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Optimizing ships‘ traveling speed for maximum voyage economic results

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Abstract

Ship fuel is the single largest budget cost on a voyage. While bunker prices and freight rates are determined by the marked and macroeconomic conditions (e.g., trade, toll barriers), there seems to be an untapped potential by actively adjusting ship speed to improve voyage economic results. This study explores the relationship between ship fuel oil consumption, ships speed and the voyage economic results for a commercial operator in the chemical parcel tanker market. Calculations on 4 different ship classes were performed using a quantitative model. The model illustrates potential bunker cost savings versus revenue win or loss, using scenario and sensitivity analysis. The results show a negative effect on the voyage economic results, by increasing ships speed from budget speed. The results also show a negative effect by traveling with low ship speeds, as the revenue loss for the lost trading days would be greater than the bunker cost savings for the commercial operator. The thesis furthermore discusses how adjusting ships speed could lead to changes in the market, using prisoner´s dilemma as framework. The dilemma shows that each player´s dominant strategy would be to increase ships speed. Possibly leading to an overcapacity on the market.

Keywords: Optimal ship speed, voyage economic results, fuel consumption, prisoner´s dilemma, Nash equilibrium

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Preface

This master thesis is a result of the two-year programme, Maritime Management, Technical specialization at the University of South-Eastern Norway. The master thesis, from this point referred to as the thesis, is based on content from the program's different courses and focus areas (e.g., Ship Operations, Maritime Economics and Research Methods). There are however some theories applied which has not been extracted from the program´s curriculum. The thesis is written in close collaboration with a shipping company in the chemical parcel tanker market, with access to privileged information. The shipping company is from this point on referred to as the commercial operator. The commercial operator wishes to be anonymous due to competitive considerations. The data presented in this thesis has therefore been anonymised, in accordance with the commercial operator's preferences.

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Chapter 1 - Introduction

Background

What does the future hold for the chemical parcel tanker market? Different shipping segments has historically been an important contribution in building up countries. Resources shipped around the world as a result of international trade, has been the very building blocks in global economic development. Leading to comparative advantages and shared resources. Being valued as necessary contribution, the shipping industry has been very profitable for the internal parties, e.g., the shipowners. Capitalizing by transporting cargo across the globe. A high yield market, e.g., a market with high profit margins, is expected to spur the flow of capital to a profitable market. Following the very nature of capitalism. The flow of capital investments will result in new players and dense competition. Which in sum will lead to oversupply and reduced profits.

The chemical parcel tanker market is currently a highly competitive market (commercial operator, 2021). In a competitive market, company management make their decisions based on expected market development. If they are optimistic about the future market conditions, they can choose to operate a ship in the spot market. Performing trades based on daily freight rates. If they expect poor market conditions, they can time charter their ships for a defined period. Giving them predictability concerning both cash flow and profitability. I.e., profit seeing opportunistic behaviour versus the need for a hedge.

If there is oversupply of excessive tonnage in a market, the best dominant strategy for the industry would be for each ship to travel with as low speed as possible (commercial operator, 2021). Creating a scenario with fewer ships available in the market to handle the demand. Thereby pushing the freight rates up. A precondition for such a scenario is that supply cannot handle the demand from the market. The strategy collapses however, if a player unexpectedly decides to increase the ship speed of his fleet. Leading to earlier arrival at berth, getting more of the market tonnage than the remaining players. And by doing so, following his own dominant strategy. This is a similar concept to what Kou & Lou described in their study regarding fleet expansion (Kou & Lou, 2016). When a player notice that one of the competitors is traveling with higher ship speed than the remaining fleet, he will likely reply by increasing ship speed. The scenario repeats itself, and as a result the market is flooded by supply. Leading to decreased freight rates and reduced revenue for each player. Making it the poorest collective outcome for the industry. This is known as the prisoner's dilemma and it is a scenario most relevant for the chemical parcel tanker market. Both national and international regulations forbid dialog between players (e.g., regarding intentions, contracts, strategy and preferred trade lines). Forcing them take measures and choose a strategy best suited for their own competitive interest (commercial operator, 2021).

What can different shipowners do in order separate themselves from their competitors? They can reduce operational expenses or increase company earnings. Operational expenses are reduced by performing e.g., underwater hull cleaning, propeller polishing, weather routing, trim optimization or performance monitoring with sensors. Weather routing is particularly interesting for many, as it does not change any physical aspects of the ships. In order to increase the company earnings, measures such as joining Shipping pools, Joint Ventures or Fixed revenue can be considered. Shipping Pools and Joint Ventures are strategic alliances with a central administration (Stopford, 2009). The purpose is to use market information in a more efficient manner. Furthermore, create mutual profit and long-term partnerships with other companies in the strategic alliance. Fixed revenue gives the shipowner protection from a declining spot market. All the measures listed above are methods available for the entire industry. Making each of them less efficient, seeing that competitors can use them as well.

Problem Statement

How can companies divide themselves from their competitors? A shipowner has access to enormous volumes of ship specific data for his fleet. Regarding fuel consumption, speed adjustments and voyage economic results. If a shipowner analyses ships speed adjustment based on macro economical changes, he can optimize the voyage economic results on voyages. Using adjusted speed settings for each designated ship as key variable. How will changing ship speed affect the voyage economic result on a voyage? In what scenario could it be strategic for the commercial operator to increase ships speed? How will a potential rise in CO_2 emissions affect the commercial operators' willingness to increase ships speed? Being a niche in the industry, it would seem larger segments (e.g., bulk, tanker or container shipping) have been selected as research topics, rather than the chemical parcel tanker market. Making available literature specific to parcel trading relatively deficient. There are however multiple studies in shipping which separately looks at game theory and speed optimization (e.g., Psaraftis 2019; Kou & Lou, 2016). Yet, none of the studies look at speed optimization from a game theoretical perspective. In order to address the industry problems described in the introduction, the following research questions have been stated:

Research question 1 (RQ1): What is the relationship between ships fuel consumption, ships speed and voyage economic results?
Research question 2 (RQ2): How could the commercial operator adjust the ships speed in order to optimize the voyage economic results?

Purpose of the study

The purpose of the research questions is to examine the effect of ships speed adjustments in assistance with a commercial operator. Using both theoretical framework and a quantitative model. The study includes both individual ships on designated voyages, and potential outcomes seen on the entire chemical parcel tanker fleet. The segment is complex, as chemical parcel tankers transport up to 50 different chemical cargos on the same voyage. Measures have therefore been taken in order to simplify both model and calculations. However, the thesis aims to be representative for chemical parcel trading. In order to predict savings for the commercial operator, privileged data has been acquired (e.g., fuel oil consumption for propulsion, CO_2 emission, auxiliary engine consumption). The data is analysed using quantitative research design. And as the study show, all the confidential data regarding specific ship classes are provided by the commercial operator. The thesis aims to look at the outcome of changing variables on short term perspective (i.e., quarterly). A quantitative theoretic model related to speed performance was welcomed by the operator, as this both served commercial and academic interest. Whether the operator chose to implement the quantitative model or adjust his strategy based on the findings, is nonetheless entirely the commercial operator's decision. Hopefully this study is a supplement to professional discussions regarding both fuel consumption and voyage economic earnings.

Nature of the study

As the thesis uses numerical data, quantitative methodology was deemed more suitable and therefore chosen rather than qualitative and mix-methods. The intention with four different ship classes was to present a representative commercial profile for the commercial operator. A quantitative methodology also allowed the quantitative model to be both constructed and tested before performing the calculations with actual data. In 2019 Psaraftis published an article looking at speed optimization vs speed reduction. Psaraftis saw speed optimization as the appropriate ship speed used on a specific objective of a voyage (Psaraftis, 2019). This thesis uses the same logic, and therefore define speed optimization as the appropriate ship speed used on a voyage to optimize the objective of the voyage. If the objective of the voyage is transport cargo from point A to point B using less fuel, the appropriate ship speed would be to travel with low ship speed. However, if the objective of the voyage is to is optimize the voyage economic result, ship speed must be considered in the context of other variables (e.g., change in number of trading days). The ship speed which corresponds to the objective of the voyage will in this thesis be called optimal ship speed. Since the chemical parcel tanker market is a niche, fundamental knowledge on parcel tanking had to be provided before creating the quantitative model. In that regard the commercial operator has been essential in providing necessary feedback and industry specific information. Having a continuous dialog using both mail and video telephone conference services.

Significance of the study

Speed optimization is a valid problem for all types of seaborne transportation. The different segments might have a few different problems and industry bottlenecks, all operators do however compare fuel costs against the value of extra trading days (commercial operator, 2021). The subject of ship speed optimization has been addressed by numerous studies (e.g., Psarraftis and Kontovas, 2014). Yet, few studies presented ship speed optimization for the chemical parcel tanker market. Acquiring more knowledge on central aspects of parcel trading is thus important. Furthermore, writing an academic thesis with data provided by the industry, can be seen as a relevant contribution to the already existing studies.

Definition of Key Terms

Voyage. A voyage is defined by the Cambridge Dictionary as a long journey by ship (Voyage, 2021).

Voyage economic result. The voyage economic result is calculated by subtracting the total amount of expenses from the total amount of revenues, generated on a voyage, performed by a ship.

Shipowner. According to the Cambridge Dictionary, a shipowner is a person or a company that owns a ship or ships (shipowner, 2021). In this study the definition is extended, as it also includes manages and bears the economic risk of the ship.

Charterer. Known as a person or a company who hires a ship from the shipowner over a specific period of time (Stopford, 2009). In this study the commercial operator mostly uses time charter, where the charterer has a transportation contract which allows the charterer to use the ship for a specific period (Stopford, 2009). In the chemical parcel tanker market companies often time charter other ships, believing they can profit from operating the ship relative to what they are paying in daily hire rate (Commercial operator, 2021).

Commercial operator. In order to anonymize the collaborating shipping company in this thesis, commercial operator has been defined as the appropriate term. The commercial operator owns, leases (e.g., bareboat, financial and operational) and time charterers ships in the chemical parcel tanker market.

Scenario. The term scenario is used in the context of scenario analysis, adopted by Herman Kahn (Stopford, 2009). Scenario is defined as hypothetical sequences of events through which possible future developments are made visible (Gausemeier, Fink & Schlake, 1998). Scenarios can be long term prospects, or standard deviations of daily or monthly profit returns (Hays, 2021). In this thesis, the scenarios are used in a quarterly time perspective, with changing variables (e.g., standard deviation of expected bunker prices and daily hire revenue).

Quantitative model. The term quantitative model is defined as a simplified representation of the reality, using a set of variables and their causal relationship (Brandenburg, Govindan, Sarkis & Seuring, 2014).

Shipbrokers. Shipbrokers are defined by Stopford as individuals with current market knowledge, acting as intermediary between shipowners, charterers and buyers (Stopford, 2009). The brokers get percentages in commission, based on the transaction they are accountable for (Stopford, 2009).

Thesis Structure

The Master Thesis follows the IMRAD structure (Introduction, Methodology, Results and Discussion), where the remaining chapters have the following structure: Chapter 2, Literature review, presenting necessary theory, models and earlier studies regarding maritime economics and the shipping industry. Chapter 3, Research methodology, presents the collaboration with the commercial operator, followed by a description of methods used to analysis the provided data. Chapter 4, presents the results from the calculations performed in the quantitative model, based on fuel consumption data, bunker prices and market fluctuation. Followed by a sensitivity and scenario analysis. Chapter 5 is the academic discussion and elaboration of limitations with the study. The thesis is concluded with Chapter 6, concluding the study, answering the research question and looking at potential future work on similar subjects of the study.

Chapter 2 - Literature review

The thesis combines literature taught on the master programme (e.g., ship operations, maritime economics and research method) with published article and studies relevant to the research questions. The literature review is divided into different subchapters, starting with a short presentation of the goal for the review, followed by methods used finding selected literature. The main part of chapter 2 is however the reviewed literature, which is divided into two parts. The first part presents the chemical parcel tanker market and theoretical framework used in the thesis. The second part review different studies and theories relevant to both game theory and ship speed optimization.

