cooled cargo market. Also, cooled ISO tank containers can be used for smaller quantities ($< 500m^3$), which is considered not to be relevant for the subject deep-sea shipping.

[5]an example of special conditions given by the IBC code are of ships operating in restricted areas, on voyages with restricted duration and accounting the insulation of the tanks and the time of year (i.e. temperature)

### 3.4.3. Stolt Tankers Historical Data and Experience

In this section the cooled cargo shipping in the Stolt fleet is analysed with respect to the quantities and contracts of the shipped cargoes and the utilisation of the ships. Findings in this section are used as input for the financial analysis in the next section.

#### Cooled Cargo Trade

Cooled cargoes are usually traded on the following trade lanes: TPW, HBR-U, TAE and TAW. On other routes the cooling cargoes are less frequent (less than one trip a year), so they are considered occasional trades. Figure 3.8 gives a graphical presentation of the trade flows on these trade lanes including the percentage of the tonnes of cooled cargoes traded by the D37 fleet.

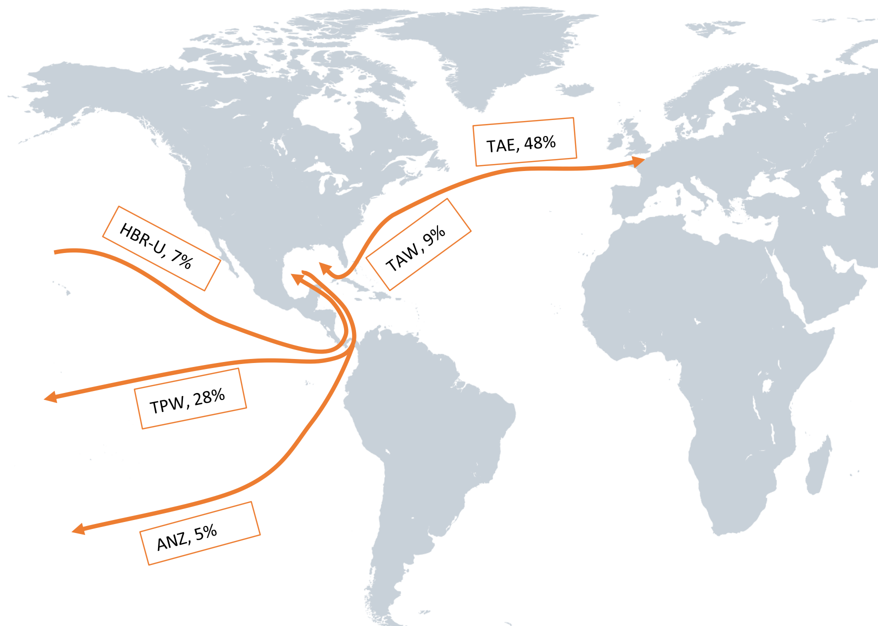



**Figure 3.8.:** Cooled cargo (IP feed, PO, isoprene) trade routes of the D37 fleet with percentage of average traded quantity (tonnes)
*Source:* Compiled by Julius Jansen from Stolt data

The figure shows that of all cooled cargoes traded by the D37 fleet the majority (48%) is traded on the Transatlantic eastbound (TAE) route, this is between Houston and Rotterdam/Antwerp. The second largest trade route for cooled cargoes is the Transpacific West (TPW) route accounting for 28% of the D37's cooled cargo trade. The three individual cooled cargoes each have different trade patterns. The two main PO trade lanes of the D37s are the Transpacific westbound (TPW), Transatlantic eastbound (TAE) with respectively 63% and 17% of the traded tonnes of PO. For isoprene the there is one main trade route, the Transpacific eastbound trade (HBR-U), accounting for 72% of the traded tonnes of IP by Stolt. The IP feed also has one characteristic main trade route where it is traded, the Transatlantic eastbound (TAE) route where 82% of the IP is traded. From this analysis the first conclusion is that the cooling equipment on board a ship is best utilised when trading in the transpacific loop (TPW - HBR-U), taking PO one way and IP on the return leg.

### Freight Rates and Contracts

The cooled cargoes can be considered valuable cargoes. The average freight rate of the cooled cargoes is 168 USD/tonne [6], however these are large variations between the trade routes. On the HBR-U trade route the average freight rate is 240, while the average on the TAW is 118. Looking at the round services of the Pacific and the Atlantic, the average freight rates are 136 USD/tonne for the Atlantic and 205 USD/tonne for the Pacific service. The standard deviations are respectively 26 USD/tonne (0.19) for the Atlantic service and 48 USD/tonne (0.23)for the Pacific. The freight rates are therefore relatively closely distributed to the mean.

The high freight rates must justify the extra investment in cooling equipment as well as additional structural strength and safety measures (pressure relief valves) in the ship's design.

The distribution of contract of affreightments and spot contracts differs for the two cargoes. Isoprene has a 50/50 ratio for CoA/spot, while the PO trade is almost 90% based on contracts of affreightments. The IP extraction feed contracts are 100% CoA. The PO and IP extraction feed revenues are more predictable than IP and the freight income is secured for a longer period. The cooling trade is therefore considered one of the trades that forms the basis for the secure source of income.

### Utilisation of Cooling Capacity

In the last 7 years, 1.3% of the cargoes carried by cooling capable vessels required cooling. Between 1 and 7 (on average 2.7 voyages) per year per vessel are with cooled cargoes. For the deep-sea ship classes that have cooling equipment, the average utilisation rates are calculated. The utilisation rate, defined in equation 3.1, is the cargo volume of a cooled cargo divided by the tank capacity of the cargo tanks with cargo cooling possibility.

$$U_{cooling} = \frac{\text{cargo freight volume } [m^3]}{\text{cooled cargo tank capacity } [m^3]} \cdot 100\% \tag{3.1}$$

The utilisation distribution of the D37 fleet between 2011 and 2017 is presented in figure 3.9. It shows that the cargo cooling capacity is fully utilised for the IP feed cargo. The capacity is most likely designed for a specific (long-term) IP feed contract of affreightment. The other cooled cargoes have a much lower tank capacity utilisation[7].

The cooling capacity for the successor of the D37 will be determined by the prospect of a continuation of the long-term contract of affreightment with the same or changed cargo volume and voyage frequency.

The quantity at which PO and IP parcels are transported is shown in figure 3.10. The PO and IP parcels usually come in bulk sizes larger than $2,000m^3$, sometimes up to $10,000m^3$. Comparing the diagram with the tank capacity diagrams, shows that the parcels must be carried in multiple tanks. This also explains why most of the PO capable tankers have a cooling capacity between $5,000$ and $10,000m^3$. Ideally, the LVC tank layout would have larger tanks, in order to divide a parcel of PO over the least amount of cargo tanks. Considering the case study of parcel tankers versus shipping cargo in tank containers mentioned by Knops [39], the parcel sizes and the trade frequency the cooled cargoes are considered too large to be economically transported by tank container. The parcel distribution could be an important knowledge for the design phase of a tanker, minimising the cost per tank (marginal cost) of the cooling system, would imply that the largest possible tanks ($> 3,000m^3$) would yield the lowest number of cargo coolers and therefore the lowest cost. Cargo cooling for tanks smaller

[6] for comparison the average D37 freight rate is 94 USD/tonne

[7] Isoprene and PO are not carried on the same voyages, so the combined utilisation per trade is the same

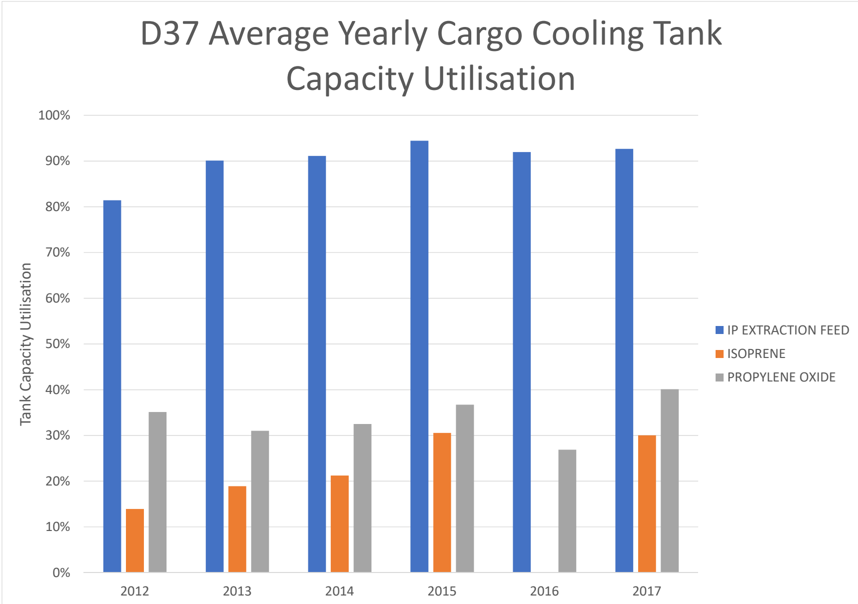



**Figure 3.9.:** Average Cargo Cooling Capacity Utilisation for the D37 Fleet ($100\% = 7,500m^3$).
*Source:* Compiled by Julius Jansen from Stolt data.

than $500m^3$ does not look to be beneficial from a cost per tank perspective since the base cost of a cooler is relatively high compared to the volume is has to cool.

The frequency at which ships ship cooled cargoes on the main trade lanes depends on the contracts that are offered. Since the PO trade mainly consists of COA's, the voyage frequency is more predictable than the IP trade frequency. The frequency is based on the number of shipments over a trade lane. Thus, shipments considered are of one ship that loads cargo in multiple ports before it sets sail to (multiple) destinations. All these independent calls are considered individual shipments.

Remarkable is the fact that not every year all ships capable of carrying cooled cargoes do carry cooled cargoes. Between 2011 and 2018 about 20% to 40% of the ships capable of carrying PO each year did not carry cooled cargoes. This counts for 6 to 12 ships on a cooling capable fleet of 30 ships. The fact that in a period the cooling functions of these ships are not used can be considered a waste (of capital). Oversupply or low demand of cooled cargoes could be a reason for the low utilisation. However, for flexibility reasons and given the high margin on the cooled cargoes and possibly a low cost of the cooling system.

### 3.4.4. Valuation of Cargo Cooling

The cargo cooling feature is valuated by means of a net present value method and sensitivity analysis to analyse the risk of changing variables. First, the gross revenue difference is derived between the cooled cargo revenues and the revenues of an average product. Subsequently the investment cost, maintenance and fuel cost are derived for a system for 8 tanks and a capacity of $10,000m^3$.

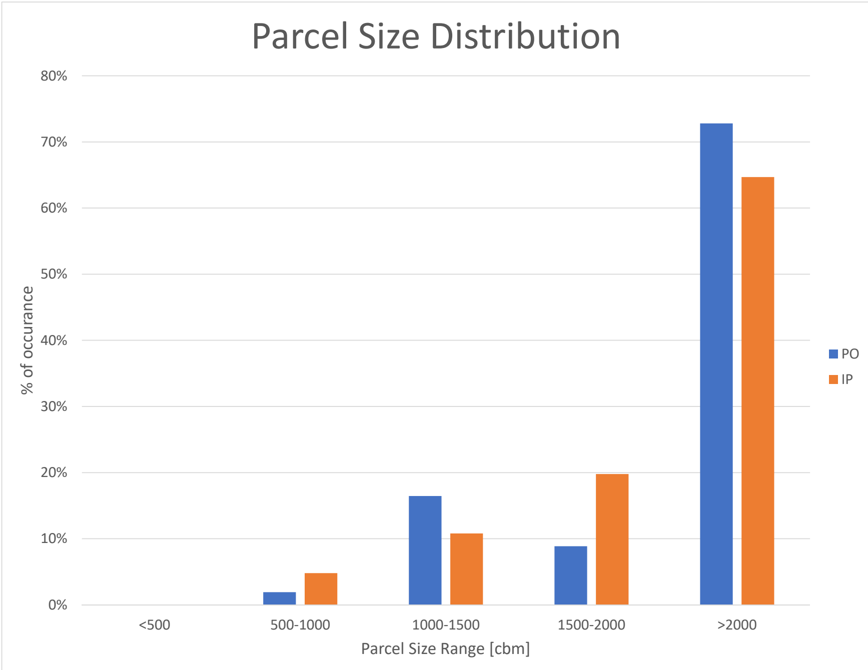



**Figure 3.10.:** Cargo parcel size distribution for cooled cargoes
*Source:* Compiled by Julius Jansen from Stolt data

### Cooled Cargo Revenues

The valuation and value-add of a cargo cooling system on a D37-like ship are based on the difference in cost and revenues between the cooling cargoes and equipment and the average 'normal' cargo. In table 3.4 shows the differential of the yearly freight revenues summed of propylene oxide, isoprene and IP feed.

**Table 3.4.:** Average yearly revenue differential of cooled cargoes for a D37.
*Source:* Compiled by Julius Jansen from Stolt data.

| Trade Lane | Revenue Differential, $ |
|---|---|
| TAE | 157,222 |
| TAW | 455,831 |
| HBR-U | 50,290 |
| TPW | 139,324 |
| Total | 734,650 |

The total average yearly revenue differential measure over the last 5 years for a D37 is $734,650. This value is the revenue that is on average made compared to the revenues that would have resulted when the cargo space was used to transport an average 'normal' cargo.

### Capital Expenses

For this valuation study the investment, potential revenues and operating cost, need to be known. An estimate of the investment cost of a cargo cooling system for 8 tanks and $10,000m^3$ is made based on quotations from previous projects[8], see table 3.5. The investment of a cargo

[8] Quotes from C38 newbuilding and N43 retrofitting project

cooling system is between 1% and 3% of the total investment of a parcel tanker.

**Table 3.5.:** Cargo Cooling Equipment Capital Cost
*Source:* Compiled by Julius Jansen from various sources.

| Component | Price, $ |
|---|---|
| Coolers | 400,000 |
| Chiller, condenser, pumps | 250,000 |
| Storage and Header Tanks | 5,000 |
| Sprinkler | 310,000 |
| Piping, Valves and Hoses | 300,000 |
| Total | 1,515,000 |

The coolers (8 x $50,000 a piece) scale directly with the number of cargo tanks. An option is to outfit 3 $3,000m^3$ and one $1,000m^3$ tanks for cargo cooling. This option could be feasible, as the figures 3.10 and 3.9 showed that the majority of the traded cooled cargoes have a parcel size larger than $3,000m^3$. This will reduce the investment with at least $50,000 because of one less cargo cooler. Also, smaller tanks can be an option. For 20 $500m^3$ tanks, which is considered the most extreme case, the cost of only the coolers is already 1 million dollars. While it is easy to optimise tank arrangements for these given costs, it has to be noted that the tanks are used for many more cargoes. Optimising the cargo arrangement has to be done with a holistic approach, which is worth a study of its own.

### Operational and Voyage Expenses

The cost to operate the cooling equipment is simplified to only the cost of power (i.e. fuel consumption) and the voyage cost are simplified to only the maintenance cost. Crewing cost is for this case not considered relevant since the crew that is already on the ship is able to handle the cooling equipment (no extra crew is required and wages will not change when cargo cooling is installed). It was not possible (within given time and scope) to study all other (potential) costs that contribute to the operational cost. The average fuel consumption is calculated taking the fraction of the power that is required for the cooling system as fraction of the total auxiliary power and multiplied with the nominal fuel consumption of the auxiliary power system (4 tonnes/day)[9]. This is multiplied by the number of estimated operating days per year of the cooling system, i.e. the utilisation. See equation 3.2.

$$\begin{aligned} fc_{cooling} &= \frac{P_{cool,avg}}{P_{DG}}\left[\frac{kW}{kW}\right] \cdot FC_{DG}\left[\frac{tons}{day}\right] \cdot U_{cooling}\left[\frac{days}{year}\right] \\ &= \frac{300}{900}\left[\frac{kW}{kW}\right] \cdot 4\left[\frac{tons}{day}\right] \cdot 61\left[\frac{days}{year}\right] \\ &= 82\left[\frac{tons}{year}\right] \end{aligned} \tag{3.2}$$

Where $P_{cool,avg}$ is the average required power of the cooling system (compressors, pumps, etc), $P_{DG}$ is the power of a diesel generator on board the ship, $FC_{DG}$ is the fuel consumption of the diesel generator, $U_{cooling}$ is the average utilisation of the cooling equipment in days per year. The calculated yearly fuel consumption for this case is 82 tonnes per year. With the

[9] this assumes that the generator set is always running at an average load of 85% mcr

current fuel price of 481 USD/ton[10] the fuel cost of the cargo cooling system is approximately to be 40,000 USD/year.

The maintenance cost of the cargo cooling equipment is estimated at $5,000 per year[11]. This includes spare parts for the piping, valves, pumps and compressors.

### 3.4.5. Strategic Considerations

Strategic factor that can influence the decision to install cooling is timing. Since the number of suppliers of cargo cooling equipment is small, the knowledge of Stolt Tankers of the market is relatively big, and this should be used as an advantage. Combining the knowledge of endings and renewals of freight contracts and the expectation the supply of ships with cargo cooling decreases in the next years. This 'first-mover' advantage is a strategic argument, but also the high probability of securing a high paid freight contract at the start of the life of a ship will benefit the investments payback period and profitability.

### 3.4.6. Conclusion

Shipping cooled products by parcel tanker fits a small niche between the tank container and gas tanker trades. The cooled cargo trade mainly relies on contracts of affreightment. This makes it a secure source of income to Stolt Tankers, as long as a (coa) contract is rewarded. The supply of cooled cargo parcel tanker capacity for is provided by only Stolt and Odfjell. The likelihood of winning and keeping freight contracts if therefore high. The cooled cargoes traded on the Atlantic have a high value compared to the average value and freight rate of product traded on the same trade routes. For Stolt the cooled cargoes have added value as they are mainly traded on the backhaul leg that is usually lacking in demand and average freight rates are lower.

Analysis of the utilisation of the D37 cooled cargo tanks showed that the quantity of the cooled cargoes are generally large, while the available tanks for cooling are relatively small. Improvements in operational and utilisation can be made by reducing the number of cargo tanks with cooling and using higher capacity tanks instead. This will both increase the utilisation of each individual tank as well as reduce the cost of the total installation since fewer coolers are required. For a same capacity plan as the D37 (see figure 3.2), one could opt to install cooling in the five largest tanks with respectively 3x$1,687m^3$, 2x$1,865m^3$ and a total capacity of $8,800m^3$. This would reduce the number of coolers from 8 to 5 and will save $150,000 on coolers. There are however practical constraints, that should be looked at in a new layout. For instance, the reach of the deck crane can be a limiting factor for the transport of the cargo coolers from the deckhouse, where the coolers are stored, to the tank hatch. The same arguments hold with respect to the fleet of cooling capable ships. Less ships could result in a higher utilisation per ship, however the cost versus the benefit of having the flexibility of more ships should be further investigated.

[10]HFO average at 20-06-2018, https://shipandbunker.com/prices
[11]according to old budgeted cost for D37

## 3.5. Cargo Heating

In this chapter the cargo heating with thermal oil are studied as part of one of the features of a parcel tanker for the case of the replacement of the D37 class ships. This chapter has a similar structure as previous chapter. The chapter starts with a introduction explaining the purpose and the use of cargo heating with thermal oil. The second section will discuss the trading needs based on a market analysis and the historical performance of the D37 fleet.

### 3.5.1. The Cargo Heating System

A common feature on parcel tankers is the means to heat to- or keep cargo at a specific temperature. The heating medium is either hot water (HW), thermal oil (TO) or directly from the boiler with steam (ST). Cargo heating with direct steam is not common on modern parcel tankers due to the high pressures required and the safety hazards related to it. The HW and TO heating system works like a central heating system present in homes and buildings. The heating fluid is heated using fuel oil- or exhaust gas driven boiler in the engine room and pumped to the cargo tanks where heating coils on the bottom of the tank are used to transfer the heat from the thermal oil to the cargo. The thermal oil and hot water systems are closed systems, the thermal oil is circulated between the heating coils and the boiler heat exchanger. The systems are not directly run trough the boiler, but separated by means of a heat exchanger to prevent chemicals to get in the boiler if there is a leak in the heating coils. Other cargo heating systems available are using a deck mounted heater (heat exchanger)[12] where cargo is circulated through with the cargo pumps. This system is not common on chemical tankers, because it requires continuous operation of the cargo pumps and is prone to cargo contamination when cargo residues remain in the heat exchanger (not easy to clean). The advantage of this system is that no heating coils in the tank are required, thus making the tank easier to clean. A safety measure is to pressurise the heating system higher than the static pressure in the cargo tank at heating coil level. In case of a leak, the heating medium will leak in the cargo tank instead of the cargo leaks in the heating piping.

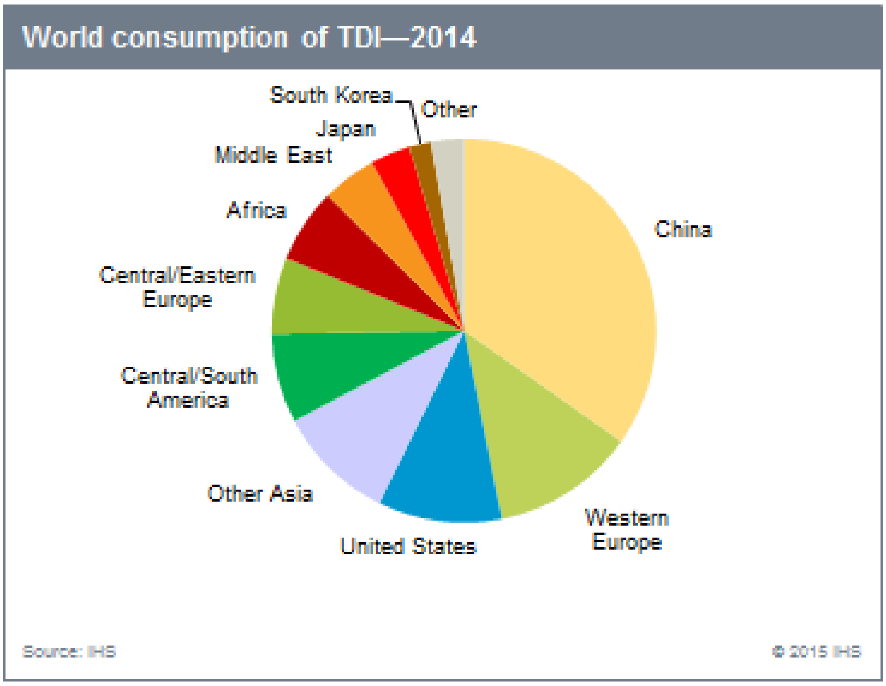
Many products do not require a specific heating medium and can thus be heated with either thermal oil or hot water. Thermal oil would be the preferred option since it is more effective in transferring the heat to the product than hot water because of the better heat transfer properties. Other products, such as edible oils, are required to be heated with hot water or steam since thermal oil will spoil the edible oils. The main two chemical products that require thermal oil heating are of the chemical group of diisocyanates. Tolueen Diisocyanaat (TDI) and Methylene Diphenyl Diisocyanate (MDI) are products that require heating and are not allowed to be heated with water. These products react with water and will waste the cargo. Both these products are used to produce different sorts of polyurethane (PU) foam and paints, coatings and adhesives.

### 3.5.2. Trading Needs

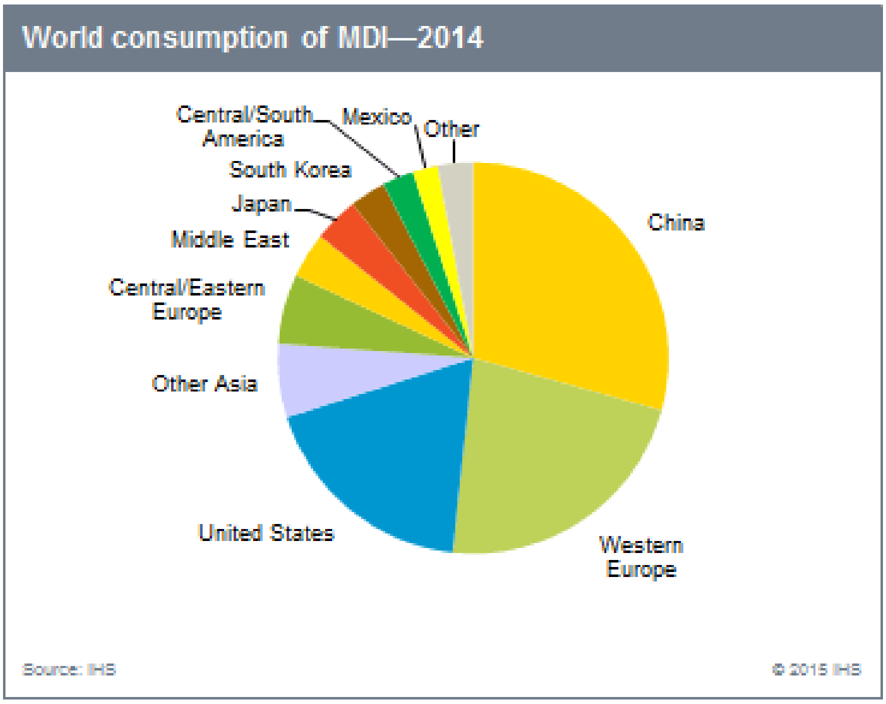
TDI and MDI are both intermediates used to produce polyurethanes that are used in many appliances such as foams and plastics. Main consumers of the two chemicals are located in China, Western Europe and the United States, see figure 3.11.