Goal(s) for the review

The goal of the literature review is to explore the assumptions made in the introduction of the thesis. Furthermore, investigate existing ideas and solutions similar to the research questions. There are as mentioned in chapter 1, a limited number of studies published on chemical parcel trading. A clear goal for the review was therefore to find a theoretical framework and studies from other shipping segments, suitable for the chemical parcel tanker market.

Method for finding and selecting literature

In the literature search, the following keywords have been used: chemical tanker, freight rates, prisoner’s dilemma, game theory, fuel consumption, forecasting, Nash equilibrium in shipping, parcel trading and speed optimization. The literature search started wide-ranging, reviewing the entire shipping industry e.g., Maritime economics 3rd edition (Stopford, 2009). As time working with the thesis progressed, the literature search became increasingly specific. Knowing what to search for in each study. The majority of studies used in the literature review has been provided by The University in Southeast Norway's search engine and overall library database. The remaining definitions and articles were collected using the search engine google.

Reviewed literature

To understand the fundamental mechanisms in the chemical parcel tanker market, it is important to elaborate who the different players are and how they interact with each other. Furthermore, how domestic and international variables affect supply and demand in a competitive market.

Firstly, what is the chemical parcel tanker market? Shipping is divided into different commodities of trade (e.g., crude oil, iron, sugar, soya beans and cement). These commodities are transported by different segments, such as bulk shipping, container shipping and specialized shipping (Stopford, 2009). The chemical parcel tanker market is a sub-industry that falls under specialized shipping, as chemical parcel tankers transport chemicals from terminal A to terminal B. The chemical parcels are often small, carried in several segregated thanks with separate pump and cargo lining for each tank (Stopford, 2009). The volume of cargo transported depends on supply and demand. Demand and supply dynamics are historically influenced by different variables. In general, the following five variables are known to have the most affect: the world economy, Seaborne commodity trade, average haul, random shocks and transport costs (Stopford, 2009). The market of chemical transportation is also affected by these variables. However, unit prices for liquid chemicals, often turn out to be the governing factor in parcel trading (commercial operator, 2021). And as the market is homogenous (i.e., products traded in the market are more or less the same), the relative elasticity of the traded products are limited.

What do they trade in the chemical parcel tanker market? In chemical shipping the traded liquid chemicals are divided into four main groups: organic chemicals, inorganic chemicals, vegetable oils and molasses (Stopford, 2009). Organic chemicals are also known as petrochemicals. They contain carbon and are made from crude oil, natural gas or coal. The industry separates organic chemicals into two groups, olefins including ethylene, propylene, butadiene and aromatics which include benzene, toluene, xylene and styrene (Stopford, 2009). Inorganic chemical does not contain any carbon. The most common inorganic elements are phosphoric acid, sulphuric acid and caustic soda, all made by combining chemical elements (Stopford, 2009). Vegetable oils are contracted from seeds and are mainly used for industrial purposes. Molasses is a thick brown syrup and is a by-product of the sugar refining operations (Stopford, 2009). The different chemical groups mentioned above are used in a variation of industries, e.g., food and pharmaceutical industry. The segregated tanks used during transportation are therefore meticulously cleaned between voyages (Stopford, 2009). Time used cleaning the tanks is reflected in the freight rate for that particular chemical.

Sophisticated chemical tankers carry up towards 400-6000 parcels between industrial plants, per annum (Stopford, 2009). Because of different parcels of specialized liquefied cargo on a voyage, the tankers are constructed with many parcel tanks and special coatings. In 2006, the world chemical tanker fleet consisted of 1015 chemical tankers with an average size of 15,000 dwt (Stopford, 2009). According to Marinetraffic, the world chemical tanker fleet consists of 1020 chemical tankers per 01 May 2021 (Marinetraffic, 2021). However, the commercial operator assesses only 481 of the 1020 are competitors in the chemical parcel tanker market. Their capacity varies, with larger ships having over 75 % of the tanks segregated and average tanks size above 2700 m3 (Stopford, 2009). In order to describe how many of the tanks are filled with cargo at a given time, the industry uses the term deadweight utilization. The term describes to what degree the tanker is traveling with a full payload of cargo. It is a measurement of fleet productivity, used in all segments of shipping (Stopford, 2009). Deadweight utilization is calculated by dividing the volume of cargo with the ship cargo capacity. If a chemical tanker carries 15.000 tonnes, but the physical maximum is 30.000 tonnes, the ship is 50% utilized. To what degree a shipowner wants to utilize his fleet depends on the freight rates. If the calculations show TCE below breakeven, the shipowner would rather perform the voyage 50% utilized than stop for another cargo enroute. If the cost outweighs the income, the incentive for being fully utilized is removed. Shifting to another terminal in order to lift a sport cargo, would in this scenario only have a negative impact on the voyage economic result.

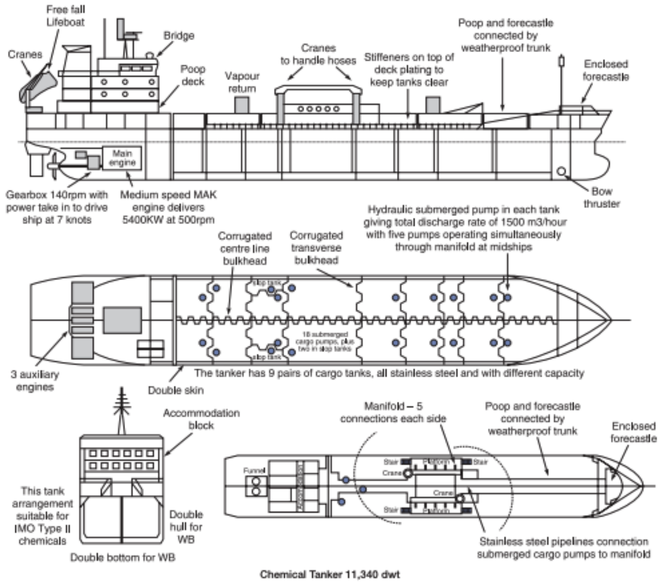


Figure 1: Drawing by Martin Stopford of an 11.000 dwt chemical parcel tanker (Stopford, 2009). The ship has a similar construct to ship A, B, C and D used in the thesis.

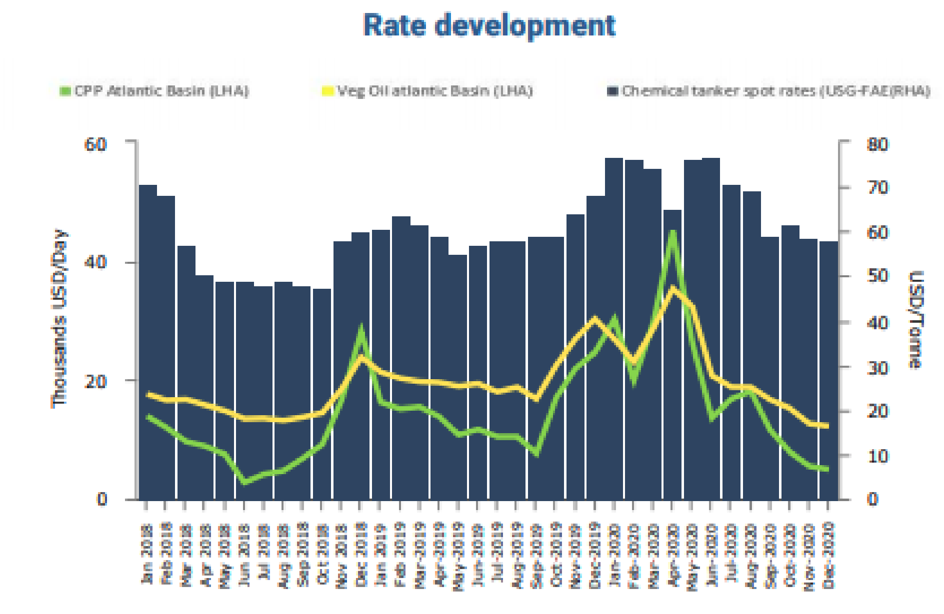
If a tanker is 100% utilized, it will have increased draught and displacement compared lower percentages, Affecting the ship´s fuel consumption. In 2016 Bialystocki and Konovessis published a study where they looked at how major factors such as draught, displacement and weather force affected the accurate fuel consumption and the speed curve (Bialystocki & Konovessis, 2016). In their study the authors used the Admiralty coefficient, which describe the relationship between ship speed, actual draught and the power supplied by the engine (ibid). The Admiralty coefficient is calculated using the following equation:

$$\mathrm{Ac} = \frac{(\mathrm{D2} - \mathrm{D1})^{\frac{2}{3}} \times \mathrm{V}^3}{P}$$

Equation 1: The admiralty coefficient, used on page 36

Where (D2-D1) is the change in displacement, V is ship speed, and P is the engine break power (ibid). By using the admiralty coefficient equation, is it possible to adjust ship speed and calculate the required engine break power, i.e., the fuel consumption for the new ship speed. The Admiralty coefficient is relevant to this study, as it describes the relationship between ship speed and fuel consumption.

In order to cover voyage expenses e.g., bunker costs, the commercial operator receives economic compensation for the affreightment. The value of the compensation is determined by the freight rates, which is directly linked to relative supply versus demand and availability. Which include chemicals in the processing industry, natural resources and restricted number of refineries that can distil the chemicals (commercial operator, 2021). Freight rate is the total amount of economic compensation for the affreightment. Paid to the company operating the ship, carrying each unit of cargo between load port and discharge port (Stopford, 2009). The unit of cargo is defined as tonne, converted into dollars per day. Giving an operational overview of the revenue on the specific voyage. The freight rates work as an interaction between cargo owner and shipowner, as they both bid on each other. The cargo owner bids on ships to transport his cargo, while the shipowner bids on available cargo he can transport. In a perfect competitive market, the shipowner maximizes his profit by traveling with ship speed at marginal cost equal to the freight rate. This is however nearly impossible, as freight rates fluctuate over time.



Source: Clarksons Platou

Figure 2: Rate development, chemical tanker spot rates (Odfjell, 2021).

Figure 2 shows a time period stretching from January 2018 until December 2020, with a clear drop for both CPP and vegetable oil spot rates in the end of Q1 2020. Even though the chemical tanker market was affected by the global pandemic, COVID-19, the rates were still higher than in June 2018. It is important to notice that even though the CPP rates were below $10, the average chemical tanker spot rates were just below $60 in the same period.

Shipowners transport several parcels of chemical cargo on the same voyage. Each of the parcels could have different freight rates, affecting the average chemical tanker spot rate (commercial operator, 2021).

If a shipowner assesses the freight rates in the spot market to be too unpredictable, measures can be taken in order to provide fixed income. Contracts of affreightment, (from now called COA) is a contract which commits a shipowner to carry a series of cargo parcels for an agreed price per tonne (Stopford, 2009). E.g., a shipowner is on a contract committing him to transport 10 consignments of 10.000 tonnes chemicals from Houston to Rotterdam over a three-month interval. The shipowner can with the commitment plan the use of the ships in an efficient manner, knowing he has fixed income on transatlantic voyages over the next three months. Contracts of affreightment are often entered for 12 or 24 months at a time. For the shipowner it is a question of a well-balanced hedge. If the shipowner bet on the spot market to maximize earnings, he shows profit seeking behaviour. However, COA gives the shipowner predictability, but he will miss highs and lows in the spot market.

A measurement often used to calculate earnings for the shipowner is Time charterer equivalent (from now called TCE). It is an important measurement in shipping as it converts the spot freight rate into a daily hire rate for a specific voyage (Stopford, 2009). In order to calculate the daily hire rate, first subtract the voyage costs from the gross revenue (freight) and then divide the difference with the total number of days used on the voyage.

$$TCE = \frac{Gross\ revenue - Voyage\ costs}{Days\ used\ on\ the\ voyage}$$

Equation 2: TCE calculations, used in chapter 4, page 43

Voyage costs include fuel, port, tolls and canal expenses. TCE is used across the industry and is just as relevant for operators transporting crude oil as bulk ore. In this thesis, TCE is a central variable. There can be several reasons for high TCE. If increased demand drives the freight rates up, the TCE will increase. Another reason might be low bunker prices. Since the daily hire for a voyage include deducting voyage costs, low bunker prices will increase the daily hire rate. However, since the quantitative model in this thesis compares TCE and historical bunker prices, variation in TCE comes as a result of fluctuating freight rates.

In a study published by Wilmsmeier and Hoffmanin in 2008, operating cost is presented using a point diagram. The study looks at the correlation between liner shipping connectivity and intra-Caribbean freight rates. Figure 3 presents the association between freight rate (in USD) and transit time (in days), in the context of the Caribbean. The freight rate outcome is a function of the transit time on the voyage. The coefficients shown in figure 3 describe the freight rate as a function of transit time. If transit time increase by one day, the freight rate increases by 55.796 (x = days). The constant 904.6 is the starting point coefficient, i.e., average freight rate, regardless of the time. R^2 is the determination coefficient, explaining how variations in one variable can be explained by the variation in the independent variable. The freight rate is explained by 29,8 percentage of using the transit time as an independent variable. As 29,8 percentage is explained, the remaining 70,2 percentage is not explained. The figure gives a good representation of the operating costs, as the freight rates increase significantly as a function of transit time.

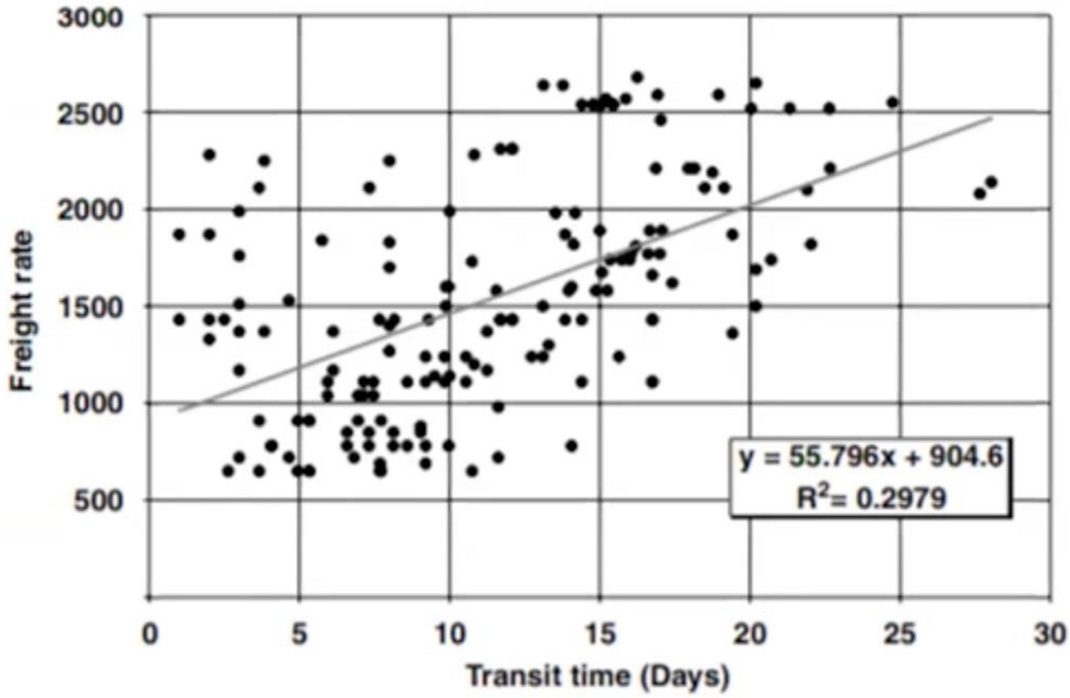


Figure 3: Correlation between freight rates and transit time, equal to voyage time (Wilmsmeier&Hoffmann, 2008)

The second part of the literature review present studies and theories relevant to ship speed optimization and game theory. An important part of this study is looking at how possible increase in CO_2 emissions influence the commercial operator´s decision. The next paragraphs therefore present both regulations and studies concerning greenhouse emission.

The governing agency of international shipping is named The International Maritime Organization (from now called IMO). IMO is a specialized agency of the United Nations and responsible for safety, security and prevention pollution from ships. As of 2018 IMO intensified their global fight against climate change by introducing mandatory measures to reduce greenhouse gas emissions (from now called GHG) from international shipping (IMO, 2021). The strategy was constructed in collaboration with the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). The strategy affects the majority of international shipping, as minimum 40% of the CO_2 emissions are to be reduced by 2030. Furthermore, 70% by 2050, compared to the levels emitted from international shipping in 2008 (IMO, 2021). Several organizations have adopted IMO´s policies. On 7 October 2020, Sea Cargo Charter was launched (Sea cargo charter, 2021). Sea Cargo Charter provides a framework for evaluating the climate alignment of ship chartering activities all over the world (Sea Cargo Charter, 2021). They are consistent with IMO´s policies and try to incentivize shipping´s decarbonization. In order to measure the voyage´s true carbon intensity Sea Cargo Charter wants the shipping industry to measure performance in real operating conditions (e.g., following Energy Efficiency Operating Indicator (EEOI)). EEOI can be beneficial, as it does not distinguish between shipowner and charterer. Including the volume of transported cargo into the equation (Sea Cargo Charter, 2021). Increased attention towards emission is also affecting the players in the industry. As the commercial operator see a rising number of cargo owners are requesting emission records to be shared when performing a trade (commercial operator, 2021). Carbon intensity on a voyage is calculated using the following equation:

$$X = \frac{CO2\ emission}{Volume\ of\ cargo * \ distance\ of\ voyage}$$

Equation 3: Voyage carbon intensity, using EEOI. Used on page 36

In the equation, CO_2 emission are calculated by multiplying the fuel consumption with the emission factor for each type of fuel.

IMO is furthermore divided into different convention, one of which is the International Convention for the Prevention of Pollution from Ships (from now called MARPOL) (IMO, 2021). In 2005 MARPOL implemented regulations limiting the maximum Sulphur content used in fuel in different areas (Fagerholt, Gusel, Rakke & Psaraftis, 2014). The areas are called emission control area (from now called ECA). When sailing inside of ECAs, shipowner must use fuel with maximum sulphur content of 0,1 percentage. While outside of ECAs, shipowners are allowed to use maximum sulphur content of 0,5 percentage. There are multiple emission control areas worldwide. The extra cost for a shipowner switching to low sulphur fuel e.g., low sulphur marine gas oil (LSMGO), on a voyage can be between $10.000 and $100.000. Depending on the size of the ship and the length of the voyage. In order reduce bunker costs, it is an important aspect looking at alternative sailing routes, reducing ECA exposure. In an article published by CRIStin NTNU, Fagerholt, Gusel, Rakke & Psaraftis performed a computational study on different sailing routes. Looking at fuel consumption, fuel prices and distance in and outside of ECA zones. Their study showed that the ship operators often would sail a longer distance to avoid or reduce ECA exposure (Fagerholt et al., 2014). Furthermore, sail at lower speeds inside of ECA zones, and higher speeds outside of ECA due to more expensive fuel. In some shipping routes the total amount of SO_x emissions could even increase, if the price difference between MGO and HFO was substantial. Making it more profitable for the ship owners to sail a longer route in order to avoid ECA. Their findings therefore go against the basic intention of ECA, mainly reducing sulphur emissions.

In a study performed by Psaraftis and Kontovas in 2014, the authors looked at the main parameters for ship speed decisions at an operational level. They discovered that different variables play a crucial part when modelling optimized ship speed (e.g., fuel prices, freight rate, inventory cost of cargo and dependency of fuel consumption on payload). Furthermore, they saw that an optimal environmental performance is not necessarily the same as an optimal economic performance (Psaraftis, Kontovas, 2014). Since a ship operator would preferably choose the optimal economic performance, the shipowner loses its incentive to reduce CO_2 emissions. Psaraftis published an additional study in 2019, looking at speed optimization vs speed reduction. The purpose of this study was to examine whether reducing speed by imposing a speed limit was a better solution than doing the same by imposing a bunker level (Psaraftis, 2019). In the study, Psaraftis argues that a specific ship speed may discriminate some ship types due to the size of the ships. Furthermore, a speed limit in changing market periods could create different sorts of distortion. Speed limits would also benefit shipowners as a direct result of low speeds is reduced transport capacity. Forcing the freight rates to go up. However, Psaraftis concluded his paper saying that a speed limit option exhibits several deficiencies as a method to reduce GHG emissions. Furthermore, owners of energy efficient ships would benefit from a speed limit, forcing competitors to sail at the same reduced speed as they do. After the paper was published in 2019, IMO held a meeting where they failed to adopt speed reduction measures, despite environmental benefits (Bannon, 2019).

The remaining part of the chapter reviews the subject game theory. Presenting both concept and a relevant study from the shipping industry. Game theory is a mathematical concept developed by John von Neumann, which analyses situations where different participants must choose between a string of alternatives (Vatne, 2019). The participants decision is based both individual preferences and knowledge regarding the remaining participants preferences and options. A key concept of game theory is Nash equilibrium, published by John Forbes Nash Jr. in 1951 (Nash equilibrium, 2021). In Nash equilibrium players try to optimize the outcome, based on the remaining players expected decision (Chen, 2021). The optimal outcome of a game or a situation occurs when the players have no incentive to deviate from their initial strategy (Chen, 2021). Nash equilibrium appears in a situation if none of the players wants to change their initial strategy after discovering the competing players chosen strategy (Chen, 2021).

A common situation in game theory is the prisoner´s dilemma, first published by Merrill Flood and Melvin Dresher in 1950 (Prisoner´s dilemma, 2021). The prisoner´s dilemma describes a situation where two criminals are separated and arrested for a crime. The length of the imprisonment depends on what each of them confesses to the police. The scenario is relevant to parcel tanking as it looks at how a dominant strategy with limited information can give the optimal outcome for a player. No matter the opposing players chosen strategy (Sætra, 2021). As described in chapter 1, both national and international regulations forbid dialog between players (e.g., regarding intentions, contracts, strategy and preferred trade lines). The dominant strategy for a shipowner would therefore be to always increase ship speed. If the competing fleet stays on slow ship speed, the shipowner will grasp more of the market, as increased speed leads to additional trading days. If the competing fleet also increases ship speed, the shipowner will at least have the same ship speed, not losing position to the competing fleet. The shipowner will only lose by staying on slow ship speed.

In 2016 Kou and Lou published an article where they studied the collective consequences of individual optimal behaviour in a competitive market. Where they performed a numerical simulation on a market with two competing shipping companies (Kou, Lou, 2016). In their study they used known market freight rate and market demand. This assumption allowed them to focus on the impact of individual capacity expansion. The companies had incentives to adjust their ships speed, depending on the different incremental freight rates and market demand. By using Nash equilibrium and Prisoner´s Dilemma, Kou and Lou discovered that individual optimal behaviour from both players would lead to an overcapacity in the market. (Kou, Lou, 2016). As for a good market, capacity expansion would initially lead a constant competition for shares. And as the market changed, both players would ultimately end up with negative profits. Figure 4 shows how expansion from both players affects the optimal speed in a market with decreasing freight rates. When the freight rates are at $100/tonne it does not matter if both players expand (v_{11}). However, if the freight rates drop, optimal ship speed goes down for all three scenarios. Scenario V_{00} is the last scenario to hit minimum speed, as none of the players expand. The study also showed that the Prisoner´s Dilemma will occur in both good and bad market conditions. If only one company expands in a good market, the profit will increase for the respective company. However, the remaining company is expected to respond as his competitor increases market position. Both companies can enjoy some incremental benefit from the competing company´s expansion. The problem occurs however, if the two companies continue to expand until excessive capacity puts the industry in a poor situation (Kou, Lou, 2016). See figure below, Nash Equilibrium occurs at both good and mediocre market condition.