The global demand for MDI and TDI has slowed in the last years, it is forecast that in the next five years the global demand for diisocyanates will grow 3-4% per year. The demand

[12] Such as the FRAMO deck-mounted system https://www.framo.com/cargo-pumping-systems/cargo-pumping/cargo-heating/




(a)




(b)

**Figure 3.11.:** World consumption of (a) TDI and (b) MDI in 2014.
*Source:* IHS Markit [47]

for diisocyanates is driven by countries in Asia. China is the main consumer of MDI and TDI and will continue to be for next five years. The growth in production will therefore be mainly in the developing countries in Asia, such as India and Indonesia and Thailand where new production facilities are opened. Recent start up of new high-efficient plants in the Middle-East and in the U.S.A. and shutdown of older plants world wide will result in a change in the quantities trades on the various trade routes as small and/or older production plants are expected to shut down worldwide [47].

Main producers of MDI and TDI are Bayer, Wanhua Chemicals, BASF, DOW and Huntsman. These five producers accounted in 2014 for 82% of the world producing capacity for diisocyanates [47]. The chemical producing market can be considered an oligopoly.

No public forecast for seaborne trade of MDI and TDI on the Atlantic and Pacific was found. The transportation market of these products were not available, other than the volumes that Stolt ships transported.

### Trade of Thermal Oil Heated Parcels by Stolt Tankers

The cargoes that are transported by the D37 fleet, 32% requires a temperature of 20° or higher. Of this 32% about 18% of the cargoes require heating with hot water, 2% of the products require heating with thermal oil, and the other cargoes (80%) do not have a specific requirement for heating medium (they can be heated with both media). The cargoes that require heating with thermal oil medium is thus relatively small.

Based on the analysis of the Stolt trading data for MDI and TDI, the following trade lane pattern of the two products is derived, see figure 3.12.

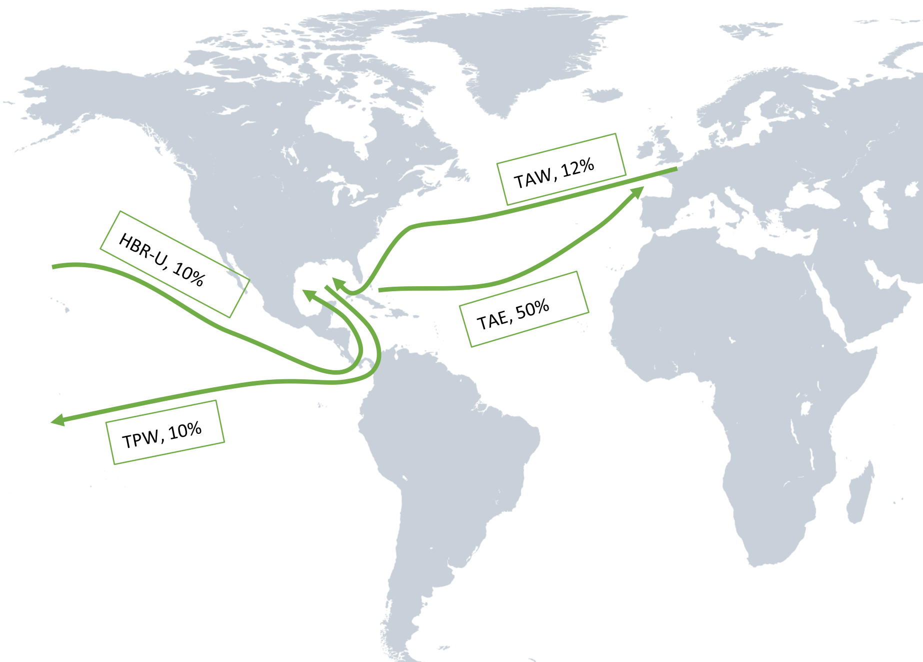



**Figure 3.12.:** Stolt TO heated trades, percentage of transported MDI/TDI by the D37 fleet.
*Source:* Compiled by Julius Jansen from Stolt data.

The two products are traded on different trade lanes. MDI is traded on three trade routes between Rotterdam and East Asia (PACS), US Gulf and Korea (TPW) and between Europe and India (EXP-P). More than 85% of the trade is going to Asia where plants are located that used the MDI to make foams for furniture, car seats and mattresses. TDI is mainly imported into the US from Asia (HBR-U) and Europe (TAW) and distributed to Brazil (LAS-East). The D37 ships take the bulk of the cargoes traded on the HBR-U, TAW and TAE trades, trading 65% of the TDI-MDI cargoes in the last 5 years for the Stolt deep-sea fleet.

The TDI trade in particular has seen a growth in the Stolt fleet over the last 6 years with on average 23% traded quantity growth year on year. This is higher than the world demand growth and the significant growth can be appointed to the winning of contract of affreightments. The available data however is not sufficient to determine a long term (sustainable) growth figure.

While the only chemical shipping companies offering cooled cargo transportation are Stolt Tankers and Odfjell Tankers, the supply of thermal oil heating is more common than the cooling in the world chemical tanker fleet. The specific number of ships and heated cargo capacity is unknown, however all Stolt key competitors are able to provide it. Within the Stolt deep-sea fleet 47 ships can heat cargoes with thermal oil. The total thermal oil heated tank capacity is $417,000m^3$ divided over 479 tanks. The D37 class ships have each 10 tanks with a total capacity of $9,023m^3$.

### Utilisation of Thermal Oil Heating Capacity

Figure 3.13 shows the parcel size distribution of MDI and TDI for the trade lanes subject to the case study. MDI is considered a typical chemical tanker product coming in parcels between 500 and $1500m^3$. TDI generally comes in a range of size depending on the specific trade lane. Both products are very well suited for the parcel tanker tank layouts.

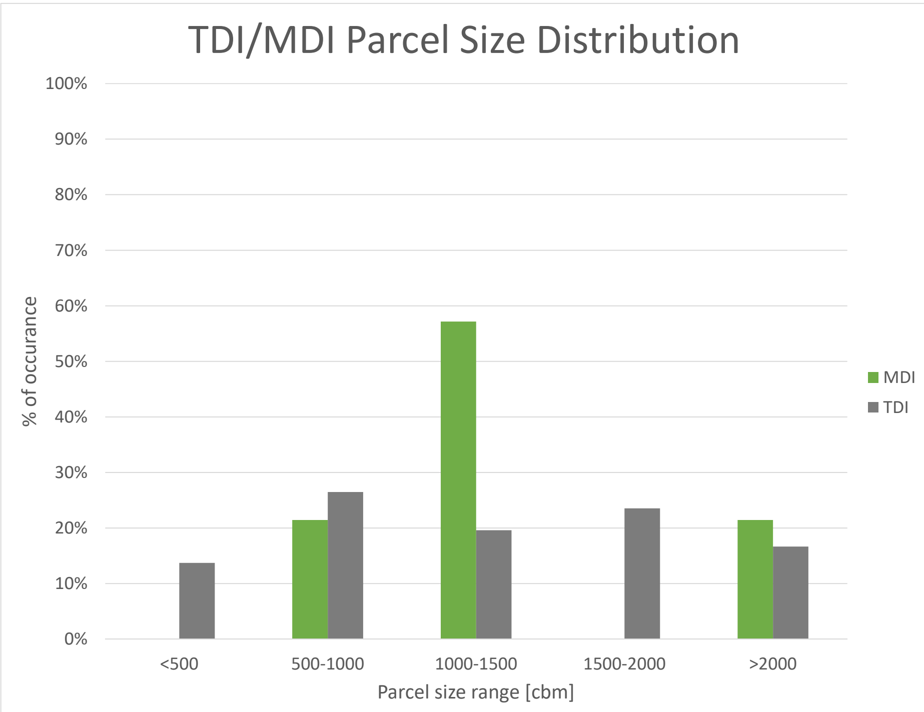



**Figure 3.13.:** MDI and TDI parcel size distribution for TPW, HBR-U, TAE and TAW.
*Source:* Compiled by Julius Jansen from Stolt data

However, the parcel size distributions on the individual trade vary a lot. This variation in distributions emphasises the dilemma between designing a fleet to a specific trade lane

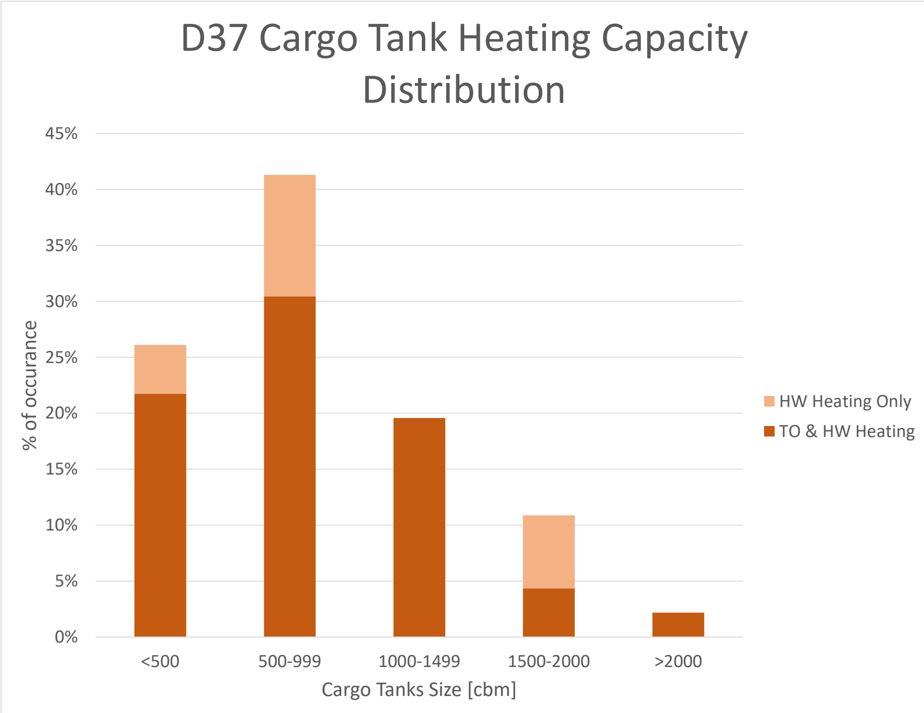



**Figure 3.14.:** D37 Cargo Tank Heating Capacity Distribution
*Source:* Compiled by Julius Jansen from Stolt data.

versus a flexible can-do-all ships that is operable in multiple fleets on different trade lanes. The flexible option is often yields a lower capacity utilisation because the system is designed to be able to handle a broad range of parcel sizes. Also, the frequency of voyages per trade lane varies, for example the main TDI trade lane, LAS-EN, had in one year five voyages and another year 14. This is all due to the COA contracts. Once a contract is lost or acquired the trade frequency can spike or reduce to zero. Somewhere a optimum (or best compromise) should be found in the combinations of cargo heating capacity, round voyage and voyage frequencies that will maximise the potential profits from TO heated cargoes. Heating capacity in the form of boilers is not only required for heating cargoes. The heating capacity of the boilers is not determined by the capacity needed for heating cargoes, but rather for tank cleaning. A higher amount of energy is required to clean multiple tanks with heated (sea) water than heating cargoes. This means that a cargo heating systems is installed on every ship anyway.

Figure 3.14 shows the cargo tank heating capacity distribution for the D37 ships. Comparing the parcel size distribution with the distribution of cargo tanks with thermal oil heating of the D37 shows that

### 3.5.3. Technical Requirements

TDI and MDI are need to be heated to a temperature of 20 and 25 degrees Celsius. The required temperature is low compared to the maximum operating temperature that the heating system is capable of maintaining, the heating system therefore is not required to be operated continuously in normal weather condition. In summer conditions the cargo does not need to be heated during the voyage. In winter conditions in the North Atlantic and North Pacific trades the cargo requires to be heated.

The boilers are not designed for the heating of the cargo tanks. In a study performed by Stolt for the C38 class it was found that the capacity of the boilers is driven by tank cleaning system rather than the cargo heating system. The tank cleaning system has the requirement to clean 4 large tanks or 6 small tanks simultaneously with water heated to 80 degrees Celsius. The heating capacity requirement for the tank heating is one third of the requirement for tank cleaning. Since the tank cleaning requirements are a *must have* item for a parcel tanker, the cost of the boilers are not considered as part of the investment cost of the tank heating systems.

### 3.5.4. Investment and Cost

Three scenarios are evaluated, a best case scenario, the expected scenario and the worst case scenario. In the best case scenario the assumption is that the added value is measured in comparing the heated cargo cost and revenues against sailing in ballast. This case is not only the best case possible, it is also a case that is likely to occur in reality. TDI is mainly traded on the TAW trade route, which is the backhaul route for the Atlantic round voyage. On this back haul route the utilisation of the cargo capacity is low. The charterers will always load TDI on this trade lane, since there is always space free and any product on board is better than sailing in ballast. It is not fair to compare it to the average normal product that can be traded on this route. The TDI is thus always a value added product on this trade lane. Therefore the best case is considered to be the differential between the TO heated products and ballast and the TO heated product. The revenue differential in this case is the average total revenue for the TO heated cargoes (i.e. no differential). The cost difference is determined by the specific for the TO heating cost and the cost of sailing in ballast.

#### Thermal Oil Heated Cargo Revenue Differential

In table 3.6 the difference between the freight rates of MDI/TDI and the average cargo are presented for the four trade lanes, as well as the gross freight revenue differential. The MDI/TDI trade on the Pacific east bound (HBR-U) leg has a significant higher value than the average product than the other trade lanes. On the pacific service the differential revenue of 185,400 USD is much higher than the on the Atlantic service, which is 26,600 USD. This is mainly driven by the lower freight rates of the average products on the pacific since the quantity of transported MDI/TDI is roughly the same on both services.

**Table 3.6.:** Average freight rate- and yearly revenue differential of MDI and TDI cargoes for a D37.
*Source:* Compiled by Julius Jansen from Stolt data.

| Trade Lane | Freight rate differential, USD/ton | Revenue differential, USD/year/ship |
|---|---:|---:|
| TAE | 33 | 19,900 |
| TAW | 3 | 7,000 |
| HBR-U | 119 | 161,000 |
| TPW | 28 | 25,400 |
| Total average | 27 | 69,200 |

#### Capital Cost

The capital cost of the thermal oil system are determined by analysing quotations and invoice of dry docking-, newbuilding and thermal oil heating conversion projects in the Stolt parcel tanker fleet. Based on these values, the numbers in table 3.7 were derived. The values are including the work and man hours. The heating coils and systems that are shared with the hot water heating are not included in the total price of the thermal oil heating system. The total price of the system is estimated at 1,025,600 USD. The three main factors that drive the price of the system are the heat exchanger, the circulation pumps and the piping.

**Table 3.7.:** Estimated equipment and installation cost.
*Source:* Compiled by Julius Jansen from Stolt dry dock and newbuilding quotes.

| Component | Price, $ |
|---|---|
| Heat exchanger | 120,000 |
| Circulation Pumps | 300,000 |
| Transfer Pump | 1,800 |
| Valves, Piping, Insulation | 250,000 |
| Expansion and Storage Tank | 10,000 |
| Miscellaneous components | 32,000 |
| Thermal Oil | 11,800 |
| Total | 1,025,600 |

### Operating, cargo handling and and Voyage Cost

The operating, cargo handling- and voyage cost that can be accounted specifically to the heating system are reduced to the cost of maintenance and fuel that is used to heat the thermal oil medium. The maintenance cost of the heating system is estimated at 5,000 USD, based on budgeted maintenance for the D37.

The cargo handling and voyage cost factors are dominated by the cost of heating the cargo. The cost of heating is approximated by calculating the theoretical heat loss though the tank bulkheads, deck and tanktop. The heat loss is calculated for a tank with a surface area of and a temperature difference $dt$ of 20° between the cargo and the outside of the tank[13]. Using the formula for heat dissipation, see equation 3.3, the heat loss is calculated for a tank with a volume of $750m^3$ ($A = 568m^2$).

$$Q = \alpha \cdot A \cdot dt \tag{3.3}$$

The loss of heat is calculated to be $91W$ (Watt). The effectiveness of the heating system is assumed to be 90%, that means that 90% of the heat input in the boiler is used to heat the cargo. This calculated to a rough number for the fuel consumption of 0.2 tonnes (heavy fuel oil) per day. If two $750m^3$ tanks are used for a $1,500m^3$ cargo, this fuel consumption doubles to 0.4 tonnes per day. Heating one $1,500m^3$ tank results in a fuel consumption of 0.32 tonnes/day. Using the heating utilisation rate of 40 days per year this equates to a fuel consumption of 8 tonnes per year for using one $750m^3$ tank and 12.8 for the $1,500m^3$ tank. Multiplied with the fuel price (481 USD/tonne) results in a heating cost of 3,850 USD and 6,150 USD respectively. The heating cost for a 2,000 ton TDI shipment on the Atlantic (TAE) is about 6,150 USD[14] this equated to a cost of 3.08 USD/tonne. The average freight premium of the product on this trade route is 33 USD/ton (see table 3.6). This means that approximately 9% of the premium is allocated for the cost of heating the cargo.

[13]Heat transfer rate for oil in an uninsulated tank ($\alpha = 8.0$) is used [48]
[14]the density of TDI is 678 $kg/m^3$, so 2,000 ton TDI equates to $1,356m^3$

In table 3.8 the cost of heating the cargo are displayed on a utilisation and voyage basis for the Atlantic East trade route. In the most extreme case, the best case from a revenue perspective, is if on all voyages the maximum capacity is utilised. In this scenario the heating cost is approximately 55,600 USD. The cost of heating more tanks will decline relatively to the volume that is heated since the heat will only dissipate though the tanktop, deck and outside, adjacent tanks. This value is used further on in the financial analysis in chapter 4.

**Table 3.8.:** MDI/TDI heating cost scenarios for ship on Atlantic East voyages.
*Source:* Compiled by Julius Jansen

| | Voyages per year | | | | |
|---|---|---|---|---|---|
| Utilisation per voyage | 1 | 2 | 3 | 4 | 5 |
| Low utilisation, $750m^3$ | \$1,808 | \$3,615 | \$5,423 | \$7,231 | \$9,039 |
| Medium utilisation $1,500m^3$ | \$2,584 | \$5,169 | \$7,753 | \$10,337 | \$12,921 |
| Full capacity, $7,500m^3$ | \$11,320 | \$22,639 | \$33,959 | \$45,279 | \$56,598 |

## 3.6. Small Capacity Cargo Tanks

In this section the cargo tanks as a feature are studied. As showed in section 2.2, parcel tanker differentiates from other chemical tanker types by the number and the average size of the cargo tanks. In the context of parcel tanker tanker 'small' volumes are considered to range between $300m^3$ and $500m^3$.

### 3.6.1. Trends in Supply, Demand and Trade

As was show in figure 2.7 the average parcel size is declining. The new ships that enter the market are generally larger and with less cargo tanks.

The number of traded small parcels on the four trade routes by the entire Stolt Tankers fleet also shows a declining trend, see figure 3.15. A decline in the traded small cargoes is especially pronounced on the Trans-Pacific West (TPW) route and Trans-Pacific East (HBR-U). The decline therefore seems to be worse on the pacific service than on the Atlantic service. The causes of this declining trend are not fully known. The increase in the number of tank containers and the trend towards a more commoditised industry could drive this negative trend in small cargo trade.

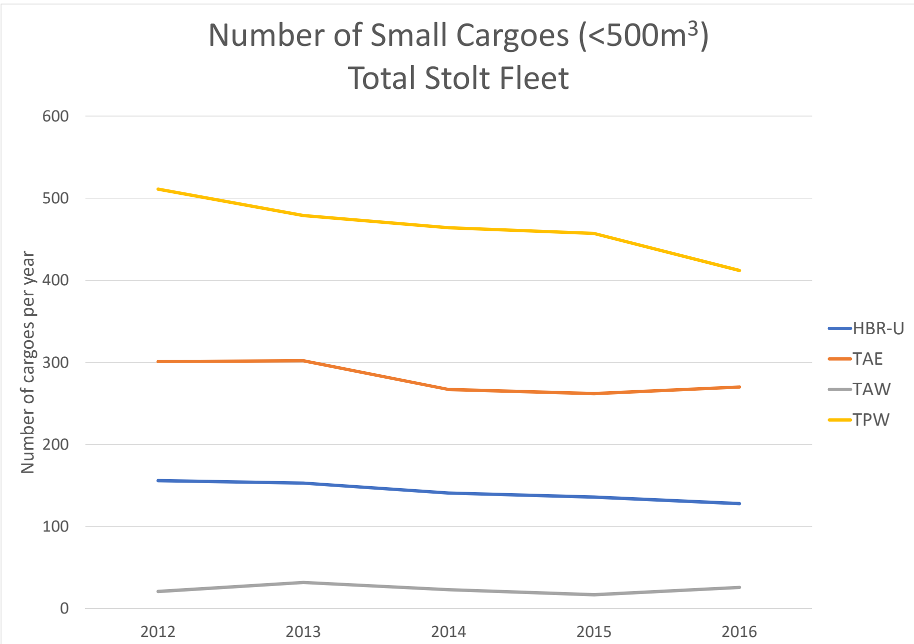



**Figure 3.15.:** Number of parcels smaller than $500m^3$ traded by the Stolt fleet.
*Source:* Compiled by Julius Jansen from Stolt data

### 3.6.2. Influencing Factors for Cargo Tank Segregations

As is the case for most design requirements, the requirements for the number and size of the cargo tanks are driven by the intended trade area and its expected cargo portfolio. Is is defined for this study the four trade routes and the example product portfolio of the D37 ships will be used.

For every ship in general the cargo capacity is a function of multiple factors. Three components together determine the cargo carrying capacity of a ship in terms of weight (tonnage) and volume. First is the displacement of the ships, which is function of the main dimensions of the ship and the hull coefficients (block-, prismatic-, midship section coefficient). The displacement and the lightweight of the ship determine the cargo weight loading capacity of the ship hull. The volume is determined by the cargo space area, which is also determined by the general arrangement of the ship, stability rules and regulations and again the main dimensions and coefficients.

#### Terminal Tank Capacity

The first and main factor that determines the range of the number of cargo tanks that a chemical tanker will have are the trading objectives, i.e. the operating strategy and the associated product portfolio. Best on the this trading strategy the ports and terminal are investigated for the storage tank quantities. Cargo contracts for deep-sea trades are preferably sized in the quantity of the loading or receiving terminal or plant storage tank capacity (whichever is the smallest). So, the cargo tank size (and capacity for cooling, heating or other features) should preferably match the capacity of the terminal tanks for every specific product. However, terminal tanks sizes are not standardised and individual tanks on the ships have to be shared with a variety of products from different terminals with different tank capacities. So, there is no perfect match possible between ship cargo tank capacity and terminal tank capacity.

#### Regulations for Capacities and Segregation Dimensions

Regulations are an major influential factor for the cargo tank segregations. As briefly explained in sections 2.2 and 2.3 the main rules with regards to cargo tank capacity and layout outs are the IBC code, SOLAS and MARPOL. In general these regulations define the minimum requirements for intact- and damage stability and safety regarding carriage of hazardous cargoes. Generally the (damage) stability of chemical tankers is not a constraining factor, since more segregations lead to a higher the damage stability.

### 3.6.3. Cargo Tank Capital Investment Considerations

The cost as a function of the volume have been studied in order to derive relation ships that could substantiate the capital investment considerations for the number and sizes of cargo tanks for a new parcel tankers. The study of the cargo cost has been based on the presumption that the cost of a cargo tank can be determined by the sum of three components, the tank material cost, the tank basic equipment cost and the man-hour cost. The study is attached in appendix I. Relation between these costs components and the tank volume have been estimated, see figure 3.16.

The figure shows that the cost of a cargo tank increases with increasing volume and that the gradient of the curve declines with increasing tank volume. Thus, a small tank costs more relative to its volume than a large tank. This is what is expected. It also shows that for small cargo tanks the equipment cost is the biggest factor in the cost of the tank. The man-hour and material cost will be the largest cost factor for tanks larger than $1,600m^3$.