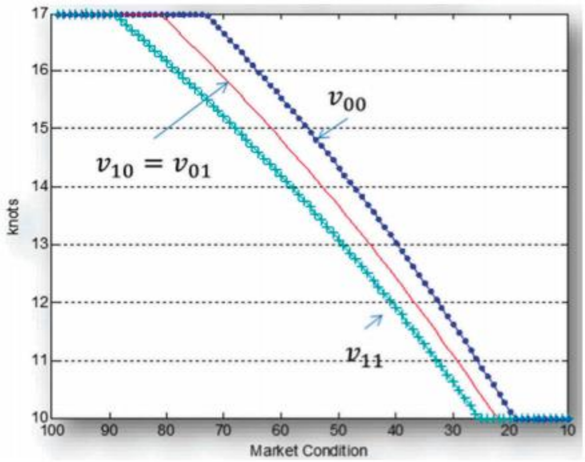


Figure 4: Development in a declined market (Kou&Lou, 2016)

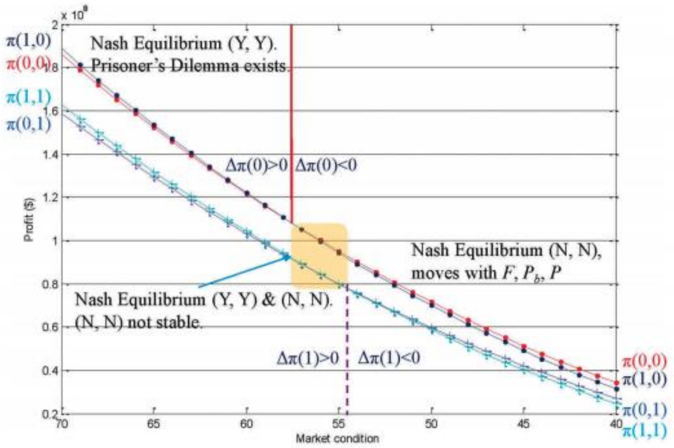


Figure 5: Optimal speed in decreasing market (Kou&Lou, 2016)

Chapter 3 - Research method

General introduction

The data collection in this thesis has been limited to a quantitative method, including fuel consumption (e.g., propulsion inside and outside of ECA, auxiliary group and in port). The bunker costs have been calculated using bunker prices in Rotterdam at a specific time (26.03.2021). The analysis compares different scenarios, with fluctuating TCE and bunker prices, ranging from low to high. The data is collected for different ships actual performance. Using data produced on Sea Trials, adjusted with a sea margin. Giving each ship class a realistic operational profile.

Research design

The research design of the study is inductive reasoning, as observations are analysed and connected to relevant theories. It is a quantitative research, with narrow research questions. Empirically investigating the quantitative properties and their relationships. The phrasing of RQ1 and RQ2 are meant to cover multiple ships, as the study compares variables for ship class A, B, C and D. The variables have been collected numerical and analysed with a both sensitivity and scenario analysis, looking at correlation, regression and deviations of the categorical data.

The collaboration with the commercial operator started midsummer 2020. The commercial operator suggested on an early stage to develop a quantitative model, looking at adjusted bunker costs up towards TCE results. Establishing the foundation of the thesis, and what was later developed into RQ1 and RQ2. In order to provide the necessary knowledge, the commercial operator arranged several initial meetings e.g., with shipbrokers in order to understand how voyage economic results are calculated. Furthermore, provided essential background information regarding all the data collected in this study. The commercial operator has also been a central advisor through the entire process, as multiple terms, calculations and scenarios have been discussed.

The data provided by the commercial operator regarding ship speed and propulsion, with corresponding fuel oil consumption is data retrieved from different Sea Trails. Undergoing sea trails is a requirement from the different classification societies (e.g., DNV GL), for all new ships in order to be commissioned (DNV GL, 2012). Sea Trails cover the effect of wind, sea, draught and trim within a BF scale 5. BF stands for Beaufort Wind Scale and is a numeric presentation of wind speed at sea (Ship Inspection, 2021). Scale 5 is defined as Fresh breeze, with 17-21 knots. The measurements performed during a Sea trail are all based on ISO certified methods, e.g., ISO 15016:2015 which determine ship’s performance in terms of ship´s speed, power and propeller shaft (ISO, 2015). The speed tests are performed using minimum 3 different configurations of power, within a reasonable operational speed range (Singh, 2021). When executing the test, ship speed is measured using GPS. Followed by plotting the 3 configurations of power, in order to give a speed-power curve (Singh, 2021). The main purpose of sea trails is to give realistic data, which represent the actual performance of the ship.

As the ship specific data is sensitive information, it was from an early stage necessary to sign an Agreement of Confidentiality. The agreement stated that all information (e.g., technical, commercial, economic information, strategies) are to be considered confidential. Using privileged information in the study has its advantages, e.g., new data unavailable to others. Furthermore, having a reference who works in parcel trading has exclusively been beneficial. Giving unique insight to industry challenges, unwritten about in published literature. However, as the study is being published, extensive work has been performed in order to anonymize both the commercial operator and the ships used in the study.

Data collection method

The majority of data used in the quantitative model has been collected directly from the commercial operator. Firstly, speed and fuel oil consumption estimates represent four different ship classes. The four ship classes have different deadweight tonnage and are normally used for different types of trades, thereby representing a realistic operational profile. The commercial operator´s fleet is also substitutable (commercial operator, 2021). I.e., ships within the same class, using the same type of equipment, can switch position. If a ship is planned on a voyage, but due to technical or operational limitations, such as machinery breakdown, is unable to perform the voyage. It can be replaced by a ship currently in the area, with available cargo capacity. Allowing the commercial operator change position without missing out of a shipment opportunity.

The ship specific data is a complete overview of ship speed and propulsion, with the corresponding fuel oil consumption. The overview is adjusted with a sea margin to incorporate the effect of expected weather factor up to BF 5. The sea margin will vary based on the design of the ship, i.e., new hull design will be affected differently than traditional design. Sea margin is normally set to 15 % added power. However, in this study the sea margin is equal to the actual performance of the ships over the last six months. The data retrieved from the Sea Trails is also adjusted for actual performance (Commercial operator, 2021). The actual performance is limited to calm seas, as it is defined in the charterparty. The charter party refer to maximum BF. In areas above the defined maximum BF scale, the ship has no warranty (Commercial operator, 2021). There are multiple factors which can affect a ship´s performance over defined time period, e.g., adverse currents or heavy sea state. Ships may even be exposed wind and sea conditions above BF 5 during a voyage. This would however be exceptions, which cannot be used when trying to forecast daily average fuel consumption. The data provided by commercial operator in this study is therefore their ship specific assumption over time. Given a hull in good condition with smooth-running engines.

In the table 1, ship speed is presented under the column v (velocity). Ship speed is calculated using speed over ground and is measured in knots. Each row represents one day of 24 hours with propulsion. If ship C travels with a ship speed of 10,6 kts, the main engine produces 1851 kW at 83,2 RPM. The ship will consume 12,8 tonnes of fuel oil per day. The actual performance presented in the table 1 gives a realistic operational profile for the specific ship class. The Actual Performance does however only present the ships fuel oil consumption regarding speed and propulsion. It does not comprehend the Auxiliary Engine of the ships.

Table 1: Actual Performance, fuel oil consumption ship C (Commercial operator, 2021)

Actual Performance (Calm Weather)			
V	**P_B**	**RPM**	**FOC**
10,6 kts	2851 kW	83,2	12,8 tpd
10,7 kts	2865 kW	83,2	12,9 tpd
10,8 kts	2884 kW	83,3	12,9 tpd
10,9 kts	2906 kW	83,4	13,0 tpd
11,0 kts	2932 kW	83,5	13,1 tpd
11,1 kts	2963 kW	83,6	13,2 tpd
11,2 kts	2997 kW	83,8	13,3 tpd
11,3 kts	3036 kW	83,9	13,5 tpd
11,4 kts	3078 kW	84,1	13,6 tpd
11,5 kts	3125 kW	84,3	13,8 tpd
11,6 kts	3175 kW	84,5	14,0 tpd
11,7 kts	3230 kW	84,8	14,2 tpd
11,8 kts	3289 kW	85,0	14,4 tpd
11,9 kts	3352 kW	85,3	14,6 tpd
12,0 kts	3418 kW	85,6	14,9 tpd
12,1 kts	3489 kW	85,9	15,1 tpd
12,2 kts	3564 kW	86,2	15,4 tpd
12,3 kts	3643 kW	86,5	15,7 tpd
12,4 kts	3726 kW	86,9	16,0 tpd
12,5 kts	3813 kW	87,3	16,3 tpd
12,6 kts	3904 kW	87,7	16,6 tpd
12,7 kts	3999 kW	88,1	17,0 tpd
12,8 kts	4098 kW	88,5	17,4 tpd
12,9 kts	4201 kW	89,0	17,8 tpd
13,0 kts	4308 kW	89,4	18,2 tpd
13,1 kts	4420 kW	90,0	18,6 tpd
13,2 kts	4535 kW	90,5	19,1 tpd
13,3 kts	4654 kW	91,0	19,5 tpd
13,4 kts	4778 kW	91,6	20,0 tpd
13,5 kts	4905 kW	92,2	20,5 tpd
13,6 kts	5036 kW	92,8	21,1 tpd
13,7 kts	5172 kW	93,5	21,6 tpd
13,8 kts	5311 kW	94,1	22,2 tpd
13,9 kts	5455 kW	94,8	22,8 tpd
14,0 kts	5603 kW	95,6	23,4 tpd
14,1 kts	5754 kW	96,3	24,1 tpd
14,2 kts	5910 kW	97,1	24,7 tpd
14,3 kts	6070 kW	97,9	25,4 tpd
14,4 kts	6233 kW	98,7	26,1 tpd
14,5 kts	6401 kW	99,6	26,8 tpd
14,6 kts	6573 kW	100,4	27,6 tpd
14,7 kts	6749 kW	101,3	28,3 tpd
14,8 kts	6929 kW	102,2	29,1 tpd

14,9 kts	7113 kW	103,1	29,9 tpd
15,0 kts	7301 kW	104,0	30,6 tpd
15,1 kts	7493 kW	104,9	31,4 tpd
15,2 kts	7689 kW	105,8	32,2 tpd
15,3 kts	7889 kW	106,7	32,9 tpd
15,4 kts	8093 kW	107,5	33,6 tpd
15,5 kts	8302 kW	108,3	34,3 tpd

In the quantitative model, the fuel oil consumption is compared to TCE. The TCE range for the different ships were also obtained from the commercial operator. The TCE range presented in table 2 represents the spectre of daily revenue hire for each ship class over the last two years. Some of the ships have performed voyages outside of the defined TCE range. These results are however exceptions and would be misleading for the quantitative model.

CLASS	**LOW**	**HIGH**
Ship A	**USD 8,000**	**USD 18,000**
Ship B	**USD 15,000**	**USD 25,000**
Ship C	**USD 20,000**	**USD 35,000**
Ship D	**USD 25,000**	**USD 60,000**

Table 2: TCE range, Ship A-D (Commercial operator, 2021)

In order to calculate the overall fuel consumption, average fuel consumption for the Auxiliary group during sea operations are included. The data is acquired from the commercial operator and is the overall average for each ship class (table 3). As none of the ships have a shaft generator driven by the main ship engine, all the internal currents are generated by fuel burned in the auxiliary system. A shaft generator could be used to supply extra power (e.g., compressors or hydraulics) by converting mechanical energy from the main engine, to electrical energy (Generator Technologies, 2021). The fuel consumption will vary depending on the different operations. It is however suitable using average instead of unique consumption, in order to downgrade the complexity of the model. The measurements are performed by an independent third party. The table is given in metric ton per day. The quantitative model uses dynamic ECA calculations for the Auxiliary group fuel consumption, i.e., depending on sulphur emission requirements (SECA).

If the ship travel inside of a ECA zones, the auxiliary group uses LSMGO. Outside of ECA the auxiliary group uses VLSFO (Commercial operator,

2021).

CLASS	FOC
Ship A	**1,5 mtpd**
Ship B	**3,0 mtpd**
Ship C	**3,5 mtpd**
Ship D	**3,5 mtpd**

Table 3: Average fuel consumption for Auxiliary group at sea (Commercial Operator, 2021)

The average fuel consumption in port was also included when calculating the overall fuel consumption. In parcel trading, the chemical tankers have a high port percentage per annum compared to other segments. Due to time consuming operations, e.g., cleaning tanks or loading and unloading cargo for multiple charters simultaneously. The consumption is presented in the table 4, and is the overall sum of heating, loading, unloading, shifting, mooring and auxiliary group. The average consumption is measured in tonne/day and is the total port consumption / hours in port / 24.

CLASS	FOC
Ship A	**3,0 mtpd**
Ship B	**6,5 mtpd**
Ship C	**7,5 mtpd**
Ship D	**6,0 mtpd**

Table 4: Average fuel consumption at port (Commercial operator, 2021)

The model connects the retrieved data to a variation of bunker prices. Chemical tankers refill fuel worldwide. However, in order to limit the number of variables used in the model, the bunker prices where only obtained from Rotterdam. The bunker prices are presented in low – average – high interval. The commercial operator uses mainly LSMGO at port and when sailing in ECA zones, following the 2015 ECA Regulations (Ship&Bunker, 2021). When sailing outside of ECA the commercial operator uses VLSFO, known as IMO2020 grade bunkers (ibid). The period chosen for the model is January to March 2021.

Using bunker prices ranging from \$390,00 to \$505,50 with an average bunker price at \$454,50. See figure 6 below:

Figure 6: VLSFO bunker price 26.03.21, Rotterdam (Ship&Bunker, 2021)

The LSMGO bunker prices fluctuates similar to VLSFO shown in figure 6. However, as a measure used in order to reduce the model complexity, the LSMGO bunker price is defined as constant. I.e., the average bunker price (\$426,00) in Rotterdam on 26 March 2021 (ibid).

As mentioned in chapter 1, CO_2 emissions are an important aspect regarding speed optimization in this study. CO_2 is a chemical compound produced during combustion. The CO_2 fuel consumption estimates are calculated by multiplying the fuel oil consumption with emission factor per fuel grade (IMO, 2021). This is a standardized conversion factor for each type of fuel, presented in resolution MEPC.308(78) (IMO, 2021). The emission factor fuel grade depends on what type of fuel the ship is consuming. Furthermore, what kind of equipment the ship is fitted with. For the commercial operator, the emission conversion factor must be applied for VLSFO and LSMGO. For VLSFO the emission conversion factor is 3,1510. Meaning for each mt fuel burned, 3,15 mt of CO_2 is produced. For LSMGO the emission conversion factor is 3,2060 (IMO, 2021).

In parcel trade, a ship can carry products for multiple cargo owners simultaneously. Thereby having numerous port calls per annum. This is the nature of parcel trade, and what makes the segment complicated when creating a model. In this study, the commercial operators the top 10 port calls have been used as waypoints, in order to create 8 representative trade routes. I.e., the different trade routes are distances travelled between the waypoints. They are calculated by using a function called Voyage Planner in MarineTraffic. The voyage planner function is based on historical data and inputs from the different users (Voyage Planner Pro, 2021). Voyage Planner also provide the ECA distance with different alternatives for each specific voyage.

Data analysis method

In this comparative study, data is retrieved using a method called sample. I.e., data regarding specific ship classes have been collected from the commercial operator. The data is used as variables in the quantitative model, where different scenarios are compared to each other. Trading routes with a variation of waypoints have been created, in order to characterize the commercial operator's representation in global trade.

In the comparative study both sensitivity and scenario analysis are performed in order to determine how changing ship speed influences the dependent variables in the study. Ship speed is the sole measure that the operator can rule over, thereby defined as the independent variable. Ship speed affects e.g., overall fuel consumption, CO2 emission, days at sea, days in port, days in and outside of ECA. These variables change by adjusting ship speed and is therefore defined as the dependent variables. All others, such as bunker prices and freight rates are determined by the market, i.e., outside of the model. These variables are defined as exogenous, and their fluctuating values are presented as different scenarios in the quantitative model.

What is a sensitivity analysis?

In this study sensitivity analysis is used when analysing the model. Sensitivity analysis looks at how particular dependent variables are affected by changing independent variables under a given set of assumptions (Kenton, 2020). Furthermore, how uncertain variables in a mathematical model contributes to the model´s overall result. The sensitivity analysis performed starts with a base case forecast using reasonable set of assumptions (Stopford, 2009). The first set of assumption is that a ship will travel on budget speed, thereby having the calculated bunker cost for the planned voyage. The speed will then work as the independent variable, affecting all the other variables considerably. The sensitivity analysis is performed by presenting the different ship speeds on each row, ranging from 15,4 knots and all the way down to 10 knots. The interval is 0,1 knots per row, resulting in 55 rows. The sensitivity analysis has multiple advantages. Firstly, it acts as an in-dept study of all the different variables. Furthermore, it allows decisionmakers to identify potential revenue (Kenton, 2020). The method does however have some limitations. The outcome of the model is based on the assumptions, which are based on historical data. Error may therefor occur when applying the analysis to future predications (Kenton, 2020).

What is a scenario analysis?

Scenario analysis simulates specific changes in each scenario (Hayes, 2020). Scenario analysis is based on mathematical and statistical principles, where outcomes change, due to fluctuating variables. Scenario Analysis uses the same basic principles as what if analysis and is therefore a method to forecast future values (Stopford, 2009). It is a helpful tool for decisionmakers for the unknown future. The scenario analysis in this study starts with a base-case scenario, a continuation of the recent past (Stopford, 2009). The scenario then develops into different possible scenarios, some more realistic than others. Preparing decisionmakers for different scenarios can ease the process if one of the scenarios becomes reality (Stopford, 2009). In this thesis, the changing outcome will be fuel cost savings and potential economic revenue win or loss, presented through TCE range. The model compares potential trading days against potential bunker cost savings. The potential revenue of additional trading days is calculated using the provided TCE range. The potential revenue for the different ships is then lined up next to each other covering 11 different scenarios. For bunker cost, three scenarios are lined up, dividing them only by the bunker prices. All the different scenarios accumulate into a risk assessment. Where the commercial operator can change his planned strategy based on possible market development. Scenario analysis have multiple advantages. Firstly, it presents a variety of scenarios, which hopefully gives the decisionmaker a better understanding of the market in question. Scenario analysis is however only as good as the inputs and assumptions made by the analyst (Hayes, 2020).

In the overall data collection process, evaluating the validity of the received data has been important. This is however data with high significance for operational planning. It is therefore an assumption that the commercial operator has attempted to eliminate statistical errors. However, there are possibility of errors in the data retrieved. Firstly, the GPS measurements performed during Sea trails could be inaccurate. Caused by e.g., signal blockage or atmospheric conditions. Secondly, the distance on the trading routes retrieved using Voyageplanner could be unprecise, (e.g., distance in ECA is greater than measured). Both errors would make the calculations performed in the model inaccurate. Furthermore, increased ship speed does not necessary lead to extra trading days. Early arrival could be consumed in congestion. In such a scenario the increased ship speed would only have a negative impact to the voyage economic result regarding extra bunker costs. The only thing certain when increasing ship speed, is increased bunker costs. There is also an assumption in the quantitative model, that the different ships will use their time in berth efficient. I.e., do not have to wait for occupied berths, thereby losing the voyage potential by increasing the ship speed. The assumption is based on first come first served and demurrage. Saying that the shipowner will not have to suffer financially because of external circumstances (commercial operator, 2021).

The model estimates overall bunker costs for each ship class at different bunker prices. Furthermore, compares bunker cost savings with potential revenue win or loss by adjusting ship speed. Since the model is dynamic, the variables change depending on the geographical voyage and the different ships. The following calculations are performed for the budget speed of the different ships, creating a baseline for the model:

Days outside of ECA (DOE):	9,1
Days in ECA (DIE):	1
Time at port (TAP):	11
FOC at port (FAP):	3
AUX at sea (AAS):	1,5
Calculated FOC (CF):	17,3
Calculated Speed (CS):	13,5
Total time (TT):	21
Round voyage, nm (RV):	3270

Table 5: Baseline calculations for ship A at budget speed (Author).

The variables shown in table 5 will vary depending on the ship, since the commercial operator uses different budget speeds for ship class A to D, when calculating the TCE for a voyage. As seen in table 5, days outside and inside of ECA zones will adjust depending on the speed of the ship. The same applies for time at port.

The model compares the bunker costs for the baseline speed with the adjusted ship speeds, interval ranging from 10 knots to 15,4 knots. The speed interval is where the commercial operator is expected to operate, due to engine specifics. Dead slow speeds are bad for the engines over time. The same applies for maximum engine load e.g., engine overheat. VLSFO and LSMGO are as stated earlier measured in bunker price per tonne. Bunker costs are calculated with the following formula:

$$BC = (\mathrm{CF} * \mathrm{DOE} * \mathrm{VLSFO}) + (\mathrm{AAS} * \mathrm{DOE} * \mathrm{VLSFO}) + (\mathrm{AAS} * \mathrm{DIE} * \mathrm{LSMGO}) + (\mathrm{TAP} * \mathrm{FAP} * \mathrm{LSMGO}) + (\mathrm{CF} * \mathrm{DIE} * \mathrm{LSMGO})$$

Equation 4: Bunker cost formula, used in chapter 4

BC	**Bunker costs**
DOE	Days outside of ECA
DIE	Days inside of ECA
TAP	Time at port
FAP	FOC at port
AAS	AUX at sea
CF	Calculated FOC
CS	Calculated speed
TT	Total time used on the voyage
RV	Length of voyage
DAS	Days at sea
VLSFO	Very low sulphur Fuel Oil
LSMGO	Low sulphur Marine Gas Oil

Table 6: Abbreviation overview (Author)

Th bunker cost savings for the adjusted ship speeds are calculated by subtracting bunker costs for new ship speed, from the baseline calculations. Presenting the difference budget speed and new ships speed. All the calculations are performed using Microsoft Excel.

In order to select the correct values for the different estimates the model uses OFFSET and MATCH functions, e.g.:

=(OFFSET(F8;(MATCH($F$37;$E$9:$E$12;0));0))

The offset function moves the reference cell to the requested position based on the choice of the operator. If the new position of the reference cell matches ship class A – D, the values in the model changes. The line of code presented above is used in the model, in order to calculate the fuel oil consumption for the auxiliary group at baseline speed. In the model, the operator chooses if he wants to calculate for ship class A-D. If ship class A is chosen, the variables used in the calculation is collected from the Average AUX at sea table. The offset function matches the name chosen by the operator with the respective name in the Average AUX at sea table.

The same logic reasoning using OFFSET and MATCH is applied when calculating Fuel consumption in port, fuel consumption at sea, TCE range, speed of the ships and the specific trade route. Fuel consumption, using specific speeds as variables is however a bit more complicated, as the volume of data requires 55 rows. The different ships are therefore lined up next to each other using columns, see table 7 below:

Speed (knots):	Fuel consumption tons per day	Fuel consumption tons per day	Fuel consumption tons per day	Fuel consumption tons per day
	Ship class A	**Ship class B**	**Ship class C**	**Ship class D**
15,4	28,6	26,9	33,6	49,9
15,3	27,8	26,3	32,9	48,5
15,2	27,1	25,7	32,2	47,2
15,1	26,3	25,1	31,4	46,0
15	25,6	24,6	30,6	44,9

Table 7: Fuel oil consumption for Ship A-D at 15-15,4 knots (Commercial operator, 2021)

Ethical considerations

In order to conduct the research in accordance with ethical principles, several measures were contemplated. Collecting data using an evaluation in accordance with the Norwegian Centre of Research Data was considered. It was however deemed excessive. As the study did not require any participants to reveal information identifying them as individuals. The thesis anonymizes confidential data. In order to protect confidentiality some of the values have also been changed, along with names of ship classes and the identity of the commercial operator. The entire thesis has been approved by the commercial operator before being published.