To see the difference in cargo tank price for different types of tankers, the following comparison is performed. Four cases are created with different ship types. Two MR tankers with 14 tanks of about $2,800m^3$ (one with stainless steel tanks, one with mild steel tanks), a 'basic' chemical tanker with 28 stainless steel tanks in different sizes, and a parcel tanker with 46

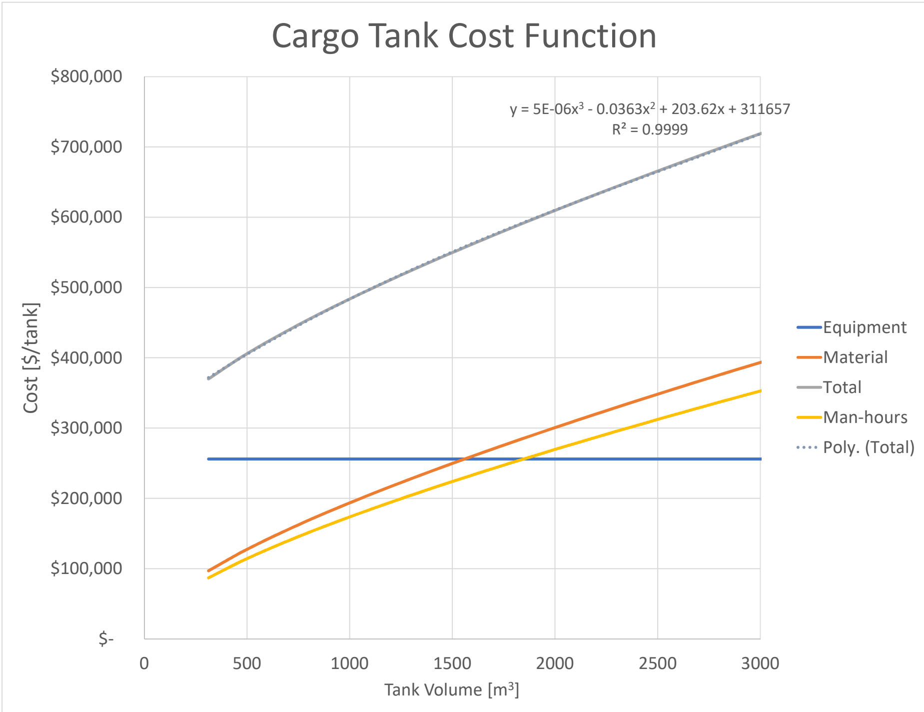



**Figure 3.16.:** Chemical tanker cargo tank cost functions
*Source:* Own composition

stainless steel tanks in different sizes. Four the chemical tanker the C33 tank distribution was used to determine the tank size distribution, for the parcel tanker the C38 was used as example. The tank sizes are chosen so the total cargo capacity is about $40,000m^3$ for each of the ships. Only the integral tanks are calculated in the model, deck tanks are excluded. Table 1 shows the result of the cargo tank related costs.

**Table 3.9.:** Cargo Tank Cost Comparison of Tanker Types
*Source:* Own composition

| | Tanks $[-]$ | Avg. tank size $[m^3/tank]$ | Avg. Cost $[USD/tank]$ | Avg. Cost $[USD/m^3]$ | Total Cost $[USD]$ |
|---|---|---|---|---|---|
| MR Tanker (mild steel) | 14 | 2,813 | $307,527 | $109 | $4,305,381 |
| MR Tanker (stainless) | 14 | 2,813 | $970,508 | $345 | $13,587,108 |
| Chemical Tanker | 28 | 1,321 | $653,138 | $495 | $18,387,867 |
| Parcel Tanker | 46 | 909 | $564,707 | $621 | $24,282,400 |

According to the model the difference in cargo tank cost between a parcel tanker and a product tanker (coated) is approximately 13m USD. This value can be considered the cost of the cargo flexibility and small parcel sizes of a parcel tanker. While it is nice the see the difference between the different types of chemical tankers, it may not be that relevant since it was already concluded that these ships have different purposes and operate in different markets. However, in order to compare different parcel tanks is may be more valuable to look at the cost in relation to the average tank size. The impact of the average tank size on the on the total cost of the cargo area is displayed in figure 3.17 for a ship with a total cargo capacity of $40,000m^3$.

The average tank size of a parcel tanker is in the range 800-1000 $m^3$/tank. The curve in the figure is linearised in this range in order to see the relative impact a small change in average

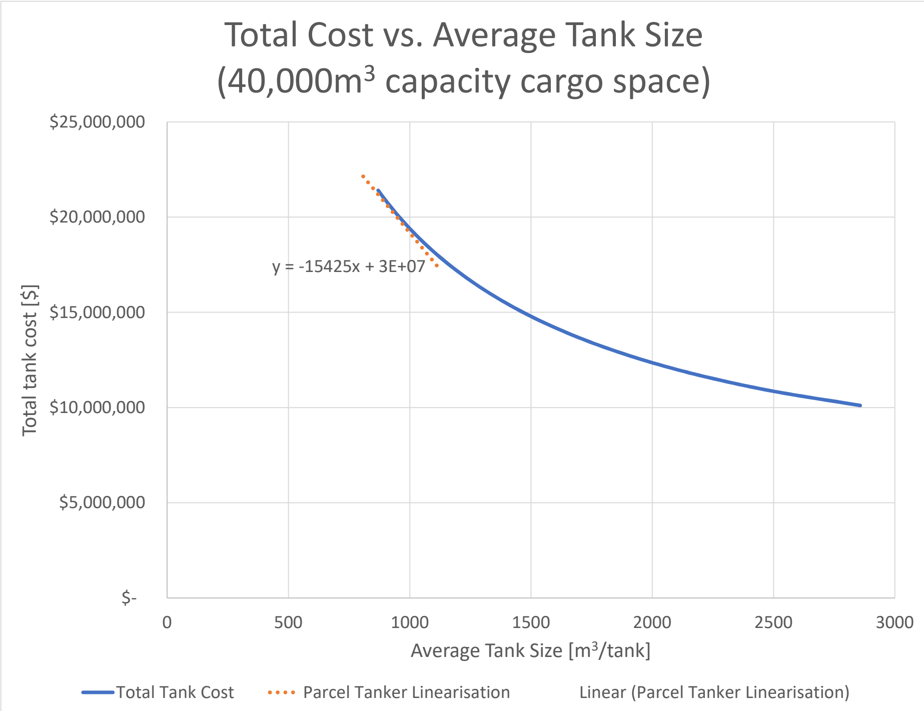



**Figure 3.17.:** Cargo tank cost as function of average tank size for a ship with $40,000m^3$ cargo capacity.
*Source:* Own composition

tank size has on the cost. For every $100m^3$ added to the average tank size are reduction of approximately 1,540,000 USD is achieved for a tanker with $40,000m^3$ cargo capacity. The steepest gradient can be seen in this part of the curve. This means that a small increase in average parcel size for a parcel tanker will reduce the cargo tank cost more than is the case for chemical tankers in the ranges of higher average tank size. This could explain the trend of the increased higher average tank size in the latest series of parcel tankers. Since revenues per ship do not growing as was shown by the freight rate corrected for inflation in section 2.6.3 and the operating cost of is a ship do increase because of increased fuel, and crew cost it makes sense for a shipowner to cut the cost of a ship by reducing the capital cost. The graph shows that an effective way to do this without reducing the carrying capacity (cargo volume) is to reduce the average tank size. This basically means that flexibility is traded for lower capital cost since the total capacity is the same.

So, what is the cost of flexibility and what is the allowable cost for the required operational flexibility of a replacement of the D37? This question can only be answered with the help of simulations which could not be achieved in this thesis. The case is explained using the simplified illustration below of three possible options for cargo tank arrangement of a $2,000m^3$ cargo space in a tanker. The first option is one $2,000m^3$ tank, the second option is to have two $1,000m^3$ tanks and the third is four $500m^3$. All three options have the same total volume capacity, but a 2,000 , 1,000 and 500 $m^3$/tank average tank size respectively.

As one can directly see, is that the option with 4 $500m^3$ cargo tanks has the highest flexibility in terms of possibilities to carry different cargoes at the same time. This arrangement is able to take up to four $500m^3$, two $1,000m^3$ or one $2,000m^3$ cargo, while the $2,000m^3$ one tank arrangement can only have one cargo up to $2,000m^3$. This flexibility comes with

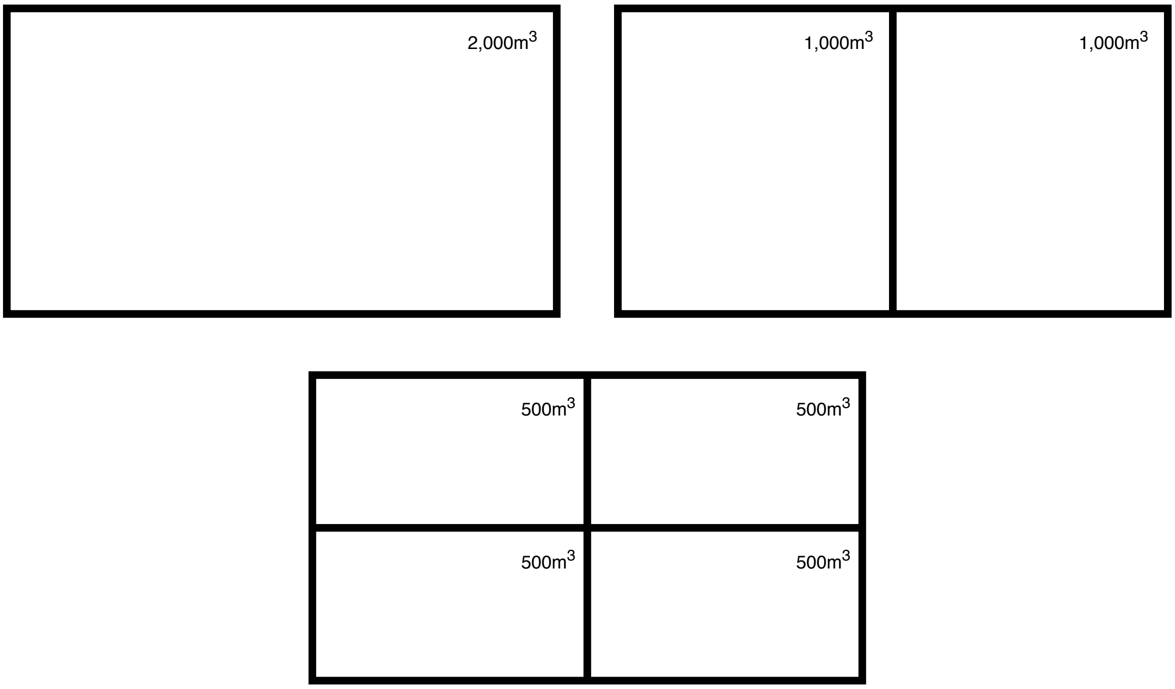



**Figure 3.18.:** Three possible options for $2,000m^3$ cargo space
*Source:* Own composition

an additional cost. The difference in cost of four $500m^3$ tanks versus two $1,000m^3$ tanks is 618,000 USD. And the difference between four $500m^3$ and one $2,000m^3$ tank is about 951,000 USD according to the values found in the cargo tank cost study. This means that the extra cost of the small cargo tanks should be recovered by either the price of the small cargoes or the amount of cargoes that will be additionally carried over the other cases.

### 3.6.4. D37 (Small) Tank Utilisation

The distribution of the cargo tanks of the D37 is presented as a histogram in order to simplify the comparison with the sizes of the cargoes that are traded, see figure 3.19

The trading profile of the D37 is determined by looking at the statistical distribution of the number of cargoes that are carried on a voyage on each of the four trade routes. For nine the D37 ships on every cargo that has been shipped voyages have been grouped in the seven bins. This gives a distribution by size of cargo as well as a distribution on the number of cargoes per voyage[15]. These findings are presented in the following histograms presented in figures 3.20a and 3.20b for the front haul routes (TAE and TPW). Since the cargo arrangement is usually optimised for the front-haul routes, these two routes are analysed in more detail in this section. The figures for the backhaul routes (TAW and HBR-U) as well as the total of the four routes can be found in appendix H.

The figures confirm that the parcel tankers primarily carry small cargoes on the voyages (blue boxplot). It can be concluded that small parcels are still a significant part in the parcel tanker cargo portfolio from the averages of 12 cargoes per voyage on the TAE route and 9 on the TPW route. Between the two trade routes there is a difference in the spread between

[15] A note to the data quality: some cargoes that are shipped in one tank are counted as two separate cargoes because of different discharge locations. It was not possible to filter all these occurrences from the data, however, samples taken showed that this is the case for about 6% of the cargoes. The impact is a slightly lower mean, median and 75-percentile value.

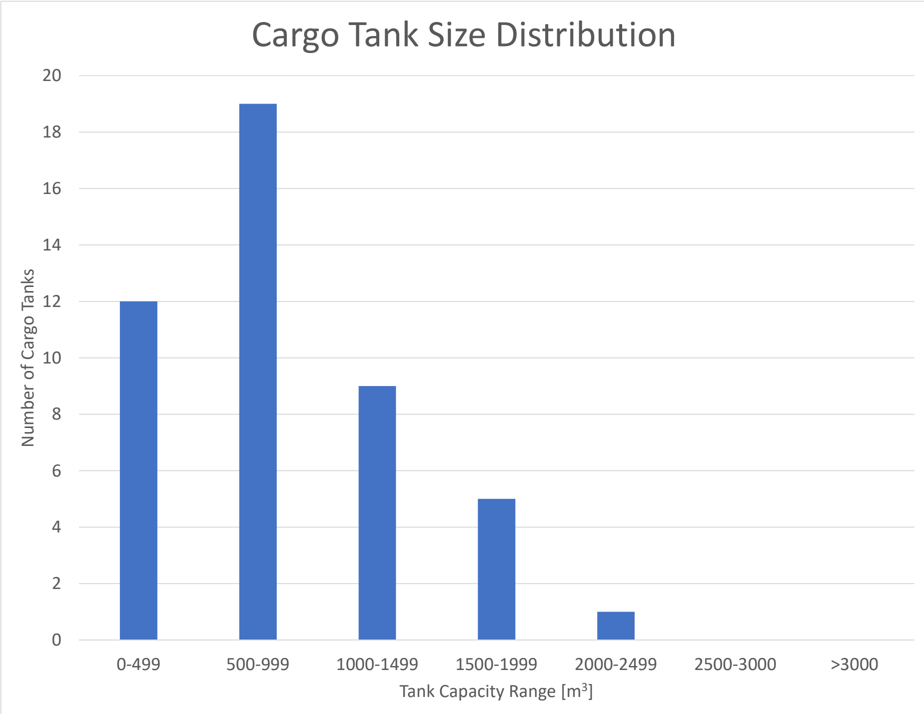


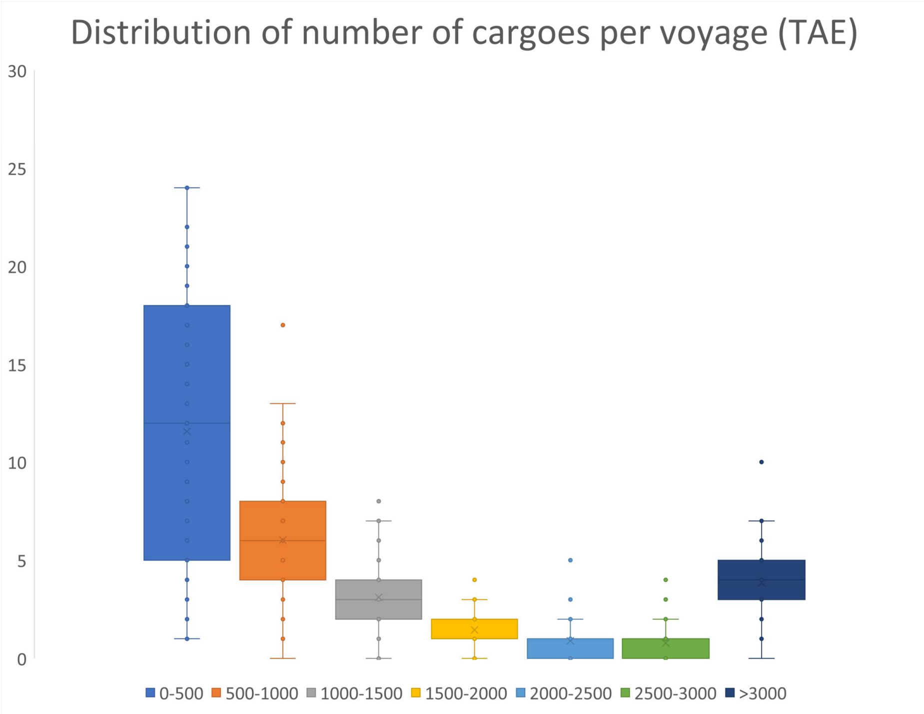

**Figure 3.19.:** Count and size distribution of D37 cargo tanks
*Source:* Stolt D37 capacity arrangement

the 25- and 75-percentile. In 25% of the TAE voyages 5 or more cargoes in the $0-500m^3$ range are carried and in 75% of the voyages less than 18 small size cargoes are carried. There is thus a large spread in the number of small cargoes per voyage. For the TPW route this range between the 25- and 75-percentile is smaller, meaning that less cargo tank flexibility is required to carry the majority of the cargoes. For this specific trade route, the amount of required small cargo tanks can be determined with more certainty. The D37 ships have only 12 cargo tanks in the $0-500m^3$ range as figure 3.19 shows. The median and mean of the TAE voyages in this range is (coincidentally) also 12, thus in 50% of the voyages larger tanks are utilised to accommodate the small parcels. The D37 tank distribution of small tanks is better suited for the TPW routes as in 25% of the voyages more than the 12 cargo tanks are required. The D37 has 19 tanks in the $500-1,000m^3$ range, which are for the TPW route in 7.5% of the voyages not enough. For the TAE this amount of cargo tanks is always enough for the number of cargoes that it will see on that route.

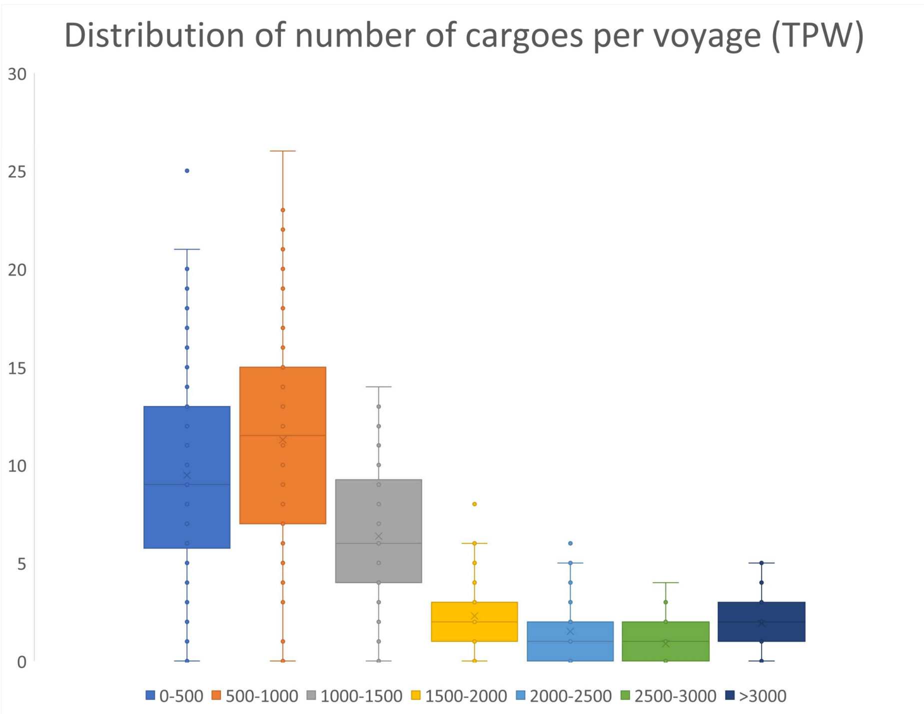
These findings contribute to the considerations for the amount of small cargo tanks in a new design for the D37 replacement. This is the requirement from a trading perspective. However, the cost factor should be included since the trading optimum might not be economically feasible.

### 3.6.5. Conclusions on Small Cargo Tanks

This section focused on the cost-benefit of the small cargo tanks. It was first concluded that small parcel shipping can be considered a niche in the deep-sea chemical shipping sector since only a limited number of ships has a average tank size lower than $1000m^3$. Secondly, Stolt tankers is, among its key competitors, one of the operators of a fleet with the lowest average tank size. Stolt Tankers is thus a large market player in small parcel shipping. It has also shown that for the D37 parcel tankers the small parcels count for the majority of the cargoes




**(a)** Trans-Atlantic East (TAE)




**(b)** Trans-Pacific West (TPW)

**Figure 3.20.:** Distributions of the number of cargoes per voyage
*Source:* Stolt Tankers

on board the ship for the average voyage. One some trade routes the current tank capacity is not sufficient to efficiently carry the small cargo, in which case larger tanks have to be utilised. The capital cost of a cubic meter of a small cargo tank is up to three times higher than a large tank. These relations could not be found in the freight rates.

The scope of this study limits further statistical modelling to obtain a solution for the ideal tank layout based on the statistical data.

## 3.7. IBC Ship Type 1 Notation

The number and the size of the cargo tanks, the layout of the cargo space and the IBC ship type notation are factors that are closely related and depending on each other. In this study the value of the *ship type 1* notation, also known as 'IMO 1', is analysed for future parcel tankers. The value will be determined by analysing the impact on the market, the Stolt parcel tanker business as well as the profitability of a ship. This section will conclude with the recommended MoSCoW priority for this feature for future parcel tankers.

### 3.7.1. Revenues of type 1 Cargoes

In the Stolt deep-sea tanker fleet 45 of the 75 ships carry the ship *type 1* notation. Analysis of the traded cargoes by Stolt resulted in no records of ships in the entire Stolt fleet that transported cargoes required ship *type 1*[16] in the last 5 years. Over a longer period, going back to 2006, transportation of *type 1* cargo was recorded once in the Stolt fleet. This single shipment resulted in a revenues of approximately 300,000 USD. The expected yearly revenues from this group of cargoes are very low. This one recording is not reliable to use in calculations as it is insignificant relative to the generated revenues and the number of voyages and cargoes recorded by the fleet during this period. It can be concluded that *type 1 cargoes* are a

Based on this the case seems straight forward; ship *type 1* notation is not adding significant value. In order to quantify and see what the financial impact is of the *type 1* notation, the cost should be determined. The financial impact could be valued in two ways, first it can determine the potential savings that can be had, and secondly it gives the break-even revenue for the investment. A *type 1* ship could be viable if the costs are lower than the earnings potential. In the next section the cost will be determined.

### 3.7.2. Design Impact of a Ship Type 1 versus Type 2

The ship type notation is linked to regulatory requirements stated in the IBC code. The main requirements for a *type 1* ship state are listed below. Figure 2.5 presented on page 11 shows the tank location requirements of the ship type notation.

- The maximum quantity of the cargo must be less than $1250 m^3$ [IBC 16.1.1]
- The tanks should be inboard a distance the lesser of Beam/5 or 11.5, and nowhere less than $760 mm$ [IBC 2.6.1.1 & 2.5.1.1.2]
- The double bottom should be the lesser of Beam/15 or $6m$ this should be below the pump well [IBC 2.6.1.1, 2.5.1.2.3 & 2.6.2]

This case is set up and evaluated by looking at the design of the D37 parcel tanker in retrospect. Since the feature is embedded in the design of the ship it shares design features with other (design) requirements. It would therefore not be fair to include to cost/investments of these items only on the ship type notation. The cost will be determined by the counting the cost of the measures that were specifically required to comply to the *type 1* notation. For the D37, as well as the other parcel tankers in the Stolt fleet, the tanks centred around the centerline of the ship follow the *type 1* requirements. In the design of the D37 the focus was on the creation of more segregations not only on creating cargo capacity for *type 1* cargoes.

[16]The list of the products from the IBC code that require a ship *type 1* (IBC Chapter 17) can be found in appendix E

The easiest way to create more cargo tank segregations is to have two dividing longitudinal bulkheads (or cofferdams) instead of one single longitudinal bulkhead. For example, a cargo space layout with two longitudinal cofferdams or bulkheads creates tree rows of tanks, adding 50% of the segregations compared to the design with one centre bulkhead. The illustration in figure 3.21 on page 86 shows layout options used on various parcel tankers. For this study only layout *c)* with two longitudinal bulkheads is studied as this is the layout used in the D37.

The *type 1* criteria for the transverse distance is met for the centre tanks if the longitudinal cofferdams(/bulkheads) are extended far enough from the side shell plating (B/5 or 11.5m). It would be an unfair comparison to take the stainless steel and construction cost of the longitudinal cofferdams for the cost/investment of the *type 1* notation as it is not its main purpose. So, the longitudinal cofferdams are considered a free benefit that support the *type 1* notation. Note that this is only valid for parcel tanker designs with longitudinal cofferdams or bulkheads. If the intent is to analyse the cost-benefit of *type 1* notation on a chemical tanker layout with a single longitudinal cofferdam the cost of added bulkheads must be included. However, this case is not within the scope of this study. The IBC requirement that not more than $1,250m^3$ of cargo can be carried, has no effect on the cargo tank volume. Hence, this requirement does not require any specific additional impact on the cost of the ship.