Chapter 4 - Results

In this section both input and output data from the model are presented numerical and visually. In the first part of the chapter, a variation of the results from the quantitative model is presented as tables. Followed by a sensitivity analysis of the accumulated data, looking at fuel oil consumption and CO2 emissions with adjusted ship speed as the main variable. The second part of the chapter presents the scenario analysis, looking at fuel oil consumption at different speeds for different trading routes. The scenario encompasses different bunker prices and TCE estimates based on historical figures. The scenario analysis is performed without discussing relevant literature.

Since the quantitative model include calculations performed on four different ship classes, some of the tables show a specific ship class. The methodology and calculations are however applicable for every ship class in the study. The overall design of the quantitative model is presented in appendix A. As stated in chapter 3, all the calculations are performed in Microsoft Excel.

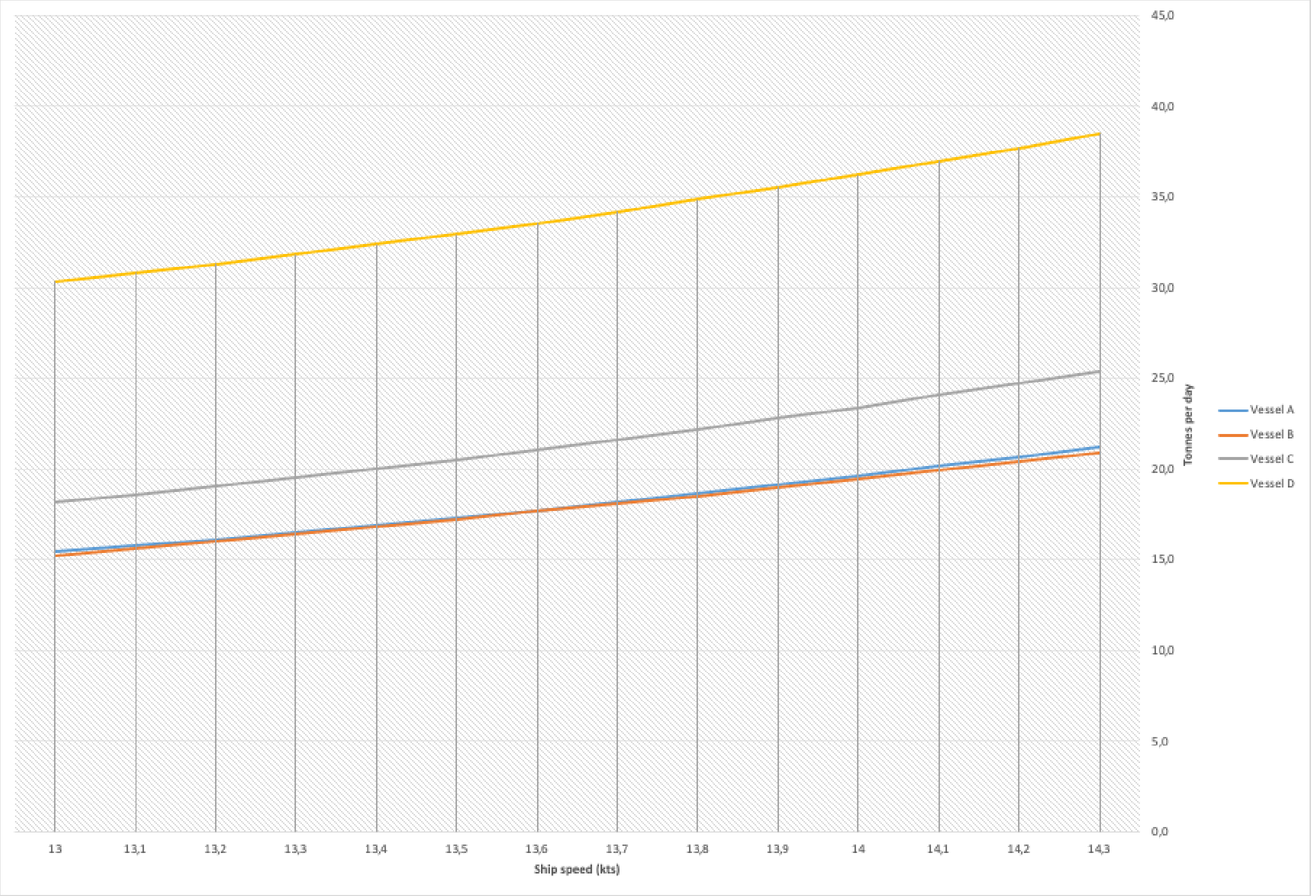


Figure 7: Increase in fuel oil consumption as a function of speed, Ship class A-D (Commercial operator, 2021)

Figure 7 gives a visual presentation of the fuel consumption for ship class A to D. The ships increase ship speed from 13 to 14,3 knots, which is a realistic speed adjustment due to e.g., changing weather, or traffic at the destination port. The consumption curves develop similar for each ship class as ship speed increases. At higher speeds, ship class D does however show the lowest relative increase with 27.1 percentage increased consumption. Ship C has the highest increase in fuel with 39,56 percentage. Relative increase of fuel oil consumption for ship class A-D is shown in table 8. Each ship class increases ship speed with 10 percentage. Based on the significant difference in increased fuel consumption, ship C is the most exposed ship class for fluctuation in bunker prices, if increasing ship speed.

The increased fuel consumption correlates with the assumption made regarding the admiralty coefficient in chapter 2. As the water resistance increases as a result of higher ship speed, the ship´s displacement rises. With increased ship speed and displacement, the requirement for engine power break rises. Showing a 1:3 relationship between ship speed and fuel consumption. Fuel oil consumption is measured in tonnes per day. The relative increase is calculated as follows:

$$Relative\ increase = \frac{\text{FOC at 14,3 kts} - \text{FOC at 13 kts}}{\text{FOC at 14,3 kts}}$$

Equation 5: Relative increase

Class:	**FOC at 13 knots**	**FOC at 14,3 knots**	**Relative Increase fuel oil consumption:**
Ship A	15,4	21,2	37,66%
Ship B	15,3	20,9	36,60%
Ship C	18,2	25,4	39,56%
Ship D	30,3	38,5	27,06%

Table 8: Relative increase in fuel oil consumption for Ship class A - D, by increasing ship speed with 10% (Commercial operator, 2021)

Table 9 show relative increase of CO2 for ship class A-D by increasing ship speed with 10 percentage. CO2 emissions are measured in tonnes per day. As stated earlier, the CO2 calculations are performed by multiplying the fuel oil consumption with the emission factor per fuel grade. As table 9 show, ship C has the highest relative increase in CO2 emissions by increasing the ship speed with 10 percentage.

Class:	**CO2 13 knots**	**CO2 14,3 knots**	**Relative increase, CO2 emissions:**
Ship A	48,6	66,9	37,65%
Ship B	48,1	65,8	36,80%
Ship C	57,3	80,0	39,61%
Ship D	95,6	121,3	26,88%

Table 9: Relative increase in CO2 emission for Ship class A-D by increasing ship speed with 10% (Commercial operator, 2021)

Sensitivity analysis

As described in the chapter 3, this study analyses different calculations using sensitivity analysis. Dependent variables e.g., fuel oil consumption, time in ECA and CO_2 emissions are all affected by ship speed. Table 10 show examples of different trade routes in the chemical parcel tanker market. Total Distance and ECA distance are as described in chapter 3 calculated using voyage planner in Marinetraffic. The different trade routes are used in order to calculate different scenarios. The chemical parcel tankers trade differently than other segments in the shipping industry. The trade routes are more dynamic, with loading and discharging cargo at multiple ports. A voyage from Europe to USA is not characteristically just two stops, in could include several ports (e.g., Rotterdam, Antwerp, Le Havre, New York, Mississippi and Houston). Before returning to Rotterdam and repeating the same process (commercial operator, 2021). Being a quantitative model, the trading routes had to be simplified.

Trade routes		
From - To	**Distance (nautical miles)**	**ECA Distance (NM)**
Rotterdam - Houston	5099	1735,2
Houston-Santos	5619,3	358,1
Santos-Aratu	968,5	0,0
Aratu-Texas city	4692,8	332,9
Texas-city-Ulsan	9795,5	2748,6
Ulsan-Singapore	2543,6	13,7
Singapore-Durban	4919,1	0,0
Durban-Antwerp	7034,9	409,6
Average	5084,1	699,8
Total	**40672,7**	**5598**

Table 10: Representative trade routes, chemical parcel tanker market (Author).

The trade route chosen for the sensitivity analysis is Durban-Antwerp, a common trade route in the chemical parcel tanker market due to terminals for loading and discharging. Durban – Antwerp has the total distance of 7034,9 nm, whereas 409,8 nm are travelled in ECA zones. Table 11 show the bunker costs for ship class A-D. The average bunker prices at Rotterdam, 26 March 2021 are used in the calculations. Furthermore, applied for the budget ship speed for each ship class.

Class:	**Budget speed:**	**Bunker cost:**
Ship A	13,5 knots	$202 630,59
Ship B	13,5 knots	$237 760,54
Ship C	14,0 knots	$299 886,68
Ship D	13,0 knots	$381 399,69

Table 11: Bunker cost at budget ship speed Ship class A-D (Author)

A situation occurs, forcing the ships to increase the ship speed with 10 percentage from budget speed. Table 12 show the bunker cost for the same trade route, but with higher ship speed.

Class:	**Budget speed:**	**10% increase in ship speed:**	**Bunker cost, budget speed:**	**Bunker cost, increased speed:**	**Relative increase in budget cost:**
Ship A	13,5 knots	14,8	$202 630,59	$251 644,75	24%
Ship B	13,5 knots	14,8	$237 760,54	$263 749,26	18%
Ship C	14,0 knots	15,4	$299 886,68	$350 529,35	23%
Ship D	13,0 knots	14,3	$381 399,69	$414 590,30	12%

Table 12: Bunker cost 10% increase in ship speed, Ship class A-D (Author)

As table 12 show, 10 percentage increase in ship speed leads to 12% to 24% increase in bunker costs. Out of the four ship classes, ship A has the highest relative increase with 24%.

Scenario analysis

As stated in the chapter 3, the scenario analysis in this study looks at possible outcomes, given several possible scenarios. The scenario analysis includes different bunker prices, trading routes, speed adjustments and freight rates. The fluctuating freight rate are presented through the TCE range for the different ships and covers the demand for chemicals. The trade routes selected for the scenario analysis are based on representative voyages between loading and discharging ports, provided by the commercial operator. A precondition for the analysis is that the commercial operator is not affected by changes in internally e.g., lack of crew management. The scenario analysis does not include possible weather systems affecting the chosen trade route. Which can be assesses as a weakness with the scenario analysis. Furthermore, the port expenses are set to be constant, as they are unavoidable expenses, unrelated to ships speed. In this thesis the base case scenario is only presented for Ship C. The methodology would be same for the remaining three ship classes. Presenting the same base scenario for the other classes is therefore assessed to be excessive. The scenario analysis is short term, meaning the development of e.g., unmanned ships is not takin into account.

Base case scenario:

1. Ship class:

Summer DWT:	50.000 mt
Fuel consumption:	17,3 tonnes/day
Average speed:	14,0 knots

2. Voyage Information:

Route:	Rotterdam - Houston
Distance:	5099 nm
Cargo:	30.000 tonnes
Average freight rate:	$50/tonnes
Fuel price:	$454,50

3. Days on voyage calculation:

Average speed:	14 knots
Voyage distance:	5099 nm
Time at sea:	15 days
Time at loading and discharging:	14 days
Total days on the voyage:	29 days

4. Time charter equivalent calculations:

Freight earnings:	$3.000.000
Bunker costs:	$226.338
Port costs:	$120.000
Cargo expenses:	$20.000
Tolls:	$200.000
TCE (daily hire per day):	$32 000

Table 13: Base case scenario Ship C (Author)

Ship C is to travel from Rotterdam to Houston, with averaging budget ship speed of 14 knots. Being a segregated parcel chemical tanker, ship C loads 3 different cargos of arbitrary organic chemicals (Toluene, Styrene and Benzene) mentioned in chapter 2. 10.000 tonnes each, giving a total of 30.000 tonnes of cargo. The commercial operator pays the average bunker price for fuel, approximately $454,50. The voyage distance from Rotterdam to Houston is 5099 nm, with 1735,2 nm inside of ECA. The freight rate paid for the voyage is $50 per tonne transported. In order to simplify the model freight commission, demurrage, off hire expenses and transhipment costs have not been included. The commercial operator's economic revenue result for the voyage in question is somewhere around $32.000 Which is in the higher level of the TCE range provided by the commercial operator, showing that even with moderately low freight rates, the daily hire is acceptable for ship C.