The height of the double bottom is the only criteria that requires an alteration to the general design of the parcel tanker for the only purpose of meeting the *type 1* requirements over type 2. For the height of the double bottom the *type 1* and 2 notations have the same requirement with one exception [IBC 2.6.3] which requires that the suction well, i.e. pump sump or pump well, cannot "protrude the vertical extent" for *type 1* ships. This means that the height of the double bottom for a *type 1* ship is measured from the bottom shell plating to the bottom of the pump well, instead of to the tanktop. The tanktop height of the D37 at its lowest point is $2150mm$. For the D37 the pump well is about $80 - 100mm$ deep and including plate thicknesses and tolerances the well is about 150mm deep. Compared to a type 2 ship the tanktop is raised by $150mm$ over the entire length and beam of the cargo area. This has the following three direct effects: a reduced cargo space volume, increased center of gravity and added steel in the double bottom.

#### Reduced cargo volume

While the *type 1* notation requirements are only applicable to the tanks close to the centerline, the double bottom is raised over the entire beam of the ship for the D37 . This reduces the volume of the cargo space by $379m^3$ compared to a similar ship with only type 2 notation. The volume counts for a 1.2% loss of integral cargo volume. This is equivalent volume of a small cargo tank. This would mean that on the fronthaul legs (such as TAE) with a high tank utilisation the possibility of one more cargo is lost. In the next section the implications are further worked out for two cases and compared to the current design of the D37.

#### Higher centre of gravity

The increase in tanktop height yields an increase in of the centre of gravity in loaded condition as the cargo centre of gravity will increase with about $150mm$. This could result in lower stability of the ship, and therefore requirements for additional counter measures. However, this is considered to have a negligible impact.

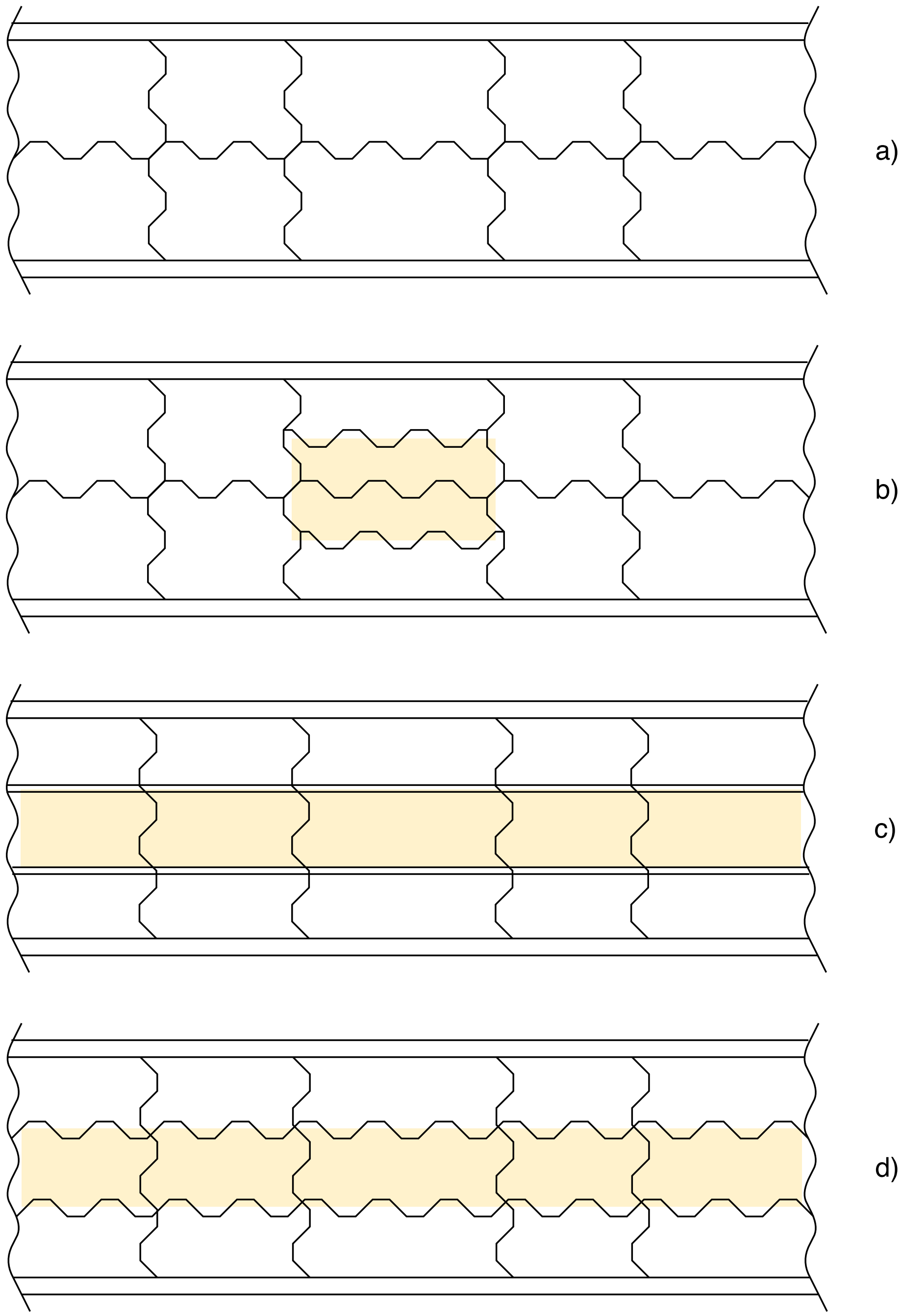



**Figure 3.21.:** Cargo Area Bulkhead or cofferdam Layouts. Yellow area shows *type 1* spaces and white cargo spaces are *type 2* areas. (Not to scale, exaggerated corrugations)
*Source:* Julius Jansen

#### Added Steel

In order to raise the double bottom 150mm steel added over the entire double bottom area. Since the double bottom has a high relative density of steel plates, raising the double bottom 150$mm$ has a significant effect on the amount of steel. Since it is possible that a lower double bottom requires more steel to meet the strength requirements, it is difficult to give an exact reduction of weight and cost for a lower double bottom. A lower double bottom for the D37 ships saves approximately 47 tonnes of steel from the double bottom webframes and girders.

Although a slightly higher double bottom looks technically insignificant, there are impacts that should not be ignored. The added steel weight and the lost cargo volume are deemed to hold the highest significance. Therefore, these two items are analysed further in the next section for two scenarios for future ship design choices.

### 3.7.3. Investment and Cost Scenarios of Ship Type Notations

In this section the difference between the *type 1* and type 2 ship are compared for cases on the Atlantic and the Pacific round service. Two scenarios are set up to measure the potential savings from removing the ship *type 1* notation or the cargo revenue required for a profitable case for the ship *type 1* investment. The scenarios are measured against the 'business as usual' scenario that assumes the operation of the D37 to continue in the same way as is has in the past 5 years. This business as usual scenario assumes ship *type 1* notation, and no *type 1* required cargo.

The first scenario is the D37 cargo layout without the ship *type 1* notation. For this scenario the double bottom is lowered 150mm over the entire cargo area compared to the business as usual case, see figure F.1 in appendix F. The second scenario shows a hybrid solution, where the ship *type 1* notation is kept, but the double bottom height is optimised to the ship type notation (1 or 2) for the specific tanks. In midship section figure F.2 in appendix F the double bottom height for the centre tanks is the 2150$mm$, while the wing tanks have a lower double bottom of 2000$mm$ according to the ship type 2 requirements.

The second scenario could become a valid decision choice if it is expected that *type 1* products are carried more frequently. From a structural viewpoint, this option is not favourable since adding discontinuities in the structure results in stress hot spots that require additional care and strengthening that could possibly outweigh the benefit. Table 3.10 shows the investment and technical differences between the business as usual and the other two scenarios.

**Table 3.10.:** Technical differences from 'business as usual'
*Source:* Compiled by Julius Jansen

| | Only ship type 2 | Ship type 1/2 optimised |
|---|---|---|
| Double bottom height, mm | 2000 | 2000/2150 |
| Change in volume, m3 | 379 | 267 |
| Change in DB steel weight, tons | 47 | 28 |
| Investment(saving), USD | -94,042 | -37,179 |
| Investment as percentage of D37 newbuild price, % | 0.13% | 0.05% |

The differences in weight are small compared to the 12,400ton lightweight of these ships. The investment, in terms of steel cost, to have a *type 1* ship over a type 2 ship is 0.13% extra on the newbuilding price. The investment to have a *type 1* ship might look appealing, from this perspective as a small investment could open opportunities in a new market of products. However, the revenue regenerating capacity that is reduced with a *type 1* ship must be counted as this contributes in a negative way for the scenarios with ship *type 1* notation.

The scenarios are tested for the two selected round services to determine the freight revenues that are generated. As the trade data showed, the D37 is a certain number of voyages fully loaded on volume (100% cargo space utilisation). Table 3.11 shows the percentage of voyages that the D37 is in fully loaded condition for the various routes.

**Table 3.11.:** D37 voyages and utilisation (fully loaded on volume)
*Source:* Compiled by Julius Jansen

| | TAE | TAW | TPW | HBR-U |
|---|---|---|---|---|
| Number of voyages voyages/year | 6 | 6 | 3 | 3 |
| Percentage of voyages fully loaded on volume | 46% | 0% | 31% | 18 |
| Average number of voyages per year fully loaded on volume | 2.76 | 0 | 0.93 | 0.54 |

For the fully loaded voyages it is presumed that the additional cargo space is used to stow more cargo and therefore result in a higher freight revenue. In the number of voyages that are not fully loaded (the TAW legs and the percentage of voyages with less than 100% utilisation on the other routes) the effect of the additional volume is not counted in terms of additional cargo but in a reduced draft and thus a reduction in fuel consumption. However, the steel construction weight savings are relatively low compared to the total lightweight of the ship. For the D37 the immersion at summer draft is $48ton/cm$. This means that for the scenario with 47 tons weight savings the draft is reduced by about one centimetre. This results in a marginal fuel consumption reduction that is considered insignificant to analyse further. This leaves the added cargo volume and the investment in double bottom steel as the two variables between the scenarios.

In table 3.12 the estimated additional cargo quantities, in tonnes/year, are displayed as well as the difference in the yearly revenues. The business as usual case has no revenues from cargoes with *type 1* tanks requirement. The net present value therefore is only based on the investment for the higher double bottom which cannot be paid back as there are no cashflows after the investment. As expected, the scenario with a ship type 2 optimised design yields the highest change in revenues from the current (business as usual) case. The Atlantic service proves to hold the highest potential if the ship *type 1* notation is dropped. An additional yearly revenue of 85,585 USD is the potential gain for this scenario. This calculates to a net present value of 974,937 USD over 25 years for a discount rate of 7.5%.

**Table 3.12.:** Scenario Results: revenues and net present value
*Source:* Compiled by Julius Jansen

| | Business as usual | Only ship type 2 | Ship type 1/2 optimised |
|---|---|---|---|
| **Atlantic Service** | | | |
| Average Cargo quantity , $m^3/year$ | 0 | 1,046 | 737 |
| Freight revenue, $USD/year$ | 0 | 85,585 | 60,351 |
| NPV over 25 years @ 7.5%, $USD$ | -87,481 | 974,937 | 660,385 |
| **Pacific Service** | | | |
| Average Cargo quantity, $m^3/year$ | 0 | 557 | 393 |
| Freight revenue, $USD/year$ | 0 | 58,333 | 41,134 |
| NPV over 25 years @ 7.5%, $USD$ | -87,481 | 692,353 | 461,118 |

Approaching these results from a different perspective, the investment in ship *type 1* notation becomes profitable if a gross revenue stream is secured to payback the investment plus revenue higher than the best alternative, that is the 'ship type 2 only' revenue of 85,585 USD/year. This means that a yearly revenue of 102,446 USD/year from *type 1* cargoes must be guaranteed in order to justify the investment in *type 1* notation over the ship type 2 only scenario.

Extrapolating these results over the fleet of 9 D37's trading in the Pacific and Atlantic a total increase in yearly gross freight revenue of 634,008 USD/year for the 'only type 2' case and 447,078 USD/year for the 'ship *type 1* and 2 optimised' scenario could have been achieved over the current situation.

### 3.7.4. Other Considerations Regarding type 1 Notation and Cargo Volume Maximisation

Three thing should be considered with regard to the *type 1* notation and the maximising of the cargo space.

#### Deck tanks

Deck tanks are a feature of parcel tankers that are not covered in the scope of this thesis. While not covered as such, deck tanks can contribute to *type 1* cargo tank capacity. Deck tanks provide additional storage of chemicals in tanks up to $700m^3$ each. The main function of the deck tanks is to add additional carrying capacity without increasing the length and beam of the ship. They can also be used to provide a solution for carriage of chemicals that are required by the IBC code to be kept in independent tanks, tanks that are not part of the structural part of the ship[17]. They are a necessity because trim requirements of the ship and buoyancy. However, the deck tanks can also to meet the IBC ship *type 1* requirements, if they are placed far enough inboard (i.e. the 6.2 meters from the hull side). This design option is not examined in detail, since the calculations and results in table 3.12 showed that the need for *type 1* capacity is limited. However, it is possible to have the benefit of the lower double bottom height with integral tanks meeting the ship type 2 requirement, while carrying *type 1* products in deck tanks. This is an option that can be investigated further, as it could serve as an alternative to integral *type 1* capacity.

#### Changes in IBC code

The IMO always has the choice to change the classification of products, as was done in 2007. Currently the IMO is working on a new revision of the chapters in the IBC code where the products are categorised. Among the items that are evaluated is the classification of various chemicals from *type 2* to *type 1* products. The changes in the draft amendment contain the following changes in the list of *type 1* products compared to the 2007 version of the IBC Code. Ten of the current 25 products that are listed as *type 1* will change to *type 2* products and 111 products that were *type 2* will change to *type 1*. Also, two new products are introduced [49, 50]. This means that the list of products will grow from 25 to 28. This amendment will, if accepted, come into force the first of January 2021. At this point it is not clear what the potential impact might be of the change on the markets or on Stolt's trade portfolio. It is therefore recommended to study this further. Among the new products proposed for *type 1* is the product group *'cresols'*(all isomer forms). These products have been transported as cargoes on Stolt ships in the past. The cargoes are transported by Stolt on a small scale in

[17] IBC Code 4.1.1

the past 7 years as spot cargo. The other products subject to the changes have not been carried in Stolt tankers in the past. For the cresols a total of 33 voyages are recorded in the entire Stolt deep-sea fleet in the last 7 years, of which 20 were on the Pacific and Atlantic routes on various ship classes. The NPV calculation has been performed for the scenario with cresols as type 1 products. In this scenario, that is considered likely to happen in the future, the results come out negative, see table 3.13. The 'new' *type 1* cargo scenario has still a negative NPV for both round services. The transport of cresols on the Atlantic could become a larger after reclassification since Stolt is the the main owners of *type 1* ships. In order to have a positive Net Present Value, the average quantity of shipped cresols should increase to 153 tons/year and about 1100 tons/year to become a viable investment of the *type 1* notation over *type 2* only.

**Table 3.13.:** Results future scenario
*Source:* Julius Jansen

| | Business as usual | 2021 ship type 1 revision |
|---|---|---|
| **Atlantic Service** | | |
| Average Cargo quantity , $m^3/year$ | 0 | 97 |
| Gross Freight revenue, $USD/year$ | 0 | 16,379 |
| NPV over 25 years @ 7.5%, $USD$ | (87,481) | (53,514) |

#### Inclined Versus Level Tanktop

During the investigation of the double bottom it was noticed that the tanktop is inclined. The midship illustration of the D37 (appendix F) shows that tanktop is under an angle. For Stolt parcel tankers this design feature allows for easier cleaning and stripping of the cargo tanks (the cargo residues gravitate to the pump well). Other, simpler, tanker designs have a level tanktop and use heel tanks[18] to heel the ship to move the residuals to the pump wells as this is a cheaper solution to build. An added benefit to the level tanktop is that it allows for more cargo space. The D37's tanktop is sloping 1.5°, that is a height difference of $400mm$ from the centreline to the inner hull. The sloping tanktop deducts a portion of the cargo area compared to a level tanktop. The difference is calculated for the D37 and equates to $427m^3$.

### 3.7.5. Conclusion on the Ship Type Notation

The analysis showed that the *type 1* ship notation is only applicable to a small number of ships in the chemical tanker fleet. A percentage of 74% of the world fleet with *ship type 1* notation is sailing with the Stolt logo, expressing the dominating position of Stolt Tankers in this segment of the market. The low number of ships in this segment indicates that the transported quantities of this type of chemicals is also low. Based on Stolt's historic trade data it is concluded that the seaborne trade of *type 1* products is almost non-existent. The earnings from *type 1* cargoes are very weak, and non existent for D37 fleet. The investment of *type 1* notation on a parcel tanker is low compared to the ships total newbuilding price, however the loss in potential earnings from type 2 cargoes is significant. The earnings potential from *type 1* cargoes does not weigh up against the losses by the reduced cargo volume. Also, the risk of not carrying *type 1* cargoes is higher than the certainty of income from *type 2* cargoes

[18] Heel tanks (also known as 'anti-heel tanks' on container ships) are tanks on either side of the ship connected to a two-way pump that can pump water from one to the other tank to create a heel of the ship or to counteract heel.

in a *type 2 only* ship. The conclusion is that the ship *type 1* notation does not add value for future parcel tankers at this moment. Therefore, it is recommended that a ***'Won't have'*** priority, the lowest priority according to the MoSCoW method, is adopted for this feature. The scenario with 'only ship type 2 notation' showed the highest earnings potential over the current design and the ship *type 1/2* optimised design. Also, the option to use deck tanks for *type 1* cargo capacity should be investigated as an alternative for ship *type 1* capability is required in the future. The focus should therefore be to maximise the *type 2* cargo capacity in the ship designs in order to maximise cargo revenues. This measure is considered a to make the ship 'leaner', in the sense that 'waste' void space is reduced. The future of the need for *type 1* notation on parcel tankers is potentially changing with the implementation of a revision of the IBC code chapter with the categorisation of products. Regulatory changes are expected to take effect in 2021 that could change the current situation. While the list of *type 1* products is not expected to grow much, there might be products added that could increase the demand for ships with the notation. It is therefore recommended to further study these new *type 1* products and the impacts that they might have on the demand for *type 1* ships.

# 4. Financial Evaluation

In this chapter the features are evaluated for the future value of the investment. A discounted cash flow analysis has been performed to evaluate and compare the added value of the features. The cash flow analysis is a commonly used method to evaluate the profitability of a project or investment. This chapter starts with the explanation of the setup of the model in section 4.1. Section 4.2 elaborates on the use of the investment indicators for the evaluation and comparison of the results from the model. In section 4.3 the scenarios and the results from the model are presented. A display of the Excel spread sheet can be referenced in appendix G.

The framework for the cash flow analysis is based on the evaluation of the yearly cash flows of a basic parcel tanker over a operating period of 25 years. The study consist of a base scenario of a basic parcel tanker without the cooling, heating and *type 1* notation features. In four other scenarios the combination is varied. In the first three scenarios one of the features is added to the basic parcel tanker. The last scenario includes the basic parcel tanker and all features combined. This is the scenario that is the closed to the scenario of the current parcel tanker. The goal of this approach is to determine the relative change in financial performance of each individual feature. Furthermore these five scenarios are tested for three cases; the base case, the best-case and the worst case. The base case is the case which represent the current operating conditions of the features. The 'worst-case' assumes that the feature is installed, but that it will never be used. This is condition could happen if for instance a contract of affreightment is not won, which leaves the feature unused. The third case that has been evaluated for the scenarios is the 'best-case'. The best-case scenario is defined as the case in which the feature can be utilised to the most probable maximum. This means that it must make sense operationally. It is, for instance, not probable that cooled cargoes are carried every voyage since not all trade routes offer the demand for cooled cargoes trading. Therefore, the assumption is adopted that on the main trade routes every voyage is will ship the feature related cargoes. The quantities, average freight rates, operating cost and number of voyages are not varied. The combination of scenarios and cases results the following matrix with combinations that are calculated with the cash flow model, see table 4.1.

**Table 4.1.:** Cases and scenario matrix
*Source:* Julius Jansen

| Cases/Scenarios | Base-case | Best-case | Worst-case |
|---|---|---|---|
| PT + No Features | - | - | - |
| PT + Cargo Cooling | - | - | - |
| PT + Thermal Oil Heating | - | - | - |
| PT + Type 1 | - | - | - |
| PT + All Features | - | - | - |

## 4.1. Discounted Cash Flow Model

The cash flow model consists of three cash flow components: the investing cash flows, the operating cash flows and the financing cash flows.

### Investing Cash Flows

The first cash flow component is the cash flows from investments. These cash flows consist of the purchase of the ship and the feature and the price that is received from the selling of the vessel at the end of its lifetime. The purchase price of the ship is calculated as a price for the basic parcel tanker plus a price that is depending on the features installed. The income from selling the ship at the end of its lifetime is assumed 7% of the purchase price. In reality the purchase price and the scrap value do fluctuate according to supply and demand. However, since the aim of this study is to compare the value of the features, and not the profitability of a parcel tanker as such, it was decided not to vary the purchase and scrap prices. A price of the parcel tanker including all its features is 72.5 million dollar.

### Operating Cash Flows

The second part are the operating cash flows, consisting of the gross revenue, operating cost, voyage cost, cargo coast and periodic maintenance cost, according to Stopford [6]. The gross revenue is based the D37 five year average revenue. The base freight revenue are the revenues from the cargoes that do not require the features. For the scenarios with the features these revenues from these specific cargoes are added to the revenue from the base cargoes. The operating cost of the ship consist primarily of the crew wages, Maintainance & Repair (M&R), consumables and General & Administrative Expenses (G&A). The cost of these items have been estimated for the base parcel tanker (base-case, no features), see table 4.2a. The total operating cost is 4.95 million USD per year. For the scenarios that include features, the maintenance- and fuel cost estimated in the concerning sections in chapter 3 are added. The model has the option to calculate the income tax over the EBIT (Earnings Before Interest and Tax). However, Stolt ships are flying the flags of convenience of states that collect a tax based in tonnage (tonnage tax) rather than a tax on income. The voyage cost consists of the fuel cost, port cost, canal dues and the cargo-handling cost. The cost of bunkers is a large factor in the total cost of the ship. The average yearly bunker cost of a D37 is used in the model. However, new parcel tankers with modern engines, would consume considerably less fuel.

**(a)** Operating cost, '000 USD/year

| | |
|---|---|
| Manning | 2,000 |
| Consumables | 324 |
| M&R | 1,038 |
| Insurance | 350 |
| G&A | 1,208 |
| Tonnage Tax | 4 |
| Total | 4,924 |

**(b)** PM cost, '000 USD

| | |
|---|---|
| 5 year SS | 450 |
| 10 year SS | 1,100 |
| 15 year SS | 2,100 |
| 17.5 IS | 750 |
| 20 year SS | 1,300 |
| 22.5 year IS | 800 |

**(c)** Voyage cost, '000 USD/year

| | |
|---|---|
| Bunkers | 3,000 |
| Port cost | 1,200 |
| Canal Dues | 200 |
| Cargo Handling | 30 |
| Total | 4,430 |

**Table 4.2.:** Operating-, periodic maintenance and voyage cost for base-case parcel tanker with no features
*Source:* D37 estimates and historic averages, compiled from various sources in Stolt Tankers

#### Financing Cash Flows

The third component are the financing cash flows, which consist of the loan advancements and financing fee when the ship is bought and the loan repayments in every consecutive quarter. The sum of the yearly cash flows of the three components is added and results in the yearly net cash flow of the ship including feature(s). As mentioned at the start of this chapters a loan-to-asset ratio is used of 60%, an interest rate of 5% and a maturity period of 15 years. A fixed annuity is proposed, meaning that the repayment amount is fixed every year. For the base-case parcel tanker with no features the yearly financing cost are 4,055,159 USD. This is the loan repayment plus the interest. An overview of the financing calculation sheet is inserted in figure G.1 in appendix G.

## 4.2. Investment Evaluation Performance Indicators

The success of the investment is evaluated by the Net Present Value and Internal Rate of Return, the Payback Period, the Return on Investment and the Profitability Index (i.e. profit-investment ratio). It was chosen to do the evaluation of the features in the context of the total ship as it was found that cash flow analysis of a feature was subject to more uncertainties, assumptions and therefore inaccuracies in the results. Evaluating a single feature would mean that the operating cost of the ship must be known that is accounted to a specific cargo and feature. This was hard to establish with confidence. For a total ship, these cost and revenues could be easier accounted as they are recorded by Stolt per ship or voyage (rather than cargo). The purpose of the evaluation is to determine the incremental cost/benefit of a feature on a parcel tanker.

#### Net Present Value, Internal Rate of Return

The most common method used to valuate a project or investment is the Net Present Value (NPV) method. This method calculates the total value of a investment over the duration taking into account the time value of money. The yearly cash flows are adjusted for the present value by using a discount factor. The sum of the discounted cash flows gives the net present value, see formula 4.1

$$NPV = \sum_{t=0}^{N} \frac{CF_t}{(1+i)^t} \tag{4.1}$$

Where $t$ is the number of years, starting with the year where the investment is done (year 0), $N$ is the total years of the project, $CF_t$ is the net cash flow at year $t$ and $i$ is the discount rate. The discount rate is the factor that determines how much the cash flows are discounted to have the present value. In this thesis the cash flows are discounted with the Weighted Average Cost of Capital (WACC). The (WACC) is often used as discount factor for companies that have different financing methods (equity, stocks, bonds, loans etc.) that each required a certain return. The WACC averages these cost to have one factor that determined the minimal required return of an investment. Other approaches are to use a discount factor that is related to a earnings factor that could be had with a other investment (i.e. opportunity cost) or the factor in a risk factor. For this study these two approached are not used as the risk and comparison of an investments will be dealt separately. For the NPV calculations in this thesis a discount rate (=WACC) of 7,5% is used[1].

[1]Based on common practice within Stolt

Another way to determine the profitability of an investment is to use the Internal Rate of Return (IRR). This methods uses the same formula for the net present value, but the NPV is set to zero and, using iterations, the discount rate is calculated, see equation 4.2.

$$NPV = \sum_{t=0}^{N} \frac{CF}{(1+irr)^t} = 0 \tag{4.2}$$

The internal rate of return $irr$ is the discount rate where the present value of the investment and cash flows are zero (i.e. break-even). The IRR can be compared to other projects with different investment and cash flow values. A project is considered successful if the IRR is higher than the than the WACC.

### Payback Period

The payback period (PBP) is the period, usually measure in years, in which the initial investment is recovered (paid back) by the cash flows after the investment. The payback period is calculated by counting the number of years (excluding the year of the initial investment) until the year that the cumulative cash flow is positive. The payback period (PBP) is a factor that is compared by shipping companies when considering investment opportunities. If the initial investment is payed back the ship owner again has the financial freedom to put his money to work in other projects. The payback period indicates the period that the owner is at risk of losing its invested amount. A short payback period is less risky than a project with a long payback period since the investment risk increases with time. The payback period does not take into account the time value of money[2], risk and opportunity cost. The payback period only says something about the duration to recover the investment, it does not mean that the investment is profitable over a longer period. The cumulative net cash flow could go negative again after the payback period is passed and result in a loss-making investment. It should therefore be used in combination with other investment determinants, such as NPV, IRR and a risk assessment, to gain a complete view of the profitability of a project. The payback period is often compared for projects with similar intentions. The payback period should always be considered relative to the total duration of the project and not judged by only the number itself. For this study no minimal requirements are proposed for the payback period of the features.

### Valuating under Market Uncertainty

Future income and cost are subject to uncertainty. The valuation methods should therefore take into account the uncertainty of the potential positive, or negative, profits from future cash flows. On the revenue side there are three factors that determine the uncertainty in the future revenues; (1) volatility of freight rates, (2) uncertainty of quantities and (3) uncertainty in the shipping frequency (utilisation). The main cost-related uncertainties are the changes in fuel price (and consumption), the ship/feature purchase and scrap price, and cost for (un)expected maintenance and repairs.

There are many methods to assess the financial risk and to quantify the uncertainty of the profitability of an investment. Methods that are generally used to measure the uncertainty of cash flows in valuating investments are: Sensitivity Analysis, Monte Carlo Simulations, Expected Value method or the use of cases/scenarios. All these methods need to some degree statistical data or knowledge of the potential variations in input or output of the evaluation.

[2]The time value of money can be included by counting the discounted cash flows, the PBP is than referred to as discounted payback period

## 4.3. Scenarios and Results

The three features (cargo cooling, cargo heating (TO), and the ship type 1 notation) that were analysed in section 3 are evaluated and compared for their added value. In table 4.3 the results of the investment analysis for the base case are displayed. Note that the absolute values are not that important, since the emphasis is on the profitability of the features, and not the total ship. The base case with no features shows a positive Net Present Value, this means that, under the defined assumptions, a parcel tanker without features would be profitable. For the base ship including only the cargo cooling feature a significantly better result is obtained. The profitability indicators show positive results, but most importantly, is the difference between the values. The Internal Rate of Return almost doubles, and the Payback Period of the total investment is almost halved. The base ship with only the thermal oil heating feature shows negative results. However, compare to the base case with no features it improves. Therefore, the thermal oil heating feature adds value to the ship. The 'type 1 notation' feature does not add value to the ship, as was already concluded in the analysis in section 3.7.

**Table 4.3.:** Base scenario results
*Source:* Julius Jansen

| Base-case scenarios | NPV | IRR | PBP | Added NPV |
|---|---|---|---|---|
| Base - No Features | $ (4,414,560) | 6.2% | 17 | - |
| Base - Cargo Cooling | $ 2,206,737 | 8.1% | 15 | $ 6,621,297 |
| Base - Thermal Oil Heating | $ (4,518,876) | 6.2% | 17 | $ (104,316) |
| Base - Type 1 | $ (4,499,041) | 6.2% | 17 | $ (84,481) |
| Base – All Features | $ 1,458,585 | 7.9% | 15 | $ 5,873,145 |

Concluding on these results, the cargo cooling feature has the highest value-add to the parcel tanker followed by the thermal-oil-cargo-heating-system. For this case the cargo cooling system can make the difference between a profitable ship or a loss-making ship. For that reason, the cargo cooling feature must be considered a 'must have' feature. The high potential of the cargo cooling system if mainly driven by the high freight rate and the relatively large quantities of cargo that are shipped on a regular basis (COA). While the purchase price of the heating system is less than the cooling system, the average revenues are a factor 13 lower.

### 4.3.1. Worst-Case Scenarios

The second scenario that has been tested is the case where the feature is installed, but never used. This is the worst case possible, and it defines the maximum potential downside of the investment. For this scenario the base scenario is used including the investment of the feature, no revenues from the feature, and only maintenance cost. The following results are obtained from the cash flow model, see table 4.4.

The worst-case scenarios have, as expected, a negative influence on the profitability of the ship. Determine the relative impact of this scenario, the added NPV is compared to the Added NPV in the base situation (including the revenues from features).

### 4.3.2. Best-Case Scenarios

For the cooled cargo revenues, the two options where evaluated, the first was for the Atlantic round service, taking 8,000 tonnes of IP feed on the TAW route and 2,700 tonnes of PO on the way back (TAE) for six voyages on each trade route per year. This was compared to the

**Table 4.4.:** Worst-case scenario results
*Source:* Julius Jansen

| Worst-Case (WC) Scenario | NPV | IRR | PBP | Added NPV |
|---|---|---|---|---|
| Base - No Features | $ (4,414,560) | 6.2% | 17 | - |
| WC - Cargo Cooling | $ (5,719,801) | 5.8% | 17 | $ (1,305,241) |
| WC - Thermal Oil Heating | $ (5,280,156) | 6.0% | 17 | $ (865,596) |
| WC - Type 1 | $ (4,499,041) | 6.2% | 17 | $ (84,481) |
| WC – All Features | $ (6,669,041) | 5.6% | 17 | $ (2,255,318) |

maximum likely revenue on the Pacific round service, this calculated to 1,947,000 USD per year. This means that the highest likely revenues are generated when every voyage on the Atlantic service is fully utilised. The same method is used to derive the maximum revenue for the thermal oil heating cargoes. It is not possible to determine the best case with the combination of all features if the method of calculation explained before is used. This is because the best case for the cargo cooling feature is when the ship is sailing the Atlantic service, while the best results are achieved for the heating feature if the ship is sailing on the Pacific round voyage. Thus, for this calculation both round services where analysed for the maximum possible returns. The Atlantic round service hold the highest potential, as the combination of heated and cooled cargoes is shipped.

**Table 4.5.:** Best-case scenario results
*Source:* Julius Jansen

| Best-Case (BC) Scenarios | NPV | IRR | PBP | Added NPV |
|---|---|---|---|---|
| Base - No Features | $ (4,414,560) | 6.2% | 17 | - |
| BC - Cargo Cooling | $ 25,756,945 | 15.1% | 6 | $ 30,171,505 |
| BC - Thermal Oil Heating | $ 8,251,121 | 9.9% | 11 | $ 12,665,681 |
| BC - Type 1 | - | - | - | - |
| BC – All Features | $ 67,599,757 | 27,5% | 3 | $ 72,014,317 |

The ‘ship type 1’ notation is not included in this analysis because of a lack of information on potential earnings. It is assumed that every feature cargo replaces a ‘normal’ cargo. This means that the difference in freight rate determines the height of the added revenue of the feature. As we saw in the section about the cargo heating feature, this is not always the case as some products are traded on ‘backhaul’ legs where the ship is not fully loaded (on volume or deadweight). This introduces an underestimation of the net freight revenue from a feature, and therefore also an underestimation of the projects profitability performance indicators.

The worst-case and best-case scenarios are the most extreme limits that define the band in which the valuation of the feature can be. This also shows the downside- and upside potential of a feature, compared to the base (current) situation. Table 4.6 shows the best-case and worst-case NPV results.

**Table 4.6.:** ’Added’ NPV range. Worst-, base-, and best-case scenarios
*Source:* Julius Jansen

| | Worst Case | Base | Best Case |
|---|---|---|---|
| Cargo Cooling | $ (1,103,241) | $ 6,621,297 | $ 30,171,505 |
| Thermal Oil Heating | $ (865,596) | $ (104,316) | $ 12,665,681 |
| Type 1 Notation | $ (84,481) | $ (84,481) | - |
| All Features | $ (2,255,318) | $ 5,873,145 | $ 72,014,317 |

The worst-case scenarios have, compared to the base scenario, a lower impact than the best-case scenarios. However, these values should be interpreted with care since the distribution of the likelihood of occurrence is not given. The probability distribution would indicate the risk, but this requires elaborate statistical modelling which could not be done for this study. It is therefore recommended that further studied focus on this (by Monte Carlo, Markov, or other probabilistic modelling techniques). The potential real-world situations that are close to the best- and worst cases for the 'all features'-scenario should be interpreted as having a much lower likelihood of occurrence compared to the individual best cases. It is not possible to attach numbers on the likelihood of for those best cases, however, probability that these combinations both occur is extremely low. Subjectively, the probability to the lower side of the base scenario is more likely than the (extreme) up side.

Interestingly, the Net Present Value can be lower than the worst-case scenario. This was found when varying the revenue values in the base scenarios. This is caused by the higher operating cost in the base scenario compared to no operating cost in the worst-case scenarios. While the maintenance cost of the equipment is included in the worst-case scenario, the cargo related cost (heating/cooling fuel consumption) is not included in the worst-case scenarios. So, the worst-case situation as defined is not the real worst-case situation. The limitation of the cash flow model is that the cargo related cost does not (automatically) increase with the quantity of cargo transported. One fixed number was assumed for the cargo related cost, which is incorrect, as it will increase if more cargo is transported.

# 5. Conclusion

The objective of this study was to investigate of the traditional parcel tanker has a future in its current form by looking at the trading needs and the functional requirements for a replacement of the ageing class of Stolt Parcel tankers. The study first looked at the developments in the chemical tanker sector. Secondly, the primary features that differentiate a parcel tanker from other chemical tanker types have been studied for operating, technical and economic/financial factors.

Based on the analysis of the developments in the the chemical sector the following is concluded. The main developments that have impacted the chemical tanker sector and the parcel tanker business can be summarised by regulatory changes, supply and demand changes, technical innovations, and micro economic developments.

It is found by the analysis of the developments in the chemical tanker markets, the parcel tanker operations and features that the current parcel tanker will have a future in its current form as there is still a demand for the features and the service it provides. However, changes are required for new parcel tankers to cope with the changes and trends in the sector.

Five features were identified that have the highest differentiating impact: cargo cooling, cargo heating with thermal oil, small parcel sizes, cargo tank material and coating and the IBC ship type notation. The following conclusions came forward from the analysis of the features:

Cargo cooling equipment has a high potential to add value to Stolt parcel tankers. The financial risks are relatively low and in the current and best case scenarios additional revenues are high. The priority for cargo cooling on the next newbuilding parcel tanker is recommended to be have ***'should have'*** priority. Currently, the cargo cooling capacity in Stolt fleets is higher than the long term average demand (i.e. the number of ships utilising the equipment is low), therefore there are opportunities to increase the utilisation of the cooling feature if less ships are equipped with this feature. This requires a fleet based optimisation.

Cargo heating with thermal oil is given a ***'could have'*** priority for future parcel tankers. While the current (base) scenario of the investment analysis resulted in a net present value of -648,844 USD, there are high potential positive factors of this feature. The best-case financial scenario that showed a positive net present added value of 12.6 million USD, while the worst-case is -0.87 million USD. The priority is given based on the high upside potential, the relatively low net present value at risk and the fact that heating with thermal oil can be used for many more products than the ones that specifically require it.

The IBC ship type 1 notation is a feature that is solely used by the Stolt parcel tanker fleet. It was found that the products that require this notation are not traded in the last 5 years by Stolt ships, therefore the investment is not profitable in any of the tested scenarios. The loss of cargo space that is the effect of the notation's regulatory requirements results in a loss of revenue from other cargoes (type 2 and 3). In the near future there are no major foreseeable changes in the regulations that will impact the trade of type 1 cargoes. These negative factors result in a ***Won't have*** priority.

The number of small cargo tanks is the most pronounced characteristic of a parcel tanker and which defines its operating profile and service. The number of small cargoes traded showed a declining trend, however the period is too short to say that it is structural. The competition of this service could be assigned to the rapid growth of the number of tank containers. Competition from chemical and parcel tankers seems to decrease, creating an opportunity for new parcel tankers to grow in this specialised niche. The small cargo tanks and number of cargo segregations have a large impact on the price of the ship. It was found that in general the higher cost per cubic meter of cargo space is not matching the higher freight rate for smaller cargo sizes. The main dimensions for parcel tankers is limited by external factors. Therefore, the trend seems toward less cargo tanks in order to lower the cost per unit of cargo volume. It was found that an effective way to reduce the capital cost without reducing the cargo carrying capacity is by reducing the average parcel size. The trade-off is in the versatility; reducing the options to carry less cargoes or by utilising the cargo space less efficiently. More research and modelling is required to determine the number and size of the new parcel tanker cargo tank arrangement both for a single ship as well as in a fleet of ships. No MoSCoW priority is assigned to this feature because the tool is not considered appropriate for this feature.

# 6. Recommendations

The following steps and items require more attention or further research.

- The focus of this thesis has been on the requirements for feature on one ship. The aspects of the requirements in respect of the existing fleet as well as with respect to a fleet of newbuildings have not been covered in this study. Therefore, it is recommended to study the requirements of features in (1) respect to the total fleet of Stolt Tankers and (2) determine a new series of ships should all be identical or that slight variations between the ships in the series could yield more optimised results.

- It was discovered to require more advanced techniques to quantitatively determine the requirements for the number and size distribution of the cargo tanks. The time and scope of this study did not allow for these analyses. It is recommended to model and simulate scenarios with the statistical data found with the conclusions and findings that have been derived in this study. It is proposed to simulate the effectiveness of cargo tank layouts for the intended cargo tank utilisation per voyage as discussed in section 3.6. Simulations could be performed using either a Monte Carlo model or operations research methods using the statistical data of the cargo tank distribution per voyage. The following two variables could be optimised: the total cargo tank cost and the revenue (i.e. tank volume utilisation).

- This study tried to use the principles of *marginal analysis* to determine the additional costs and benefits of features on a tanker and the maximisation of these benefits. It was found that this type of analysis has limitations, namely problems occur is the incremental changes in cost of features can not be described due to insufficient data. Therefore, this method was abandoned for the cooling, heating and ship type features after failed efforts. The incremental cost and benefit of an additional cargo tank have been approximated. However, combining this marginal analysis with a future cash flow analysis have not been successful. Therefore it is recommended to develop this in further studies.

- It is recommended to further develop the operational and financial risk of features in a quantitative way. During the study it was found that for many factors a large factor of uncertainty is involved. Quantifying these uncertainties in relation to the impact will give value able information for a shipowner to make decisions. In the financial evaluation used two extreme cases, however the next step is to define the distribution of the probability of the outcomes. Therefore it is recommended to develop more specific cases.

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# Glossary

**backhaul** On a round service, the backhaul is the least profitable leg. Often losses are made on the backhaul that need to be erased by the profits on the fronthaul leg. 53

**bareboat charter** A charter agreement where the ship is leased to a third-party who is responsible for all the operational commitments. The capital ownership of the ship remains to the ship owner. 32

**commodity chemical** Chemical produced in large quantities, for a relatively low cost and interchangeable between the producers. Commodity chemicals are used in production of specialty chemicals. [4]. 1, 13, 21

**fronthaul** On a round service, the fronthaul is the most profitable leg. The return leg (backhaul) is less profitable or loss-making. 53

**marginal analysis** A method often used in economics to maximise the profits by determining the impact of a incremental change in cost on the additional benefits.. 103

**marginal producer** A company that produces a small volume, relative to the total market volume, of a product with a small profit margin and a price that depends highly on the production cost. 20

**newbuilding** New ships that are being built at a shipyard or ships that are contracted to be built. 24, 28

**niche** a niche, or niche market, it a subset of the market which is highly specialised and on which a specific product or service is focused. 47

**oil product** The collective term used to cover both noxious liquid substances and dangerous chemicals (IBC Code). Often also used to refer to clean petroleum products, this can be confusing. 6–8, 11, 13, 40

**slop** Oil/chemical/water residues that remain after tank washing and have to be stored in a slop tank. 12

**specialty chemical** Chemical that consists of a mix of different chemical substances and has a specific application and are generally produced in smaller batches compared to commodity chemicals. Typical uses of specialty chemicals are in industrial and institutional cleaners, specialty polymers, electronic chemicals, surfactants, flavors and fragrance and pharmaceuticals.[4]. 21

**swing tonnage** The group of ships that is able to carry refined oil products as well as vegetables and chemicals. Classified as swing ships by Drewry [10] are tankers with coated tanks of either IMO type 2 or 3 and an average tank size smaller than 3,000 CBM and coated chemical tankers with an average tank size larger than 3,000 CBM. 8, 28

**time charter** Freight contract where a charter party hires a vessel (including) of a shipowner for a fixed price a day for a defined time period. The shipowner still operates the vessel, the operational and capital cost and responsibilities, the charter party pays the voyage relates expenses such as fuel. 32, 33

**voyage charter** The transportation of cargo from port(s) of loading to port(s) of discharge. Payment is normally per ton(ne) of cargo, and the shipowner pays for bunker, port and canal charges. 32

# Acronyms

**CAPEX** Capital Expenditures. 25

**CBM** Cubic Meter. 14, 109

**COA** Contract of Affreightment. 34, 44, 45, 50, 64, 72, 97

**CPP** Clean Petroleum Product. 7, 8, 15, 23, 28–30, 45

**CT** Chemical Tanker. 6

**DPP** Dirty Petroleum Product. 8, 28

**DWT** Deadweight Tonnage. xiii, 3, 7, 8, 14, 23, 26, 27, 29, 33, 36

**G&A** General & Administrative Expenses. 94

**GDP** Gross Domestic Product. 18

**HSFO** High Sulphur Fuel Oil. 23

**HW** Hot Water. 68

**IBC** International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (International Bulk Chemical Code). 1, 2, 6, 9, 11–13, 15, 28, 48, 77, 84, 89, 101, 109

**IMO** International Maritime Organization. 9, 23, 28, 89

**IP** Isoprene. 49, 58, 59, 62–65

**IRR** Internal Rate of Return. 96, 97

**IS** Intermediate Survey. 94

**LCM** Lateral Cargo Mobility. 8

**LOB** Line of Business. 117

**LSFO** Low Sulphur Fuel Oil. 22, 23

**M&R** Maintainance & Repair. 94

**MARPOL** International Convention for the Prevention of Pollution from Ships. 2, 6, 28, 77

**MDI** Methylene Diphenyl Diisocyanate. 68, 70, 71

**MGO** Marine Gas Oil. 23

**MR** Medium Range (product) tanker. 8, 15, 25, 29, 30, 35, 47

**mt** Metric Tonne (1000 kg). 31

**nm** Nautical Mile. 21

**NPV** Net Present Value. 90, 95–99

**NTO** Non-Traditional Owner. 36

**OCIMF** Oil Companies International Marine Forum. 12

**OPEX** Operational Expenditures. 25

**PBP** Payback Period. 96, 97

**PM** Periodic Maintenance. 94

**PO** Propylene Oxide. 49, 58, 59, 61–64

**PT** Parcel Tanker. 6

**S&P** Sale & Purchase. 30

**SOLAS** International Convention for the Safety of Life at Sea. 77

**SS** Special Survey. 94

**STST** Stainless Steel. 7, 15

**SWOT** Strengths, Weaknesses, Opportunities & Threats. 4, 5, 43

**TC** Time Charter. 32

**TDI** Toluene Diisocyanate. 68, 70–72

**TO** Thermal (heating) Oil. 68

**WACC** Weighted Average Cost of Capital. 54, 95, 96

# Appendices

# A. Core Traditional Chemical Tanker Owner/Operators

**Table A.1.:** List of Core Traditional Deep-Sea Chemical Tanker Owner and/or Operators (January 2018)
*Source:* Compiled by Julius Jansen from Drewry fleet list [5]

| Traditional Owner/Operator | DWT | No. Ships |
|---|---|---|
| Ace Quantum | 467673 | 24 |
| Aurora | 416924 | 12 |
| BLT Chembulk | 509416 | 21 |
| Fairfield/lino | 1940847 | 73 |
| Hansa Tankers | 536170 | 25 |
| MISC | 440898 | 11 |
| MOL | 1573412 | 56 |
| MTMM | 555604 | 23 |
| Navig8 | 1907674 | 62 |
| Non Traditional Owners | 1701260 | 85 |
| Nordic | 537599 | 28 |
| Odfjell | 2579289 | 80 |
| Sinochem | 799138 | 31 |
| Stolt Tankers | 2516979 | 75 |
| Team Tankers | 349228 | 10 |
| Ultranav | 393551 | 18 |
| Utkilen | 164255 | 9 |
| Wilmar Trading | 507025 | 16 |
| Womar Logistics | 540013 | 27 |
| Zodiac | 199431 | 10 |
| Total | 18636386 | 696 |

# B. Trade Route Abbreviations and Map

**Table B.1.:** Round- and Leg Service Abbreviations
*Source:* Stolt Tankers

| Code | Name |
|---|---|
| **Round Service** | |
| CT-ACID | Express Acid (EXP-A/GIR-C) |
| CT-AG/US | Arabian Gulf/US (GIP/GIR-U) |
| CT-BAJ | Brazil Argentina Japan (BAJ/JAB) |
| CT-ECSA | East Coast South America (LAS-ES/LAS-EN) |
| CT-EXPRS | Express Chems (EXP-P/GIR-C) |
| CT-FE | Far East (AGE/AAG) |
| CT-SAS | South Africa Shuttle (SAS) |
| CT-UMR | US/Mediterranean (UMR-E/UMR-W) |
| CT-WCSA | West Coast South America (LAS-W) |
| PT-ANZ | Australia New Zealand (ANZ/HBR-U) |
| PT-FR | Full Range (TPW/HBR-U) |
| PT-PACS | Pacific Service (PACS/HBR-C) |
| PT-TAS | Transatlantic (TAE/TAW) |
| **Leg Service / Line of Business (LOB)** | |
| AAG | Asia Arabian Gulf |
| AGE | Arabian Gulf East |
| ANZ | Australia New Zealand |
| BAJ | Brazil Argentina Japan |
| EXP-A | Express Acid |
| EXP-P | Express Chems |
| GIP | Gulf India Pakistan |
| GIR-C | Gulf India Return Continent |
| GIR-U | Gulf India Return US |
| HBR-C | Homebound Return Continent |
| HBR-U | Homebound Return US |
| JAB | Japan, Africa, Brazil |
| LAS-EN | Latin America East Northbound |
| LAS-ES | Latin America East Southbound |
| LAW-W | Latin America - West |
| PACS | Pacific Service |
| SAS | South Africa Shuttle |
| TAE | Trans Atlantic East |
| TAW | Trans Atlantic West |
| TPW | Trans Pacific West |
| UMR-E | USA to Mediterranean (East) |
| UMR-W | Mediterranean to USA (West) |

# C. D37 Class General Data

**Table C.1.:** Dimensions and characteristics of D37 class ships
*Source:* Compiled by Julius Jansen from various sources

| Main Dimensions | | Unit |
|---|---|---|
| Length overall | 176.75 | m |
| Beam | 31.00 | m |
| Draft | 10.80 | m |
| Deadweight | 37,000 | DWT |
| Number of ships | 9 | |
| Year built | 1995-1999 | |
| Yard | Danyard A/S (Denmark) | |
| **Main Machinery** | | |
| Propulsion | Diesel-Electric | |
| Installed power (diesel engines) | 13365 (3x3645 + 1x2430) | kW |
| Propulsion motor (electric) | 10,000 | kW |
| Fuel consumption (@16,5 kn) | 50 | ton/d |
| Range | 13,000 | nm |
| Design Service speed | 16.5 | kt |
| Operating Speed | 13.5 | kt |
| Main boilers | 2 x 15 | ton/h |
| **Cargo Arrangement and Equipment** | | |
| Total cargo capacity (100%) | 40,000 | m3 |
| Total cargo capacity (98%) | 39,200 | m3 |
| Cargo space (LxBxT) | 151 x 27 x 14 | m |
| Cargo tanks (integral+deck) | 42+4 / 44+4 | # |
| Cargo tank material | Duplex Stainless Steel | |
| Cargo cooling tank capacity | 7,500 / 11,256 | m3 |
| Number of cargo cooling tanks | 8 | # |
| Thermal heating tank capacity | 9,000 | m3 |
| Number of thermal oil heated tanks | 10 | # |
| Number of hot water heated tanks | 46 / 48 (all) | # |
| Maximum heating temperature | 95 | ℃ |
| Maximum cargo specific gravity @ 55°C | 1.85 | t/m3 |
| Nitrogen generating capacity (95%/99.9%) | 2040 / 200 | $m^3$/h |
| Liquid nitrogen tank (high purity, 99.999%) | 4 | $m^3$ |