In the remaining scenario analysis, the main attention is towards changing bunker price and increased TCE. Variables such as port costs, time used loading and discharging and tolls will stay the same, despite changing ships speed.

Table 14 presents three different scenarios, separated by different bunker prices. The table show the bunker costs for ship class A, and what impact the variable ship speed has for the overall bunker costs. The scenarios use the same route as the base scenario, Rotterdam – Houston 5099 nm, with 1735,2 nm inside of ECA. The budget speed for ship A is 13,5 knots. The budget speed is presented on row number 2, and form this point on referred to as the baseline. The table show the difference between baseline and bunker costs for diverging ship speeds. If the ship has an average ship speed at 15,4 knots, the bunker costs would increase with $55.616,88, with an average bunker price of $452,5/tonnes for VLSFO at Rotterdam. The commercial operator thereby has negative cost savings of $55.618,88. Since bunker costs for every ship speeds are subtracted from the baseline, the difference between baseline and 13,5 knots is $0,00. If the commercial operator however reduces ship speed to 12 knots, the positive bunker cost savings would range from $16.470,20 to $19.113,79.

	Bunker cost savings by slowing (usd/voyage) JAN21 - MAR21		
Speed (knots):	LOW: bunker usd390/ton	AVERAGE: bunker usd452,5/ton	HIGH: bunker usd505,5/ton
Budget (13,5 kts)	$136 834,30	$149 416,14	$159 364,58
15,4	-$50 533,85	-$55 616,88	-$59 636,03
13,6	-$1 977,33	-$2 170,85	-$2 323,87
13,5	$0,00	$0,00	$0,00
13,4	$1 886,42	$2 070,09	$2 215,32
12	$16 470,20	$17 946,49	$19 113,79

Table 14: Cost savings for ship class A. Budgets speed 13,5 knots (Author).

Below are the bunker cost calculations for Ship class B, C and D. Ship B has a budget speed of 13,5 knots. Ship B will by increasing ship speed with 1,9 knots, have negative cost savings, ranging from $333.567 to $418.618. If the commercial operator decided to decrease ship speed to 12 knots, the bunker cost savings would range from $27.699 to $31.914, see table 15 below:

	Bunker cost savings by slowing (usd/voyage) JAN21 - MAR21		
	LOW: bunker usd390/ton	AVERAGE: bunker usd452,5/ton	HIGH: bunker usd505,5/ton
Budget (13,5 kts)	$166 886,87	$180 439,63	$191 155,76
15,4 kts	-$42 924,75	-$46 896,65	-$50 037,22
12,0 kts	$27 699,75	$30 053,65	$31 914,87

Table 15: Bunker cost savings for ship class B, by adjusting ship speed to 15,4 and 12,0 knots (Author)

Ship C has a budget speed of 14 knots. The extra voyage costs for ship C by increasing ship speed to 15,4 knots is therefore less significant compared to the other 3 ship classes. If Ship C decreased speed on the given voyage, it would save $41.617 to $47.969 in bunker cost savings.

	Bunker cost savings by slowing (usd/voyage) JAN21 - MAR21		
	LOW: bunker usd390/ton	AVERAGE: bunker usd452,5/ton	HIGH: bunker usd505,5/ton
Budget (14 kts)	$209 010,36	$226 388,11	$240 128,66
15,4 kts	-$46 201,30	-$50 622,26	-$54 117,90
12,0 kts	$41 617,44	$45 164,96	$47 969,97

Table 16: Negative bunker cost savings for ship class C, by increasing ship speed to 15,4 knots (Author)

Ship D has a budget speed of 13 knots. The calculations performed in the model show that if the commercial operator adjust ship speed to 15,4 knots, the extra bunker costs would range from $80.421 to $94.421. If however the operator decides to reduce ship speed to 12 knots, Ship D would have $4690 to $4920 in bunker cost savings.

	Bunker cost savings by slowing (usd/voyage) JAN21 - MAR21		
	LOW: bunker usd390/ton	AVERAGE: bunker usd452,5/ton	HIGH: bunker usd505,5/ton
Budget (13,0 kts)	$258 305,59	$281 844,16	$300 456,05
15,4 kts	-$80 421,29	-$88 239,70	-$94 421,71
12,0 kts	$4 690,87	$4 818,85	$4 920,04

Table 17: Negative bunker cost savings for ship class D, by increasing ship speed to 15,4 knots (Author)

In order to test the quantitative model on different trading routes, table 18 show potential revenue win if ship A increases its ship speed from 13,5 knots to 15,4 knots. The calculations are performed for the same distance as in the scenarios described above, Rotterdam – Houston. A precondition for the scenario is the average bunker price, $454,50 per tonnes. The data is presented in a TCE range, from $8000 if the freight rates are low, to $18.000 if the freight rates are high. The freight rates are calculated for 15.000 tonnes of cargo, port costs $40.000, cargo expenses $12.000 and tolls $65.000 As stated earlier in the thesis, TCE is calculated by dividing the voyage result on the number of days used on the voyage. The underlaying variable changing in this scenario is the freight rate since bunker costs will be affected similar to the voyage results. If the voyage costs are constant, the remaining variables are gross revenue and days used on the voyage. In order to get a representative freight rate for the TCE range provided by the commercial operator, the TCE equation is reorganised:

$$Freight\ rate = \frac{TCE * Voyage\ days + Voyage\ expenses}{DWT}$$

To calculate days used on the voyage, the two loading and discharging ports have been put into the calculations, with 7 days per berth. Giving a total of 30 days used on the voyage, with 15,7 used at sea. An increase in ship speed will also give 1,9 extra trading days for ship A, as days at sea are reduced from 15,7 to 13,8. The TCE range is presented on row 3. Row number 4 equals the gross income for the entire voyage. If the freight rates are above $44,5 for relevant chemical cargo, ship A can potentially increase the revenue win with §34.949,86. However, the extra bunker costs by increasing ship speed is not considered in the scenario below.

Potential revenue win/loss by speeding/slowing (usd)												
$29,35	**$30,86**	**$32,38**	**$33,89**	**$35,41**	**$36,93**	**$38,44**	**$39,96**	**$41,47**	**$42,99**	**$44,51**		
$8 000,00	**$9 000,00**	**$10 000,00**	**$11 000,00**	**$12 000,00**	**$13 000,00**	**$14 000,00**	**$15 000,00**	**$16 000,00**	**$17 000,00**	**$18 000,00**	**Days at sea:**	**Extra trading days:**
$237 901,23	$267 638,89	$297 376,54	$327 114,20	$356 851,85	$386 589,51	$416 327,16	$446 064,81	$475 802,47	$505 540,12	$535 277,78	15,7	0,0
$15 533,27	$17 474,93	$19 416,59	$21 358,25	$23 299,90	$25 241,56	$27 183,22	$29 124,88	$31 066,54	$33 008,20	$34 949,86	13,8	1,9

Table 18: Potential revenue economic win Ship class A, ship speed 15,4 kts (Author).

Table 19 addresses the missing aspect in table 18, presenting several bunker cost scenarios lined up next to each other. The bunker prices are divided into three scenarios ranging from $390 to $505,5. The distance for the scenarios is the overall average from the eight representative trading routs, covering 5084 nautical miles and 699,8 nautical miles in ECA zones. Table 19 uses the same logic as 18 by presenting the budget ship speed up against upper and lower ship speed adjustments. Bunker prices, freight rates and TCE are presented on row 3. Baseline calculation with budget speed is presented on row 4. In a scenario where bunker prices are low, the ship will have a negative cost savings of $49.517 by increasing ship speed in order to average 15,4 knots on the entire voyage. If bunker prices are high, ship A will have negative cost savings of $61.380. However, increased speed leads to earlier arrival. Ship A will arrive at the destination 1,9 days earlier than planned, meaning potentially 1.9 extra trading days. The potential revenue win for the extra trading days is lower than the extra bunker costs in any of the three bunker price scenarios. If the market indicates high TCE, the potential revenue win/loss at TCE $18.000 is $34.847,64. The negative bunker costs savings thereby exceeds the potential revenue win, no matter the bunker price. If the commercial operator reduces ship speed to 12,0 knots, the bunker cost savings will range from $16.169 to $19.615, depending on the bunker price. Lower ship speed equals fewer trading days. By decreasing ship speed to 12 knots, the commercial operator will lose 1,7 trading days. At 12,0 knots, the potential revenue loss is greater than the bunker cost savings, for TCE above $10.000, ref. table 19.

Bunker cost savings by slowing (usd/voyage) JAN21 - MAR21			**Potential revenue win/loss by speeding/slowing (usd)**										
LOW: bunker usd390/ton	**AVERAGE: bunker usd452,5/ton**	**HIGH: bunker usd505,5/ton**	**$29,40**	**$30,91**	**$32,43**	**$33,94**	**$35,45**	**$36,96**	**$38,48**	**$39,99**	**$41,50**	**$43,02**	**$44,53**
$390,00	**$454,50**	**$505,50**	**$8 000,00**	**$9 000,00**	**$10 000,00**	**$11 000,00**	**$12 000,00**	**$13 000,00**	**$14 000,00**	**$15 000,00**	**$16 000,00**	**$17 000,00**	**$18 000,00**
$134 335,41	$150 734,39	$163 701,02	$237 533,02	$267 224,65	$296 916,28	$326 607,91	$356 299,54	$385 991,17	$415 682,79	$445 374,42	$475 066,05	$504 757,68	$534 449,31
-$49 517,05	-$56 142,19	-$61 380,68	$15 487,84	$17 423,82	$19 359,80	$21 295,78	$23 231,76	$25 167,74	$27 103,72	$29 039,70	$30 975,68	$32 911,66	$34 847,64
$16 169,64	$18 093,82	$19 615,26	-$15 691,63	-$17 653,08	-$19 614,54	-$21 575,99	-$23 537,44	-$25 498,90	-$27 460,35	-$29 421,80	-$31 383,26	-$33 344,71	-$35 306,16

Table 19: Bunker cost savings versus TCE range, ship class A at 15,4 knots (Author)

Figure 7 gives a visual presentation of two different scenarios for all four ship classes. Scenario 1 shown in 7a – 7d, show the negative cost savings for each ship class traveling on the trade route Rotterdam – Houston, with a distance of 5099 nautical miles. Scenario 2 (7e – 7h) show the overall distance of the 8 trade routes combined. With a total distance of 40.672 nautical miles. The horizontal axis covers 10 percentage increase in ships speed, where budget ship speed is at the starting point. As the ships have different budget speed, the charts will have different intervals. The three stipulated lines represent best case, base case and worst-case bunker prices scenario, respectively $390, $454 and $505.