# D. Stolt Fleet Cargo Cooling & Heating Capacities Overview

**Table D.1.:** Stolt deep-sea fleet cargo cooling and thermal oil heated tank capacities as per January 2018
*Source:* Compiled by Julius Jansen from various sources (Stolt Tankers)

| Ship Class | Masterclass | No. of Ships | Ship Cargo Volume | | Cargo Cooling | | | | | Thermal Oil Heating | | | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 98% | 100% | Ship tanks | Class tanks | Ship | Total | Total | Ship Tanks | Total Tanks | Ship | Total | Total | |
| | | # | m3 | m3 | | | m3 | m3 | % | | | m3 | m3 | % | |
| C30 | LC | 2 | 37077 | 37834 | 0 | 0 | 0 | 0 | 0% | 6 | 12 | 5204 | 10408 | 14% | |
| C33 | LC | 8 | 38136 | 38914 | 0 | 0 | 0 | 0 | 0% | 8 | 64 | 8352 | 66813 | 21% | |
| C38 | LVC | 6 | 44377 | 45283 | 13 | 78 | 15599 | 93593 | 34% | 13 | 78 | 11218 | 67308 | 25% | |
| D37 | LVC | 5 | 39033 | 39830 | 8 | 40 | 7522 | 37610 | 19% | 10 | 50 | 9023 | 45115 | 23% | |
| D37A | LVC | 4 | 39033 | 39830 | 11 | 44 | 13303 | 53212 | 33% | | | | | | |
| F37 | LVC | 2 | 40144 | 40963 | 8 | 16 | 7400 | 14800 | 18% | 27 | 54 | 22422 | 44844 | 55% | |
| I27 | MC | 1 | 27584 | 28147 | 0 | 0 | 0 | 0 | 0% | 31 | 31 | 28147 | 28147 | 100% | |
| J19 | SC | 3 | 21722 | 22165 | 0 | 0 | 0 | 0 | 0% | 0 | 0 | 0 | 0 | 0% | Steam heating only |
| J23 | SC | 2 | 21988 | 22437 | 0 | 0 | 0 | 0 | 0% | 0 | 0 | | 0 | 0% | |
| J25 | MC | 7 | 30386 | 31007 | 0 | 0 | 0 | 0 | 0% | 6 | 42 | 4240 | 29680 | 14% | |
| J30 | LC | 1 | 35133 | 35850 | 0 | 0 | 0 | 0 | 0% | 0 | 0 | 0 | 0 | 0% | |
| J32 | LS | 2 | 36606 | 37353 | 0 | 0 | 0 | 0 | 0% | 0 | 0 | 0 | 0 | 0% | |
| J33 | LSss | 3 | 36108 | 36845 | 0 | 0 | 0 | 0 | 0% | 0 | 0 | 0 | 0 | 0% | |
| K44 | LSc | 3 | 47729 | 48703 | 0 | 0 | 0 | 0 | 0% | | 0 | | 0 | 0% | |
| N30 | LSss | 1 | 37309 | 38070 | 6 | 6 | 7538 | 7538 | 20% | | 0 | | 0 | 0% | |
| N37 | LVC | 2 | 39647 | 40456 | 6 | 12 | 8175 | 16350 | 20% | 0 | 0 | 0 | 0 | 0% | One cooling, one pressure |
| N36 | LVC | 6 | 38475 | 39260 | 0 | 0 | 0 | 0 | 0% | | 0 | | 0 | 0% | |
| N43 | LVC | 6 | 44545 | 45454 | 6 | 36 | 10176 | 61053 | 22% | 9 | 54 | 9314 | 55884 | 20% | |
| S22 | SC | 6 | 24720 | 25224 | 6 | 36 | 5043 | 30260 | 20% | 9 | 54 | 5476 | 32856 | 22% | |
| Totals | | 75 | 2776551 | 2833215 | | 268 | | 314416 | | | 439 | | 381055 | | |

# E. List of Chemical Products Requiring Ship Type 1

List of type 1 products extracted from chapter 17 of IBC code

Metam Sodium Solution
N-(2-Methoxy-1-methylethyl)-2-ethyl-6-methylchloroacetanilide
Alkylaryl phosphate mixtures
Alkyl (C12+) dimethylamine
Calcium hypochlorite solution
Chlorinated paraffins (C10-C13)
Chlorinated paraffins (C14-C17)*
Chlorosulphonic acid
1,5,9-Cyclododecatriene
Decyl Acrylate
2,6-Di-tert-butylphenol (n)
Di-n-hexyl adipate
N,N-Dimethyldodecylamine
Diphenylamine, reaction product with 2,2,4-Trimethylpentene (n)
tert-Dodecanethiol
Methylcyclopentadienyl manganese tricarbonyl
Motor fuel anti-knock compounds (containing lead alkyls)
Nonylphenol
Noxious liquid, NF, (1) n.o.s (trade name . . ., contains . . .) ST1, Cat X
Noxious liquid, F, (2) n.o.s (trade name . . ., contains . . .) ST1, Cat X
Phosphorus, yellow or white
Poly(2+)cyclic aromatics
1,2,3-trichlorobenzene (molten)
1,2,4-trichloroebenzene
Tricresyl phosphate (containing 1% or more ortho-isomer)

# F. Midship Sections with Changes for Ship Type Scenarios

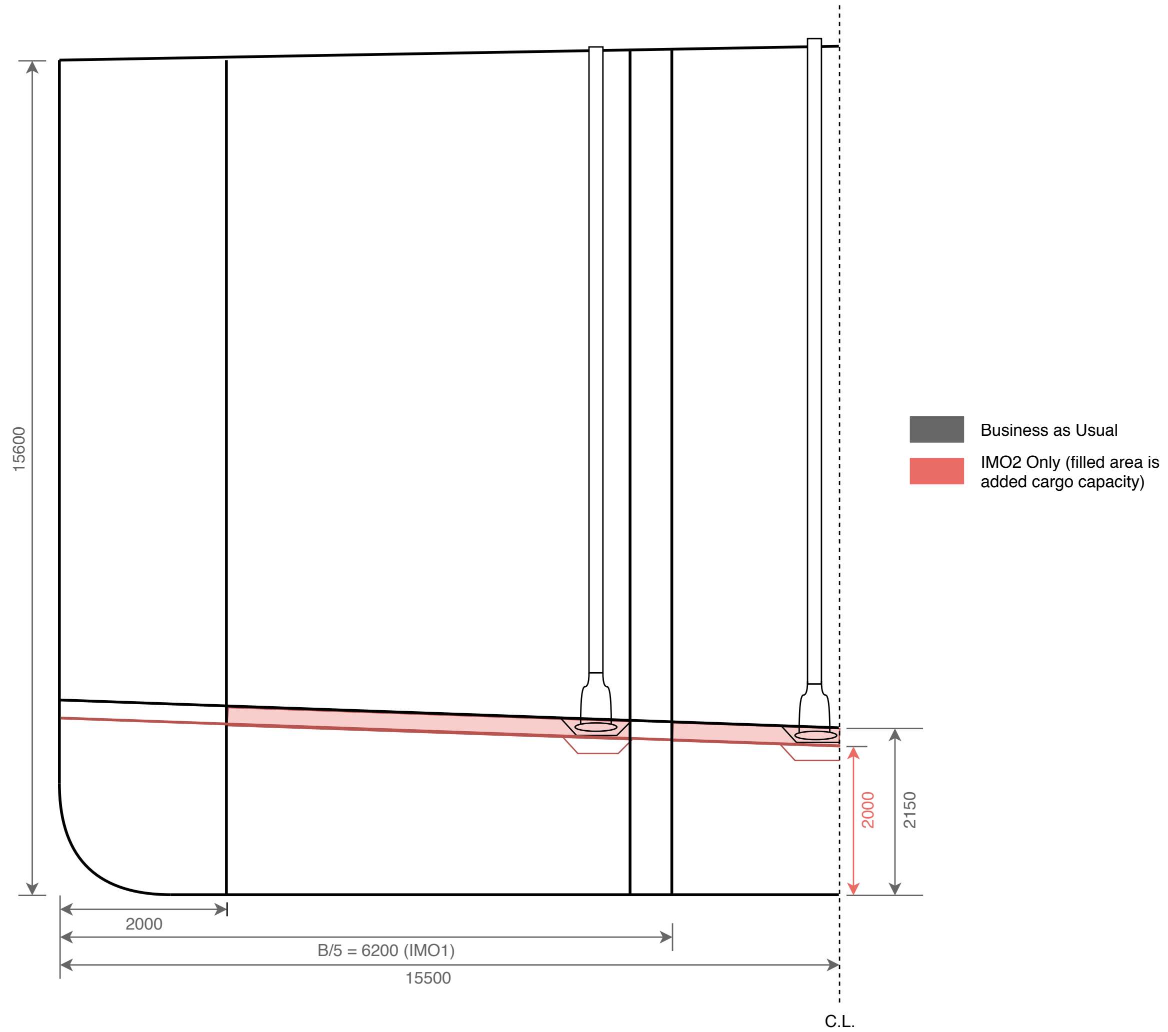



**Figure F.1.:** 'Business as usual' vs. 'Ship type 2 only' scenario
*Source:* Own composition

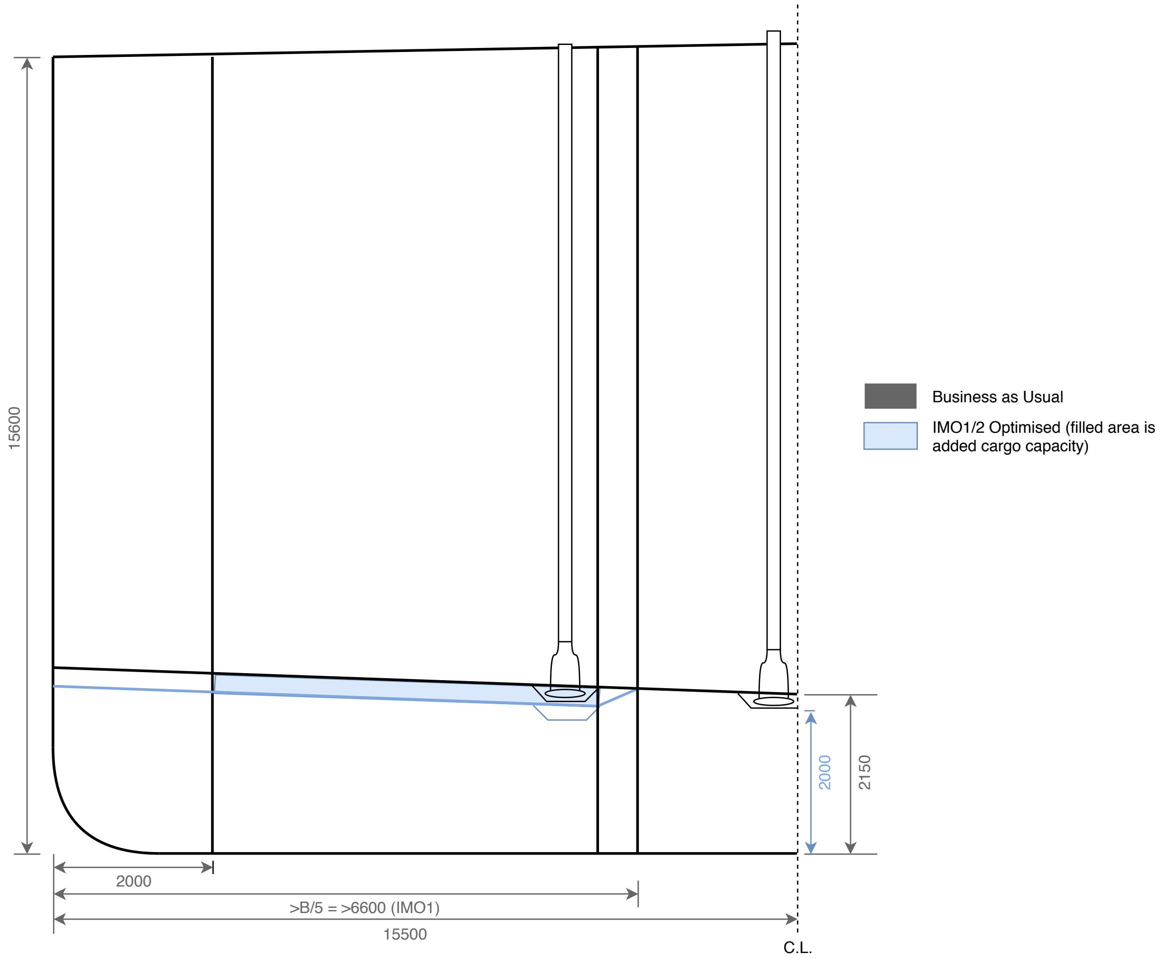



**Figure F.2.:** 'Business as usual' vs. 'Ship type 1/2 optimised' scenario
*Source:* Own composition

# G. Cash flow and Investment Model

**Finance Program**

| | | | |
|---|---|---|---|
| Purchase Price | $ 69,859,400 | USD | (Link cell later to cost calculation result) |
| Mortgage Loan | $41,915,640 | USD | |
| Loan To Asset | 60% | | |
| Bank Fees | 1.0% | | |
| Bank Fees | $698,594 | USD | |
| Tenor (15 or 25) | 15 | Years | |
| Balloon | $0 | USD | |
| Interest Rate | 5.0% | | |

| Financing Cost | | | |
|---|---|---|---|
| Yearly Amount | $ | (4,055,159) | USD/year |
| Quarterly Amount | $ | (1,013,790) | USD/Quarter |
| Daily Financing Cost | $ | (11,110) | USD/Day |

**Repayment Schedule (Quarterly Repayment Assumed, Tenor 15 Years, No Baloon)**

| No | Year | Quarter | Year # | Interest | Principal Repayment | Total Repayment | Balance (Remaining) | Discount Factor |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | Q1 | 0.00 | | | | $42,614,234 | 1.00 |
| 1 | 1 | Q1 | 0.25 | $ (532,678) | $ (481,112) | $ (1,013,790) | $ 42,133,122 | 0.99 |
| 2 | 1 | Q2 | 0.50 | $ (526,664) | $ (487,126) | $ (1,013,790) | $ 41,645,997 | 0.98 |
| 3 | 1 | Q3 | 0.75 | $ (520,575) | $ (493,215) | $ (1,013,790) | $ 41,152,782 | 0.96 |
| 4 | 1 | Q4 | 1.00 | $ (514,410) | $ (499,380) | $ (1,013,790) | $ 40,653,402 | 0.95 |
| 5 | 2 | Q1 | 1.25 | $ (508,168) | $ (505,622) | $ (1,013,790) | $ 40,147,780 | 0.94 |
| 6 | 2 | Q2 | 1.50 | $ (501,847) | $ (511,942) | $ (1,013,790) | $ 39,635,838 | 0.93 |
| 7 | 2 | Q3 | 1.75 | $ (495,448) | $ (518,342) | $ (1,013,790) | $ 39,117,496 | 0.92 |
| 8 | 2 | Q4 | 2.00 | $ (488,969) | $ (524,821) | $ (1,013,790) | $ 38,592,675 | 0.91 |
| 9 | 3 | Q1 | 2.25 | $ (482,408) | $ (531,381) | $ (1,013,790) | $ 38,061,294 | 0.89 |
| 10 | 3 | Q2 | 2.50 | $ (475,766) | $ (538,023) | $ (1,013,790) | $ 37,523,270 | 0.88 |
| 11 | 3 | Q3 | 2.75 | $ (469,041) | $ (544,749) | $ (1,013,790) | $ 36,978,521 | 0.87 |
| 12 | 3 | Q4 | 3.00 | $ (462,232) | $ (551,558) | $ (1,013,790) | $ 36,426,963 | 0.86 |
| 13 | 4 | Q1 | 3.25 | $ (455,337) | $ (558,453) | $ (1,013,790) | $ 35,868,511 | 0.85 |
| 14 | 4 | Q2 | 3.50 | $ (448,356) | $ (565,433) | $ (1,013,790) | $ 35,303,077 | 0.84 |
| 15 | 4 | Q3 | 3.75 | $ (441,288) | $ (572,501) | $ (1,013,790) | $ 34,730,576 | 0.83 |
| 16 | 4 | Q4 | 4.00 | $ (434,132) | $ (579,657) | $ (1,013,790) | $ 34,150,919 | 0.82 |
| 17 | 5 | Q1 | 4.25 | $ (426,886) | $ (586,903) | $ (1,013,790) | $ 33,564,016 | 0.81 |
| 18 | 5 | Q2 | 4.50 | $ (419,550) | $ (594,239) | $ (1,013,790) | $ 32,969,776 | 0.80 |
| 19 | 5 | Q3 | 4.75 | $ (412,122) | $ (601,667) | $ (1,013,790) | $ 32,368,109 | 0.79 |
| 20 | 5 | Q4 | 5.00 | $ (404,601) | $ (609,188) | $ (1,013,790) | $ 31,758,921 | 0.78 |
| 21 | 6 | Q1 | 5.25 | $ (396,987) | $ (616,803) | $ (1,013,790) | $ 31,142,117 | 0.77 |
| 22 | 6 | Q2 | 5.50 | $ (389,276) | $ (624,513) | $ (1,013,790) | $ 30,517,604 | 0.76 |
| 23 | 6 | Q3 | 5.75 | $ (381,470) | $ (632,320) | $ (1,013,790) | $ 29,885,285 | 0.75 |
| 24 | 6 | Q4 | 6.00 | $ (373,566) | $ (640,224) | $ (1,013,790) | $ 29,245,061 | 0.74 |
| 25 | 7 | Q1 | 6.25 | $ (365,563) | $ (648,226) | $ (1,013,790) | $ 28,596,835 | 0.73 |
| 26 | 7 | Q2 | 6.50 | $ (357,460) | $ (656,329) | $ (1,013,790) | $ 27,940,505 | 0.72 |
| 27 | 7 | Q3 | 6.75 | $ (349,256) | $ (664,533) | $ (1,013,790) | $ 27,275,972 | 0.72 |
| 28 | 7 | Q4 | 7.00 | $ (340,950) | $ (672,840) | $ (1,013,790) | $ 26,603,132 | 0.71 |
| 29 | 8 | Q1 | 7.25 | $ (332,539) | $ (681,250) | $ (1,013,790) | $ 25,921,882 | 0.70 |
| 30 | 8 | Q2 | 7.50 | $ (324,024) | $ (689,766) | $ (1,013,790) | $ 25,232,115 | 0.69 |
| 31 | 8 | Q3 | 7.75 | $ (315,401) | $ (698,388) | $ (1,013,790) | $ 24,533,727 | 0.68 |
| 32 | 8 | Q4 | 8.00 | $ (306,672) | $ (707,118) | $ (1,013,790) | $ 23,826,609 | 0.67 |
| 33 | 9 | Q1 | 8.25 | $ (297,833) | $ (715,957) | $ (1,013,790) | $ 23,110,652 | 0.66 |
| 34 | 9 | Q2 | 8.50 | $ (288,883) | $ (724,906) | $ (1,013,790) | $ 22,385,746 | 0.66 |
| 35 | 9 | Q3 | 8.75 | $ (279,822) | $ (733,968) | $ (1,013,790) | $ 21,651,778 | 0.65 |
| 36 | 9 | Q4 | 9.00 | $ (270,647) | $ (743,142) | $ (1,013,790) | $ 20,908,635 | 0.64 |
| 37 | 10 | Q1 | 9.25 | $ (261,358) | $ (752,432) | $ (1,013,790) | $ 20,156,204 | 0.63 |
| 38 | 10 | Q2 | 9.50 | $ (251,953) | $ (761,837) | $ (1,013,790) | $ 19,394,367 | 0.62 |
| 39 | 10 | Q3 | 9.75 | $ (242,430) | $ (771,360) | $ (1,013,790) | $ 18,623,007 | 0.62 |
| 40 | 10 | Q4 | 10.00 | $ (232,788) | $ (781,002) | $ (1,013,790) | $ 17,842,005 | 0.61 |
| 41 | 11 | Q1 | 10.25 | $ (223,025) | $ (790,765) | $ (1,013,790) | $ 17,051,240 | 0.60 |
| 42 | 11 | Q2 | 10.50 | $ (213,140) | $ (800,649) | $ (1,013,790) | $ 16,250,591 | 0.59 |
| 43 | 11 | Q3 | 10.75 | $ (203,132) | $ (810,657) | $ (1,013,790) | $ 15,439,933 | 0.59 |
| 44 | 11 | Q4 | 11.00 | $ (192,999) | $ (820,790) | $ (1,013,790) | $ 14,619,143 | 0.58 |
| 45 | 12 | Q1 | 11.25 | $ (182,739) | $ (831,050) | $ (1,013,790) | $ 13,788,093 | 0.57 |
| 46 | 12 | Q2 | 11.50 | $ (172,351) | $ (841,438) | $ (1,013,790) | $ 12,946,654 | 0.56 |
| 47 | 12 | Q3 | 11.75 | $ (161,833) | $ (851,956) | $ (1,013,790) | $ 12,094,698 | 0.56 |
| 48 | 12 | Q4 | 12.00 | $ (151,184) | $ (862,606) | $ (1,013,790) | $ 11,232,092 | 0.55 |
| 49 | 13 | Q1 | 12.25 | $ (140,401) | $ (873,389) | $ (1,013,790) | $ 10,358,703 | 0.54 |
| 50 | 13 | Q2 | 12.50 | $ (129,484) | $ (884,306) | $ (1,013,790) | $ 9,474,397 | 0.54 |
| 51 | 13 | Q3 | 12.75 | $ (118,430) | $ (895,360) | $ (1,013,790) | $ 8,579,038 | 0.53 |
| 52 | 13 | Q4 | 13.00 | $ (107,238) | $ (906,552) | $ (1,013,790) | $ 7,672,486 | 0.52 |
| 53 | 14 | Q1 | 13.25 | $ (95,906) | $ (917,884) | $ (1,013,790) | $ 6,754,602 | 0.52 |
| 54 | 14 | Q2 | 13.50 | $ (84,433) | $ (929,357) | $ (1,013,790) | $ 5,825,245 | 0.51 |
| 55 | 14 | Q3 | 13.75 | $ (72,816) | $ (940,974) | $ (1,013,790) | $ 4,884,271 | 0.50 |
| 56 | 14 | Q4 | 14.00 | $ (61,053) | $ (952,736) | $ (1,013,790) | $ 3,931,535 | 0.50 |
| 57 | 15 | Q1 | 14.25 | $ (49,144) | $ (964,645) | $ (1,013,790) | $ 2,966,890 | 0.49 |
| 58 | 15 | Q2 | 14.50 | $ (37,086) | $ (976,704) | $ (1,013,790) | $ 1,990,186 | 0.49 |
| 59 | 15 | Q3 | 14.75 | $ (24,877) | $ (988,912) | $ (1,013,790) | $ 1,001,274 | 0.48 |
| 60 | 15 | Q4 | 15.00 | $ (12,516) | $ (1,001,274) | $ (1,013,790) | $ 0 | 0.47 |

**Figure G.1.:** Ship financing (CAPEX) model
*Source:* Own composition

## Ship & Feature Investment Cash Flow Model

| Purchase Price | |
|---|---|
| Purchase Price Ship | $ 69,859,400 |
| Purchase Price Feature(s) | $ - |
| *Total Purchase Price* | $ 69,859,400 |
| *Scrap Value (7%)* | $ 4,890,158 |

| Feature Price and Cost (check only) | |
|---|---|
| Purchase Price Feature | $ - |
| Op. Revenue, feature related Ca | $ - |
| Operating Cost | $ - |
| Voyage Cost | $ - |

| Gross Operating Revenue [/year] | |
|---|---|
| Freight Revenue | $ 14,787,010 |
| Feature Cargoes | $ - |
| *Total Op. Revenue* | $ 14,787,010 |

| Financing Parameter | |
|---|---|
| Loan to Asset | 60.0% |
| Bank Fees | 1.0% |
| Interest Rate | 5.0% |
| Discount Rate (WACC) | 7.5% |

| Operating Cost [/year] | | |
|---|---|---|
| Manning | $ 2,000,000 | Checked with JDB |
| Consumables | $ 324,000 | 2017 Budget SINOV |
| Maintenance & Repa | $ 1,038,000 | " |
| Insurance | $ 350,000 | |
| General & Administr | $ 1,208,038 | total G&A / total stol |
| Tonnage Tax | $ 4,000 | |
| Other | | |
| Feature Operating Co | $ - | |
| *Total Operating Cost* | $ 4,924,038 | |

| Periodic Maintenance | | |
|---|---|---|
| 2.5y IS | $ - | Historical, see data fo |
| 5y SS | $ 450,000 | " |
| 7.5 IS | $ - | " |
| 10y SS | $ 1,100,000 | " |
| 12.5 IS | $ - | " |
| 15 SS | $ 2,100,000 | " |
| 17.5 IS | $ 750,000 | 2017 Budget DD cost |
| 20 SS | $ 1,300,000 | " |
| 22.5 IS | $ 800,000 | " |

| Voyage Cost [\year] | | |
|---|---|---|
| Bunkers | $ 3,000,000 | (average of D37, see |
| Port Cost | $ 1,200,000 | " |
| Canal Dues | $ 200,000 | " |
| Cargo Handling | $ 30,000 | |
| Feature Voyage Cost | $ - | |
| *Total Voyage Cost* | $ 4,430,000 | |

| Profitability | |
|---|---|
| NPV | $ (4,414,560) |
| IRR | 6.2% |
| PBP | 17 |

| Scenarios (%Changes) | |
|---|---|
| Investment | |
| Ship | 0.0% |
| Feature | 0.0% |
| Scrap Price | 0.0% |
| Freight Revenue | |
| Normal | 0.0% |
| Feature | 0.0% |
| Voyage Cost | |
| Normal | 0.0% |
| Feature | 0.0% |
| Operational Cost | |
| Normal | 0.0% |
| Features | 0.0% |

| Year (Fiscal) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Operating Revenue (Gross) | | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 |
| Operating Cost | | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) |
| Periodic Maintenance | | | | - | | (450,000) | | | - | | (1,100,000) | | |
| Voyage Cost | | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) |
| Depreciation | | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) |
| EBIT | | 2,834,203 | 2,834,203 | 2,834,203 | 2,834,203 | 2,384,203 | 2,834,203 | 2,834,203 | 2,834,203 | 2,834,203 | 1,734,203 | 2,834,203 | 2,834,203 |
| Interest | | (2,094,327) | (1,994,431) | (1,889,447) | (1,779,114) | (1,663,160) | (1,541,299) | (1,413,230) | (1,312,914) | (893,387) | (1,063,780) | (911,383) | (751,222) |
| Income tax 0.0% | | - | - | - | - | - | - | - | - | - | - | - | - |
| Net Income | | 2,834,203 | 2,834,203 | 2,834,203 | 2,834,203 | 2,384,203 | 2,834,203 | 2,834,203 | 2,834,203 | 2,834,203 | 1,734,203 | 2,834,203 | 2,834,203 |
| *Operating Cash Flow* | | 5,432,972 | 5,432,972 | 5,432,972 | 5,432,972 | 4,982,972 | 5,432,972 | 5,432,972 | 5,432,972 | 5,432,972 | 4,332,972 | 5,432,972 | 5,432,972 |
| Loan Advancement | 42,614,234 | | | | | | | | | | | | |
| Interest | - | (2,094,327) | (1,994,431) | (1,889,447) | (1,779,114) | (1,663,160) | (1,541,299) | (1,413,230) | (1,312,914) | (893,387) | (1,063,780) | (911,383) | (751,222) |
| Principal Loan Repayment | | (1,960,832) | (2,060,727) | (2,165,712) | (2,276,044) | (2,391,998) | (2,513,860) | (2,641,929) | (2,776,523) | (2,917,974) | (3,066,631) | (3,222,861) | (3,387,051) |
| Arrangement Fee | (419,156) | | | | | | | | | | | | |
| *Financing Cash Flow* | 42,195,078 | (4,055,159) | (4,055,159) | (4,055,159) | (4,055,159) | (4,055,159) | (4,055,159) | (4,055,159) | (4,089,437) | (3,811,361) | (4,130,410) | (4,134,244) | (4,138,273) |
| Purchasing Price | (69,859,400) | - | - | - | - | - | - | - | - | - | - | - | - |
| Demolition Income | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Investing Cash Flow* | (69,859,400) | - | - | - | - | - | - | - | - | - | - | - | - |
| Total (Net) Cash Flow | (27,664,322) | 1,377,814 | 1,377,814 | 1,377,814 | 1,377,814 | 927,814 | 1,377,814 | 1,377,814 | 1,343,536 | 1,621,611 | 202,562 | 1,298,728 | 1,294,699 |
| Cumulative Net Cash Flow | (27,664,322) | (26,286,509) | (24,908,695) | (23,530,881) | (22,153,067) | (21,225,253) | (19,847,439) | (18,469,626) | (17,126,090) | (15,504,479) | (15,301,917) | (14,003,188) | (12,708,489) |
| Discount Factor | 1.00 | 0.93 | 0.87 | 0.80 | 0.75 | 0.70 | 0.65 | 0.60 | 0.56 | 0.52 | 0.49 | 0.45 | 0.42 |
| Total Discounted CF | (27,664,322) | 1,281,687 | 1,192,267 | 1,109,086 | 1,031,708 | 646,277 | 892,770 | 830,484 | 753,324 | 845,806 | 98,282 | 586,172 | 543,585 |
| Cumulative (discounted) CF | (27,664,322) | (26,382,635) | (25,190,368) | (24,081,282) | (23,049,574) | (22,403,298) | (21,510,527) | (20,680,043) | (19,926,720) | (19,080,914) | (18,982,632) | (18,396,460) | (17,852,875) |
| Net Asset Base (NAB) | | 67,260,630 | 64,661,861 | 62,063,091 | 59,464,321 | 56,865,552 | 54,266,782 | 51,668,012 | 49,069,243 | 46,470,473 | 43,871,703 | 41,272,934 | 38,674,164 |
| Net Asset Value (NAV) | | 70,094,833 | 70,330,266 | 70,565,699 | 70,801,132 | 70,586,565 | 70,821,998 | 71,057,431 | 71,292,864 | 71,528,297 | 70,663,730 | 70,899,164 | 71,134,597 |
| Return on Capital Employed (ROCE) | | 4.0% | 4.0% | 4.0% | 4.0% | 3.4% | 4.0% | 4.0% | 4.0% | 4.0% | 2.5% | 4.0% | 4.0% |
| Return on Investment (ROI) | | 2% | 2% | 2% | 2% | 1% | 2% | 2% | 2% | 2% | 0% | 2% | 2% |

| Year (Fiscal) | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Operating Revenue (Gross) | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,010 | 14,787,01 |
| Operating Cost | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,038) | (4,924,03 |
| Periodic Maintenance | - | | (2,100,000) | | | (750,000) | | (1,300,000) | | | (800,000) | |
| Voyage Cost | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,000) | (4,430,00 |
| Depreciation | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,770) | (2,598,77 |
| EBIT | 2,834,203 | 2,834,203 | 734,203 | 2,834,203 | 2,834,203 | 2,084,203 | 2,834,203 | 1,534,203 | 2,834,203 | 2,834,203 | 2,034,203 | 2,834,20 |
| Interest | (582,902) | (406,007) | (220,099) | | | | | | | | | |
| Income tax 0.0% | - | - | - | - | - | - | - | - | - | - | - | - |
| Net Income | 2,834,203 | 2,834,203 | 734,203 | 2,834,203 | 2,834,203 | 2,084,203 | 2,834,203 | 1,534,203 | 2,834,203 | 2,834,203 | 2,034,203 | 2,834,20 |
| *Operating Cash Flow* | 5,432,972 | 5,432,972 | 3,332,972 | 5,432,972 | 5,432,972 | 4,682,972 | 5,432,972 | 4,132,972 | 5,432,972 | 5,432,972 | 4,632,972 | 5,432,97 |
| Loan Advancement | | | | | | | | | | | | |
| Interest | (582,902) | (406,007) | (220,099) | | | | | | | | | |
| Principal Loan Repayment | (3,559,606) | (3,740,951) | (3,931,535) | | | | | | | | | |
| Arrangement Fee | | | | | | | | | | | | |
| *Financing Cash Flow* | (4,142,508) | (4,146,958) | (4,151,634) | - | - | - | - | - | - | - | - | - |
| Purchasing Price | - | - | - | - | - | - | - | - | - | - | - | - |
| Demolition Income | - | - | - | - | - | - | - | - | - | - | - | - |
| *Investing Cash Flow* | - | - | - | - | - | - | - | - | - | - | - | - |
| Total (Net) Cash Flow | 1,290,465 | 1,286,015 | (818,662) | 5,432,972 | 5,432,972 | 4,682,972 | 5,432,972 | 4,132,972 | 5,432,972 | 5,432,972 | 4,632,972 | 5,432,97 |
| Cumulative Net Cash Flow | (11,418,024) | (10,132,010) | (10,950,672) | (5,517,699) | (84,727) | 4,598,246 | 10,031,218 | 14,164,191 | 19,597,163 | 25,030,135 | 29,663,108 | 35,096,08 |
| Discount Factor | 0.39 | 0.36 | 0.34 | 0.31 | 0.29 | 0.27 | 0.25 | 0.24 | 0.22 | 0.20 | 0.19 | 0.1 |
| Total Discounted CF | 504,007 | 467,227 | (276,680) | 1,708,056 | 1,588,889 | 1,273,999 | 1,374,918 | 972,956 | 1,189,761 | 1,106,754 | 877,940 | 957,71 |
| Cumulative (discounted) CF | (17,348,869) | (16,881,642) | (17,158,322) | (15,450,266) | (13,861,377) | (12,587,378) | (11,212,460) | (10,239,504) | (9,049,743) | (7,942,989) | (7,065,048) | (6,107,33 |
| Net Asset Base (NAB) | 36,075,394 | 33,476,624 | 30,877,855 | 28,279,085 | 25,680,315 | 23,081,546 | 20,482,776 | 17,884,006 | 15,285,237 | 12,686,467 | 10,087,697 | 7,488,92 |
| Net Asset Value (NAV) | 71,370,030 | 71,605,463 | 69,740,896 | 69,976,329 | 70,211,762 | 69,697,195 | 69,932,628 | 68,868,061 | 69,103,494 | 69,338,927 | 68,774,360 | 69,009,79 |
| Return on Capital Employed (ROCE) | 4.0% | 4.0% | 1.1% | 4.1% | 4.0% | 3.0% | 4.1% | 2.2% | 4.1% | 4.1% | 3.0% | 4.1 |
| Return on Investment (ROI) | 2% | 2% | -1% | 7% | 7% | 6% | 7% | 6% | 7% | 7% | 6% | 7 |

**Figure G.2.:** Cash flow model (model shows the input of the 'base' scenario without any features)

version 15-04-2019

**Scenario Summary**

| | | Current Values: | Base - No Features | Base - Cargo Cooling | Base - Thermal Oil Heating | Base - Type 1 | Base - All Features | Base - Worst Case - Cooling | Base - Worst Case - Heating | Base - Worst Case - Type 1 | Base - Worst Case - All Features | Base - Best Case - Cooling | Base - Best Case - Heating | Base - Best Case - All Features |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Changing Cells:** | | | | | | | | | | | | | | |
| **Purchase Price Ship** | **$B$4** | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 | $ 69,859,400 |
| **Purchase Price Feature(s)** | **$B$5** | $ - | $ - | $ 1,515,000 | $ 1,025,600 | $ 94,042 | $ 2,640,600 | $ 1,515,000 | $ 1,025,600 | $ 94,042 | $ 2,634,642 | $ 1,515,000 | $ 1,025,600 | $ 2,540,600 |
| **Freight Revenue** | **$E$4** | $ 14,787,010 | $ 14,787,010 | $ 13,438,105 | $ 14,660,755 | $ 14,787,010 | $ 13,311,850 | $ 14,787,010 | $ 14,787,010 | $ 14,787,010 | $ 14,787,010 | $ 9,555,610 | $ 13,251,010 | $ 11,328,610 |
| **Feature Cargoes** | **$E$6** | $ - | $ - | $ 2,100,000 | $ 200,700 | $ - | $ 2,260,000 | $ - | $ - | $ - | $ - | $ 8,095,200 | $ 2,806,500 | $ 10,210,200 |
| **Feature Operating Cost** | **$H$13** | $ - | $ - | $ 5,000 | $ 5,000 | $ - | $ 1,000 | $ 5,000 | $ 5,000 | $ - | $ 10,000 | $ 5,000 | $ 5,000 | $ 10,000 |
| **Feature Voyage Cost** | **$N$13** | $ - | $ - | $ 40,000 | $ 6,150 | $ - | $ 46,150 | $ - | $ - | $ - | $ - | $ 40,000 | $ 56,600 | $ 96,600 |
| **Result Cells:** | | | | | | | | | | | | | | |
| **NPV** | **$Q$4** | $ (4,414,560) | $ (4,414,560) | $ 2,206,737 | $ (4,518,876) | $ (4,499,041) | $ 1,458,585 | $ (5,719,801) | $ (5,280,156) | $ (4,499,041) | $ (6,669,878) | $ 25,756,945 | $ 8,251,121 | $ 67,599,757 |
| **IRR** | **$Q$5** | 6.2% | 6.2% | 8.1% | 6.2% | 6.2% | 7.9% | 5.8% | 6.0% | 6.2% | 5.6% | 15.1% | 9.9% | 27.5% |
| **PBP** | **$Q$6** | 17 | 17 | 15 | 17 | 17 | 15 | 17 | 17 | 17 | 17 | 6 | 11 | 3 |
| **Added NPV** | | | $ - | $ 6,621,297 | $ (104,316) | $ (84,481) | $ 5,873,145 | $ (1,305,241) | $ (865,596) | $ (84,481) | $ (2,255,318) | $ 30,171,505 | $ 12,665,681 | $ 72,014,317 |

Notes: Current Values column represents values of changing cells at
time Scenario Summary Report was created. Changing cells for each

**Figure G.3.:** Overview of the results of scenarios

# H. Number of Cargoes per Voyage Distributions on Backhaul Routes

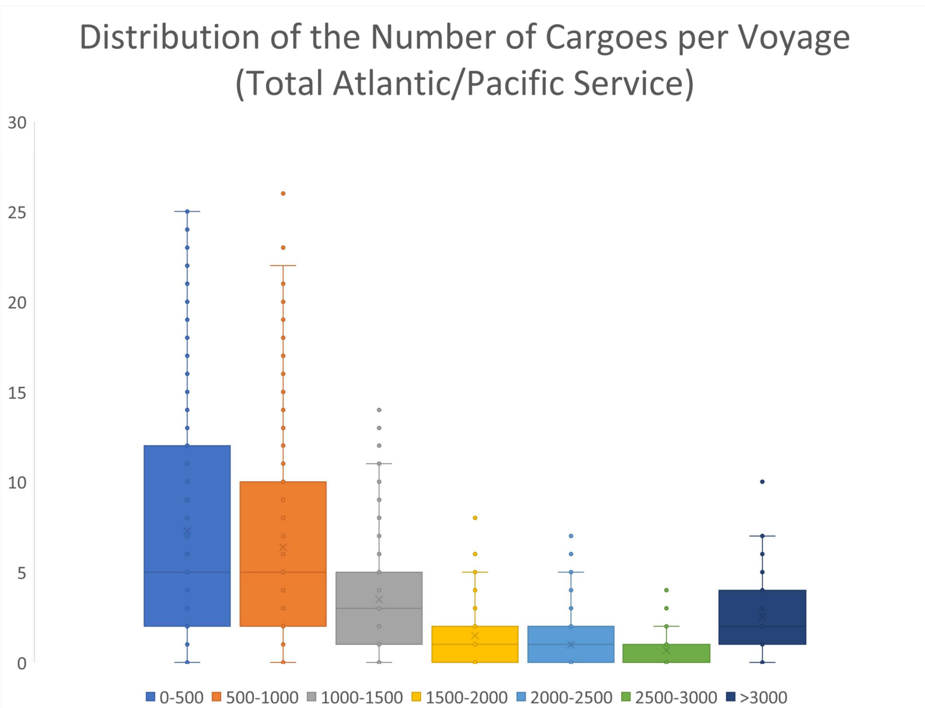
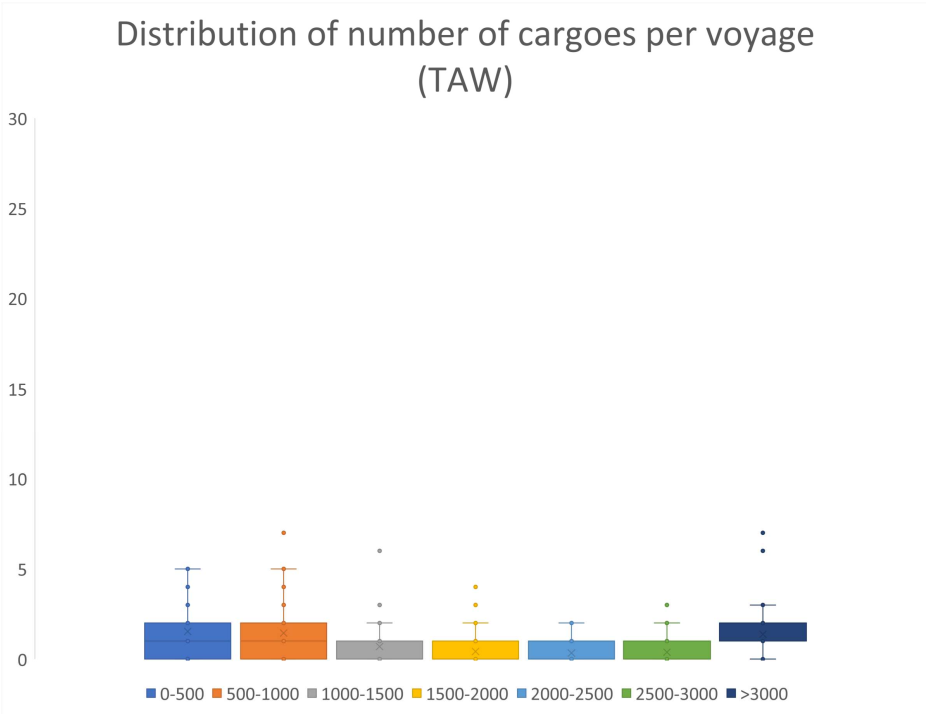
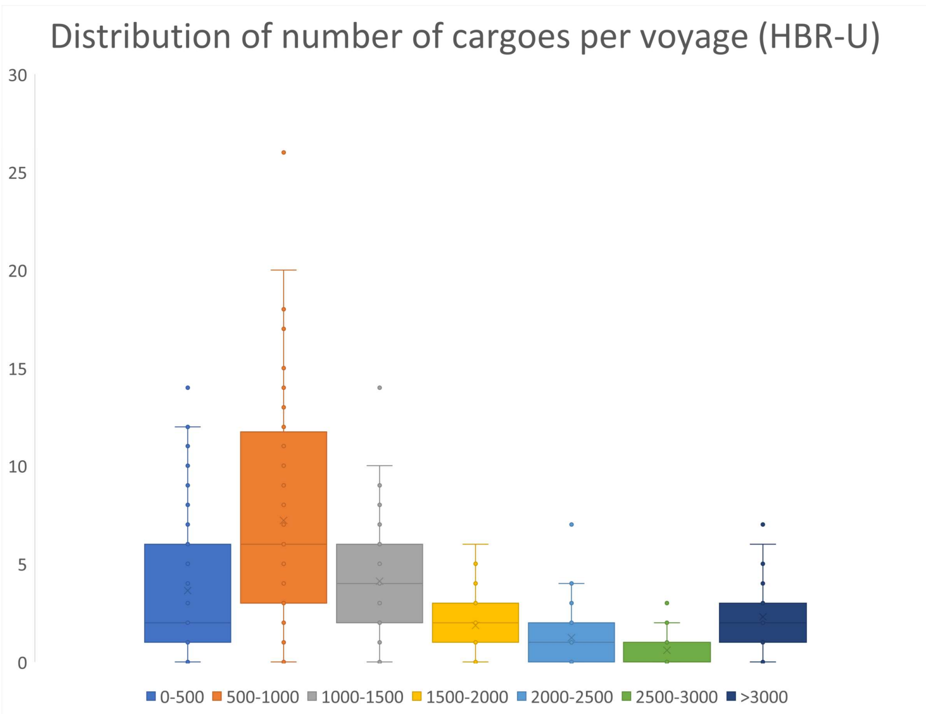



**Figure H.1.:** Distribution of the number of cargoes per voyage for the Pacific and Atlantic Service (TPW, HBR-U, TAE & TAW)
*Source:* Compiles by Julius Jansen from D37 trading data




**(a)** Trans-Atlantic West (TAW)




**(b)** Trans-Pacific East (HBR-U)

**Figure H.2.:** Distributions of the number of cargoes per voyage
*Source:* Stolt Tankers

# I. Cargo Tank Cost Study

The goal of this sub-study is to find the impact of the tank size on the cost and revenues of a cargo tank. This is a crucial step in the process to determine the relative impact of tank size choices for the profitability of a parcel tanker. The hypothesis is that a small tank has a large average cost and that the total cost will be largely determined by the cargo tank material. It must be clear that the aim of this sub-study is not to find the optimal (cost-effective) tank layout for a replacement of the D37 parcel tanker. This would require simulations and optimisation models, as will be explained in the text. This was not possible to make within the given time frame and scope of the total project. Therefore, the focus lies on finding the relation that should be considered in such a model. The findings of this study are used in the thesis as a basis for substantiation of the reasoning.

This structure of this study is as follows, the cost components for a cargo tank are determined. These components are subdivided into three components, the tank material cost, the equipment cost, and the cost of the man-hours required for the construction and installation work. The goal is to be able to determine the cost of a cargo tank relative to the size of the cargo tank (since we try to determine the relative cost-benefit of the cargo tanks relative to their volume).

## I.1. Cargo Tank Cost

For the cost function there are three factors considered that make up the cost of a cargo tank. First is the material of a cargo tank. Secondly, the cost of the equipment. And thirdly, the work to fabricate the cargo tank and install the equipment, expressed in man-hours. The total cost of a cargo tank is expressed as the sum of the three components:

$$C_{cargotank} = C_{material} + C_{man-hours} + C_{equipment} \tag{I.1}$$

### I.1.1. Tank Material Cost

The first factor is the cost of material. The cargo tank is constructed in (stainless) steel. The steel price is quoted in dollars per ton of steel. The choice was made to develop a material cost model, since available models are often complex and not developed for the use of chemical tankers. Also, the goal is to determine the cost of an individual tank and not of a complete ship, which is what many methods focus on Aalbers [27] and Hekkenberg [51].

#### Tank Area to Volume Relation

First thing is to determine the relation of the tank volume and the surface area. The surface can be related to the material volume and thus to the material cost.

Each cargo tank has a rectangular shape. The tank has a square bottom and top area ($L = B$) and a constant height. The volume of a cargo tank is thus $V = L \cdot B \cdot H = A_{bottom} \cdot H$ and the surface area of a tank is $A_s = 2 \cdot L \cdot B + 2 \cdot L \cdot H + 2 \cdot B \cdot H$. The height ($H$) is the distance from the tank top to the main deck. The double bottom structure is not counted as part of the cargo tank construction. For this study the height is considered constant at 12.5m. This is the average of the height of the cargo tanks of the C38 and C33 class parcel/chemical tanker[1]. It is assumed that all transverse and longitudinal bulkheads of the tank are corrugated. A corrugation factor is introduced that takes in to account the length of the steel plates with corrugations. The corrugation factor used in this study is $f_{corr.} = 1.3$ [m/m], this means that for each straight meter, the corrugated plate has 1.3 meter is steel. For ships with non-corrugated bulkheads or ships with longitudinal cofferdams the corrugation factor can be changed to 1 to leave out the corrugation length. No stiffeners are included in the calculations. For longitudinal cofferdams and the inner hull wall this results in an underestimation of the steel weight. However, since the inner hull is equal for all ships the stiffeners can be disregarded in the comparison.

The result of the area-to-tank volume is shown in the figure I.1. The surface area will increase with approximately the power of 0.6 of the volume. This makes sense as for a cube the relation is $A = C \cdot V^{\frac{2}{3}}$. For increasing cargo tank size, the tank surface area will increase with a decreasing rate.

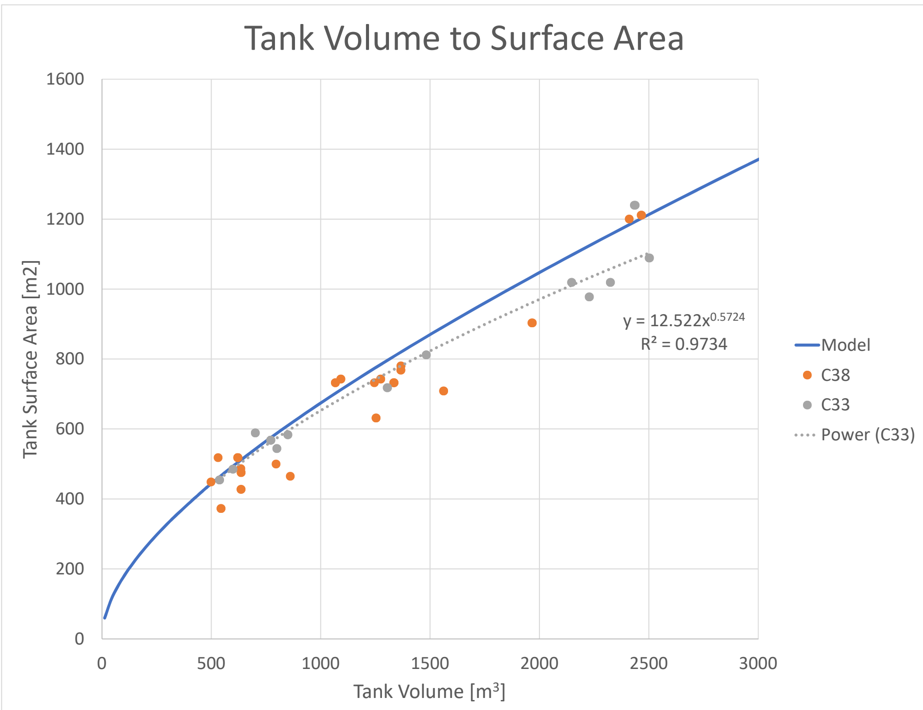



**Figure I.1.:** Tank volume to surface area, including data from C38 and C33 classes for validation
*Source:* Own contribution and C38, C33 technical drawings

Validation of the surface area-volume model is tested with the tank volumes and tank surface areas of a C38 and C33 ship. It was not possible to validate the results with the data from the D37 class ships, because these ships tank surface areas are not known (not in drawings or manuals). The results are in the table below and are plotted in figures I.1 and I.2. Figure I.2 shows a clear trend for the C33 ships, the error increases with tank size. For the C38 the error also increases but the error is more erratically distributed. Concluding, the model increasingly overestimates the tank surface area for increasing cargo volumes. The

[1]The D37 class ships where not used in this case to validate the model because for these ships no technical drawings or manuals are available with the tank surface areas.

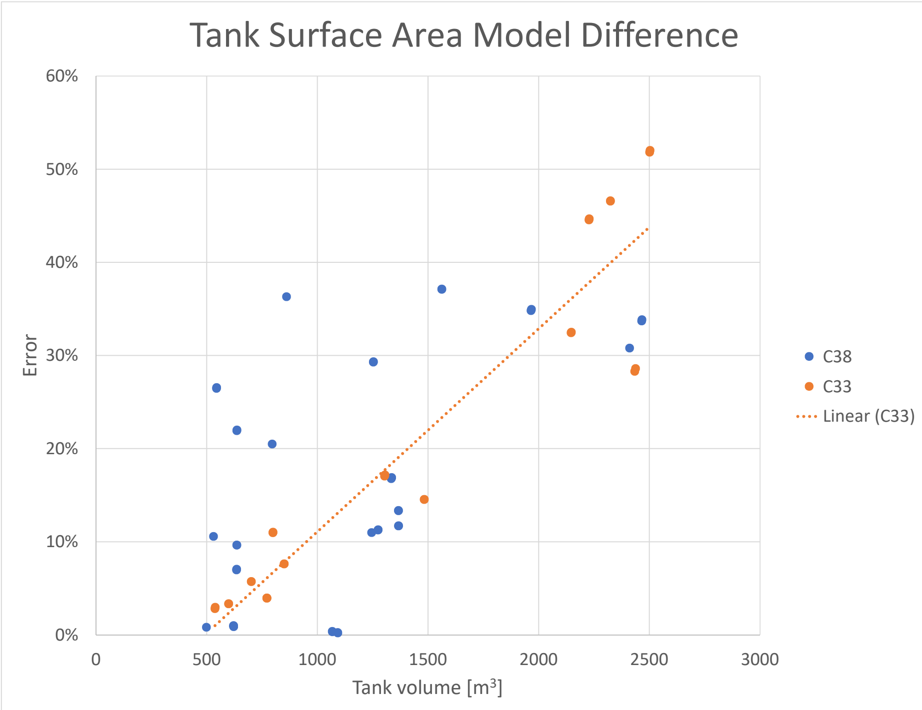



**Figure I.2.:** Cargo tank surface area model error
*Source:* Own contribution

tanks that correspond with the highest errors are located in the forward and aft part of the cargo area. The over-estimation of tank surface area is therefore most likely due to the hull shape that causes the cargo tank shapes to be not rectangular. Another factor that causes the errors is that the tanks are assumed to have a square bottom (and top). Real tanks have a rectangular bottom profile, in which one direction is longer (the longitudinal side in most cases). This longitudinal side has no corrugation while the transverse bulkhead does. The model will thus overestimate the surface area, because of the additional area by the corrugation.

### Steel Weight and Cost

In order to calculate the steel weight for one tank the tank surface area is multiplied by halve the average thickness of the bulkheads. The average is taken over the height of the tank. For example, at the tanktop side the bulkhead has a thickness of 20mm and the deck side a thickness of 12mm, the average is 16mm. This number is subsequently divided by two since each tank is sharing the bulkhead with another tank. An error that is introduced by not taking the full thickness for the bulkheads that facing the outside of the cargo area (i.e. that are not connected to another cargo tank). This error is not accounted for in the model for an individual cargo tank material cost. If the cost of an arrangement of cargo tanks is calculated this error should be corrected. For a $40,500m^3$ cargo area with dimensions $120m \cdot 27m \cdot 12.5m$ the added steel weight from the outside walls (without corrugation) accounts for 229 ton.

In the calculations a price of 4,600 USD/ton for the material is used. This number is equivalent to the 2205 duplex stainless steel price of September 2018 [52][2]. The prices of stainless

[2]Price of steel plate includes Alloy Adjustment Factor (AAF), hot rolled, annealed pickled, cutting, edge preparation, corrugation welding, and classification

steel is relatively volatile, the lowest recorded price in the last 8 years was 4,100 USD/ton and the highest 7,099 USD/ton. This means that the stainless-steel market a ship has a significant impact on the price of a stainless-steel tanker. For comparison, mild shipbuilding steel prices range between 300-1,200 USD/ton [53]. The price difference between steel and stainless steel is caused by metal elements that make stainless steel have its characteristic properties. These elements (chromium, nickel, molybdenum, manganese) come at a high price per tonne.

Figure I.3 shows the material cost for increasing tank volume for the low, current (September 2018) and high stainless-steel price scenarios. The gradient of the curve, representing the difference in material cost for a difference in tank volume, decreases with increasing tank size. A small tank requires, relative to its volume, more steel and is therefore cheaper than a larger tank.

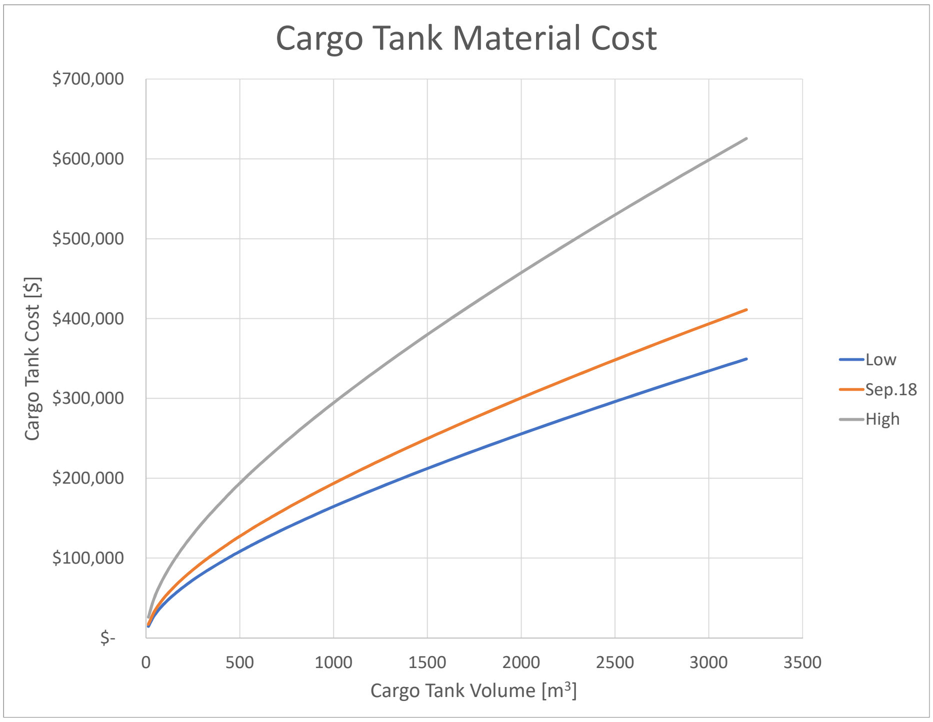



**Figure I.3.:** Cargo tank material cost
*Source:* Own contribution

### I.1.2. Man-hour Cost

The number of man-hours required to construct a stainless-steel tank are unknown, therefore it is estimated. To calculate the man-hour cost for the construction of the tank the following formula is used, see equation I.2

$$C_{man-hour} = c \cdot m \cdot W \tag{I.2}$$

Where $c$ is the cost of a man-hour, $m$ is the average number of man-hours required to work on one ton of steel, and $W$ the weight (in tonnes) of the steel in the tank. This method is limited and should only be used as a rule of thumb. However, the intent for this study is to generate a rough estimate. For the cost of a man-hour a value of 30 USD/man-hour is used, based on Stolt newbuilding experience in China. China is currently the place where most of the parcel tankers are built partly because of the low man-hour price. If a different region is used, this value must be changed according to the man-hour rate for that area since there are large differences between countries. The number of man-hours required for one ton of stainless steel is considered the same for every tank.

Two values for the man-hour per ton have been retrieved from scientific papers. The man-hours per ton required for work preparation, cutting, transport, forming of plates, assembly and welding on the results found by Leal [54] proposes a cost estimation relationship (CER) of 100 man-hours/ton. This value is proposed after studies of Portuguese shipyards that specialise in small ($< 100m$) vessels[3], which are not representative for ocean-going parcel tankers. This proposed value is multiplied with a complexity factor of 1.10 for midships sections and 1.25 for chemical tankers as proposed by Ennis et al. [55]. This gives a man-hour per ton value of 137.5 man-hour/ton for a chemical tanker.

The second paper by Kerlen [56] determines the man-hours per ton for hull construction based on the dimensions and block coefficient according to the following formula:

$$k = C \cdot 0.866 \cdot {C_b}^{-\frac{1}{3}} \cdot \left(45.36 \cdot \frac{LBD}{1000}\right)^{-0.115} + 3.5 \tag{I.3}$$

With $k$ the man-hours per ton, $C$ a factor for local situations, $C_b$ the block coefficient, and $L, B, D$ are the length, beam and depth of the ship. Using this method, the man-hours per ton is calculated with the dimensions of the D37. This results in a value of 28 man-hours per ton, no factor is included for local situations.

A Stolt newbuilding expert quoted that ship yards in China use, as a rule of thumb, 15% of the newbuilding price for labour cost. This means that for a 65 million USD parcel tanker 9.75 million USD is accounted for labour cost. The lightweight ton of such a tanker (D37 equivalent) is about 12,000 tons and the man-hour rate in China is about 30 USD/man-hour. This means that a value per ton is obtained of 27 man-hours per ton. This corresponds with the value obtained from Kerlen's method. Figure I.4 shows the man-hour cost of a cargo tank calculated with the values from the expert and the two methods.

The results show a significant difference between the method of Leal and Kerlen. Both methods have limitations for the intended use in this study. Without a better alternative, the value of 27 man-hour/ton from the newbuilding expert is chosen as it is in accordance with result from the Kerlen method.

### I.1.3. Equipment Cost

The second factor considered is the cost of the equipment that is related to an individual cargo tank. Equipment such as a cargo pump, tank cleaning machine(s) and cargo monitoring equipment is fitted for each tank. The main simplification is that the cargo equipment cost is a constant cost for all cargo tanks. This yields that all tanks have the same cargo pump, monitoring equipment and cleaning machines. The fixed cargo tank equipment cost is assumed to be $256,000 dollar based on quotations for the main cargo tank related items, see table I.1 for the included equipment. The prices of the equipment have been sourced from quotations from the latest newbuilding project[4]. While all cargo tanks all have the same basic equipment, the number, size and prices of some equipment will vary to the size of the cargo tank. The basic equipment cost excludes the cost of the cargo cooling feature, since this is not part of the basic equipment. The cargo heating is also left out of the calculation

[3] The paper contains two case studies of the construction of a fishing vessel and a hopper barge

[4] Quotations reflect the price for this specific project at a moment in time. Prices can vary considerably depending on many factors.

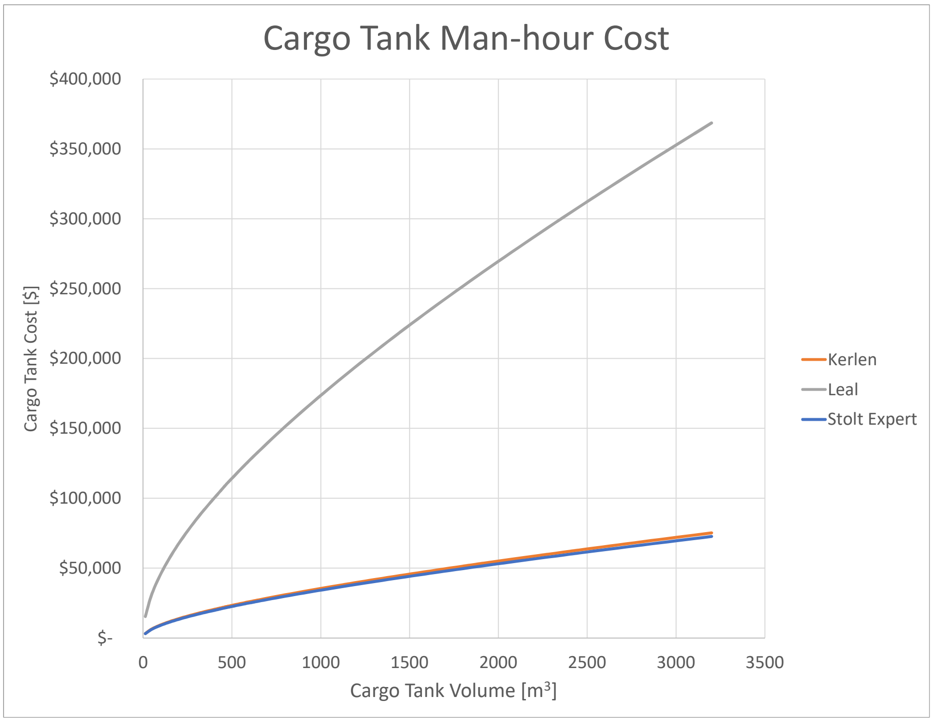



**Figure I.4.:** Man-hour cost for construction of a cargo tank
*Source:* Own contribution

since it is calculated separately in section 3.5. However, tank heating should be considered part of the of the equipment of a parcel tanker.

**Table I.1.:** Basic equipment cost per tank
*Source:* Compiled from various newbuilding project quotations

| | | |
|---|---|---|
| Cargo pumping system | 140,698 | $\tank |
| Cargo Monitoring | 6,884 | $\tank |
| Dehumidifier | 3,140 | $\tank |
| Inerting Plant | 20,000 | $\tank |
| Tank Cleaning | 14,186 | $\tank |
| Hatches (cargo + cleaning) | 18,605 | $\tank |
| Valves | 19,209 | $\tank |
| Piping | 30,233 | $\tank |
| Pressure/Vacuum Valves | 2,977 | $\tank |
| Total | 255,930 | $\tank |

Investigation of these variations found that the impact on the total distribution is relatively small. The piping systems have the same diameter independent of the size of the pump and cargo tank. The location of the tank determines the length of the piping to the manifold (and thus price), however the location of a tank is not considered in the calculation. The difference in pump sizes installed in these tankers is relatively small, and this does not yield a significant price difference[5]. Equipment such as temperature-, level gauging- and pressure sensors are the same model for all sizes of tanks. Therefore, it is concluded that the assumption of a

[5] According to a Stolt newbuilding project management expert

constant cost is appropriate for the level of detail required in this study to use for a rough estimate.

### I.1.4. Total Cargo Tank Cost

The total tank cost can now be obtained from adding the values of the three components as function of the volume of a cargo tank. The total tank cost function from equation I.1 is approximated with a third-order polynomial, see equation I.4.

$$C_{cargotank} \approx 5 \cdot 10^{-6} \cdot V^3 - 0.0363 \cdot V^2 + 203.62 \cdot V + 311657 \tag{I.4}$$

Where $V$ is the volume of a cargo tank. In a chart the functions of the all of the components look as follows, see figure I.5.

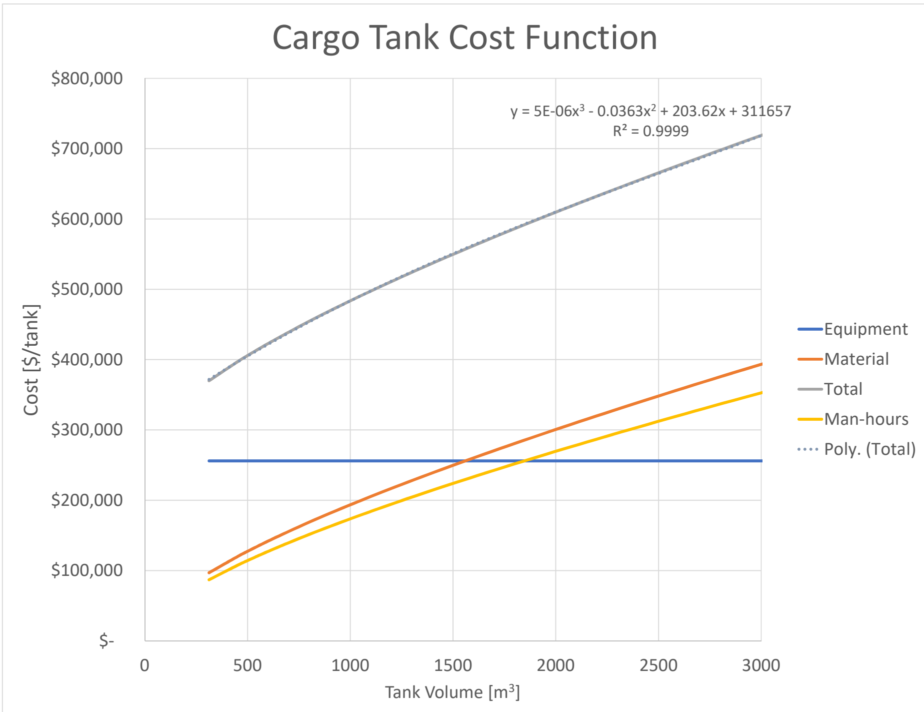



**Figure I.5.:** Cargo tank cost functions
*Source:* Own composition

The equipment cost is far more influential than the steel cost for small cargo tanks. It is presumed that these costs would be closer together, since the stainless steel is considered an expensive building material. A note must be made with regards to the equipment cost, here a value of 256,000 USD is assumed, but is assumption can be challenged as there can be a large difference in the price of components. Equipment from 'respectable' brands have a higher cost than 'low budget' products, so the difference between two different ships can be differ significantly. Stolt is known to use name branded equipment on their ships, thus this value might be on the higher end on the cost spectrum.

Figure I.6 shows the average cost of a cargo tank as function of its volume, so the cost of material and equipment per cubic meter of tank volume. The figure shows that the average cost of a cubic meter of tank space will cost less when a tank gets larger, which logically makes sense. The graph shows that the impact of the equipment cost is significantly higher than the material cost for every size tank. The value of the equipment cost determines the gradient. The higher the equipment cost the higher the delta of the average cost of small and large cargo tanks. Consider the price development in figure I.5, to investment in a two $500m^3$ tanks versus one $1,000m^3$ tank (same volume) yields a difference of 370,000 USD. The difference per cubic meter is 370 USD/$m^3$. The difference between two $1,000m^3$ tanks and a $2,000m^3$ tank is about 420,000 USD. While the absolute difference is more, the difference per cubic meter (210 USD/$m^3$) is less. This example shows that higher freight rates that are required for smaller parcel sizes in order to pay for the smaller tank.

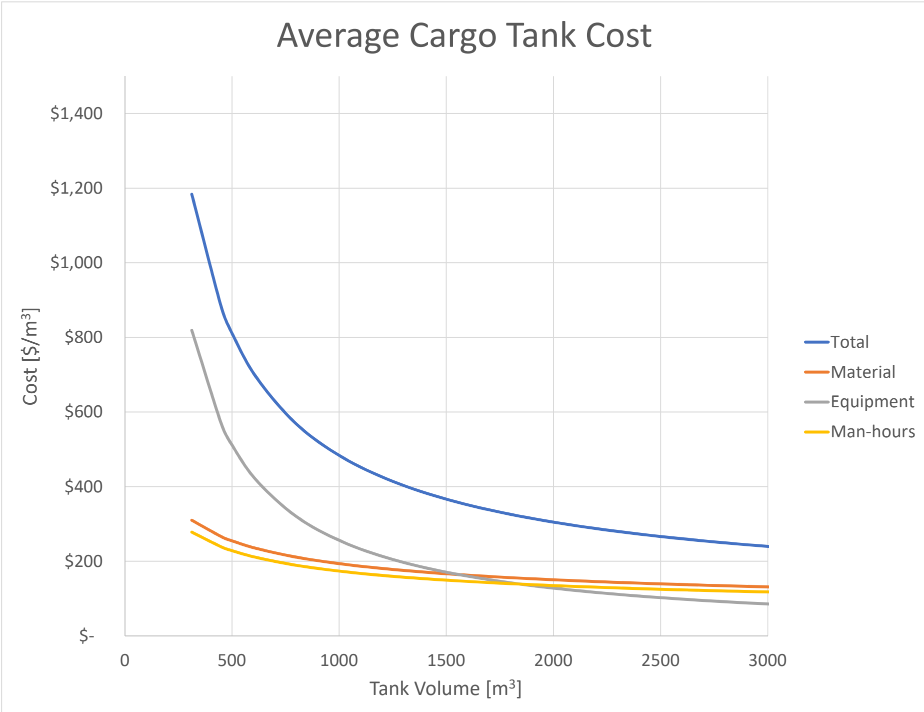



**Figure I.6.:** Average cargo tank cost
*Source:* Own composition

Since the cost price of a large tank (USD/$m^3$) is lower than a smaller tank, one expects that the freight rate of a cargo in a large quantity is also lower priced than parcels in smaller quantities. The freight rates analysed for the cargoes traded by the D37's on the Atlantic and Pacific trade lanes show indeed a correlation of declining freight rate for increasing parcel sizes. (it would be premature to say that this difference is because of the parcel size, since there are many other factors that determine the freight rate).

# J. D37 Average Freight Rates

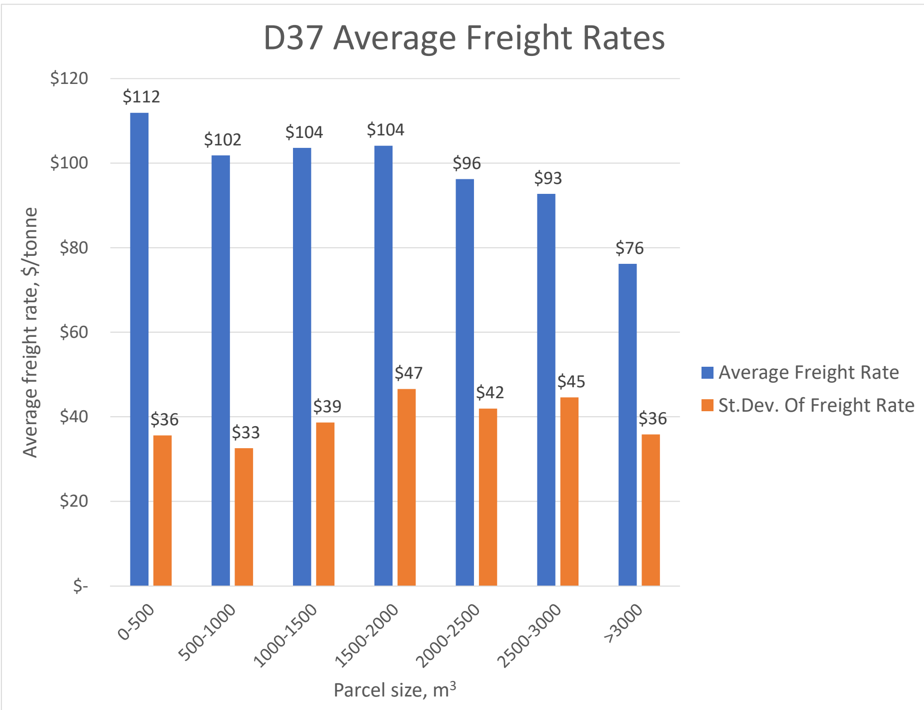



**Figure J.1.:** Average freight rate distribution of D37 parcel tanker
*Source:* Compiled from Stolt data.