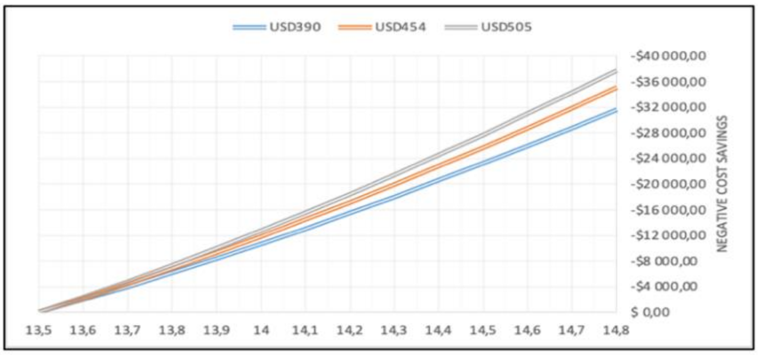


Figure 7a, Ship A. Budget speed 13,5 kts.
Rotterdam – Houston, 5099 nm

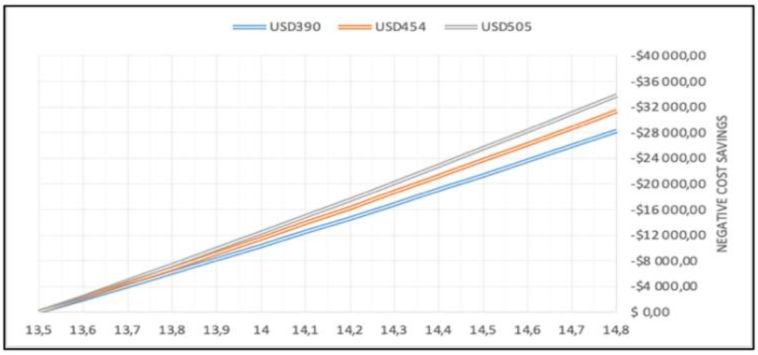


Figure 7b, Ship B. Budget speed 13,5 kts.
Rotterdam - Houston, 5099 nm

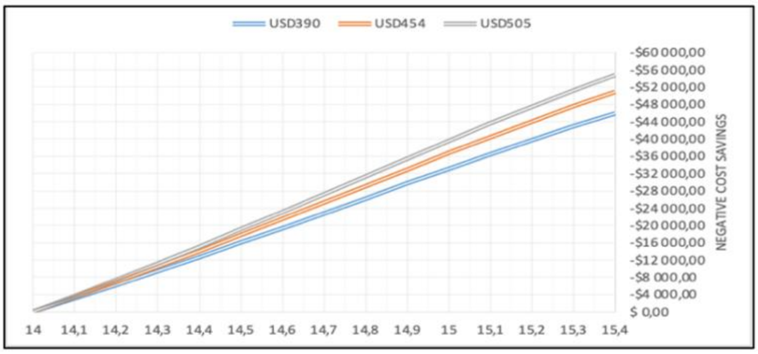


Figure 7c, Ship C. Budget speed 14 kts.
Rotterdam – Houston, 5099 nm

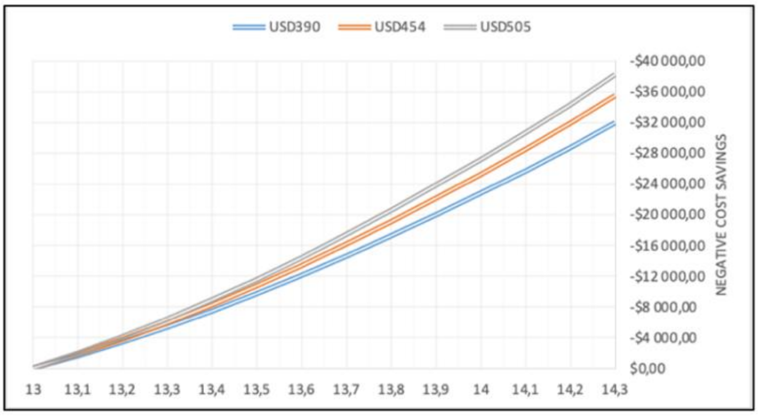


Figure 7d, Ship D. Budget speed 13 kts.
Rotterdam – Houston, 5099 nm

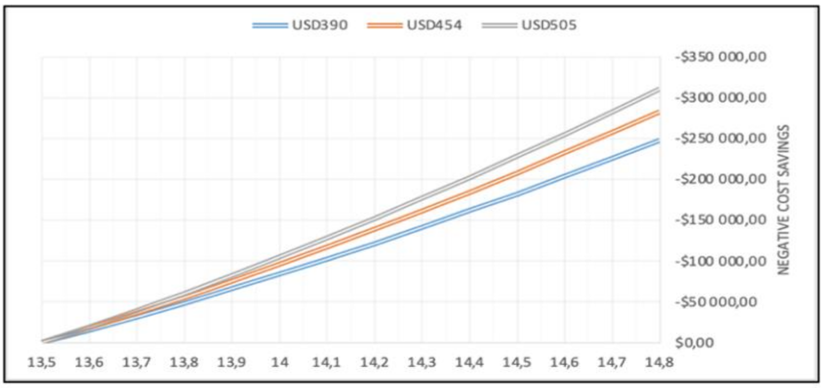


Figure 7e, Ship A. Budget speed 13,5 kts. Total distance, 40672 nm

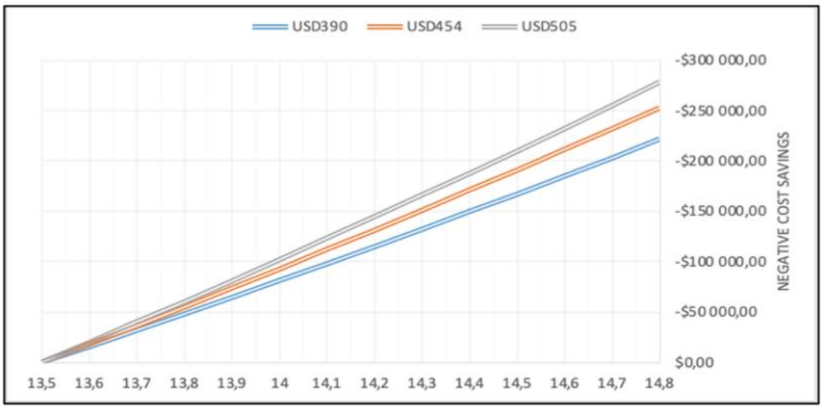


Figure 7f, Ship B. Budget speed 13,5 kts. Total distance, 40672 nm

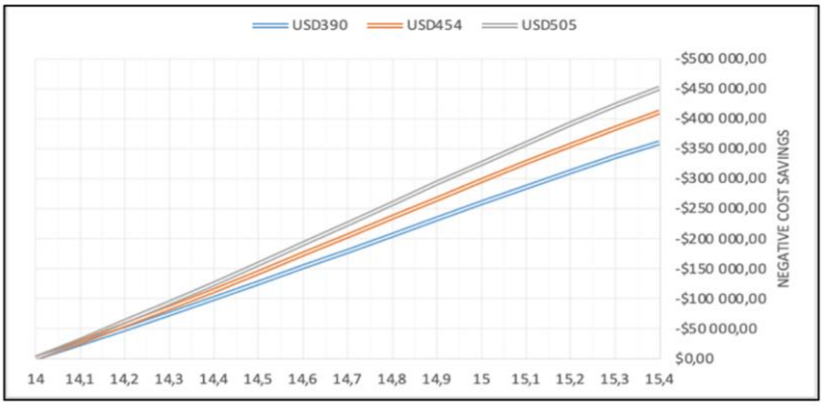


Figure 7g, Ship C. Budget speed 14 kts. Total distance, 40672 nm

Figure 7h, Ship D. Budget speed 13 kts. Total distance, 40672 nm

Figure 7: Run charts of negative cost savings, 10 percentage increase in speed for Ship class A-D (Author)

Chapter 5 - Discussion

The following chapter discusses the outcome from both the quantitative model, scenario and sensitivity analysis. The first part of the discussion debates the essential findings from the scenario analysis. Followed by the potential revenue win by adjusting ship speed versus bunker cost savings. Can the commercial operator optimize the voyage economic results, based on ships early arrival? The second part of the discussion looks at possible market consequences by adjusting ship speed on an entire fleet. How will the competitors react? The discussion is based on both research literature and theoretical framework of game theory. The third and last part of the discussion covers limitations with the thesis.

Traditionally the scenario analysis attempts to provide an accurate portrait of a future outcome. Take the bunker prices used in the analysis as an example. They are potential future prices based on historical figures. If the bunker prices go up, the bunker costs on a planned voyage will increase proportionally. Provided that all other aspects of the voyage are unaltered. However, the scenario analysis can also be used as a tool on current voyages. Calculating future adjusted cost savings, based on bunker prices already paid. E.g., the commercial operator decides to increase ship speed on a designated voyage in order to arrive at port before the competitors. Using bunker prices and freight rates seen in Q1, 2021, the quantitative model shows higher additional bunker costs than potential revenue win, for increased ship speed. Even with daily hire rates in the upper levels of the TCE range. Choosing to increase ship speed in order to accumulate extra trading days would therefore be of high risk, as the negative bunker cost savings likely would exceed the potential revenue win, ref. table 19. This applies for all ship classes used in this study.

When reducing ship speed, the different ship classes have different intersections, where potential revenue loss is greater than bunker cost savings. This is an important observation, as it clarifies that even with high bunker prices, low ship speeds are not necessarily optimal ship speeds. In 2014 Psaraftis and Kontovas concluded their study clarifying that if policymakers increased taxes on fuel, the operators would reduce ship speed. Based on the results presented in chapter 4, it would seem bunker prices are currently on the level described in their study (Psaraftis & Kontovas, 2014). Fuel prices, freight rate, inventory cost and fuel consumption pay a crucial part when modelling optimized ship speed (Psaraftis, Kntovas, 2014). As Figure 2 show, the rate development of CPP and veg oil Atlantic basin remained high during the outbreak of the pandemic in April 2020. Thereby relatively unaffected by the decreasing bunker costs. As bunker costs increase and CPP freight rate are steadily low, the commercial operator is enforced to perform the voyages at low ship speeds. The realistic scenarios used in the analysis are therefore high bunker prices, and low TCE.

As the shipping industry contributes significantly to global greenhouse emissions, there is an increased attention towards reducing overall emissions. One of the measures is to reduce operational speed of all ships. Introducing a speed limit would however be more beneficial for some operators than others. As energy efficient ships will use less fuel while traveling at the same ship speed as older types of ships (Psaraftis, 2019). The four ship classes managed by the commercial operator have different energy efficiency. Ship D has the lowest increase in ship fuel oil consumption when increasing ship speed with 10 percentage, ref. table 8. As table 8 and 9 show, CO_2 emissions and fuel oil consumptions increase simultaneously. The chemical parcel tankers are relatively small measured in dead weight tonnage compared to other ships such as VLCC. Psaraftis argued in his study that specific speeds may discriminate some ships due to the size. However, if Sea Cargo Charter sets the benchmark for calculating CO_2 emissions, a ship´s utilization will be essential. By calculating the emissions taxes using equation 2, strong incentives are introduced to fully utilize ships. This incentive would hit the chemical parcel tanker market especially, as they use segregated tankers, capable of transporting up to 50 different cargos. Calculating ship speed optimization with only higher ship speeds than budget speeds could because of the increased GHG attention be misleading. GHG emissions is becoming a parameter used by the industry, ref. Sea Cargo Charter. Ship speed optimization should therefore be directed towards reducing speed, and the positive bunker cost savings it leads to.

		K_{CS}	
	Prisoner’s Dilemma	*Competing ship fleet stays on current speed (C_F^0)*	*Competing ship fleet increases speed (C_F^1)*
K_{CO}	*Commercial Operator stays on current speed (C_O^0)*	0,0	0,1
	Commercial Operator increases speed (C_O^1)	1,0	1,1

Table 20: NASH equilibrium Commercial operator versus competing ship fleet (Author)

Nash equilibrium is as stated in chapter 2 a key concept of game theory. It discusses a condition where every participant has optimized its outcome, based on the other players expected decision. The decision must be based on the collective profit of the industry, not individual earnings. Table 20 show the Prisoner´s dilemma in context of chemical parcel tanker market. In the dilemma, the commercial operator is defined as player A. Managing the largest fleet in the market, with 100 parcel tankers. Player B is defined as the remaining chemical parcel tanker fleet, consisting of 481 parcel tankers. Giving the chemical parcel tanker market a total of 581 ships, ref. chapter 2. A precondition for the Prisoner´s dilemma is limited information regarding the competing players chosen strategy, ref. national and international regulations. Furthermore, each choice is taken simultaneously. None of the players can wait in order to see what strategy the opposing player has chosen.

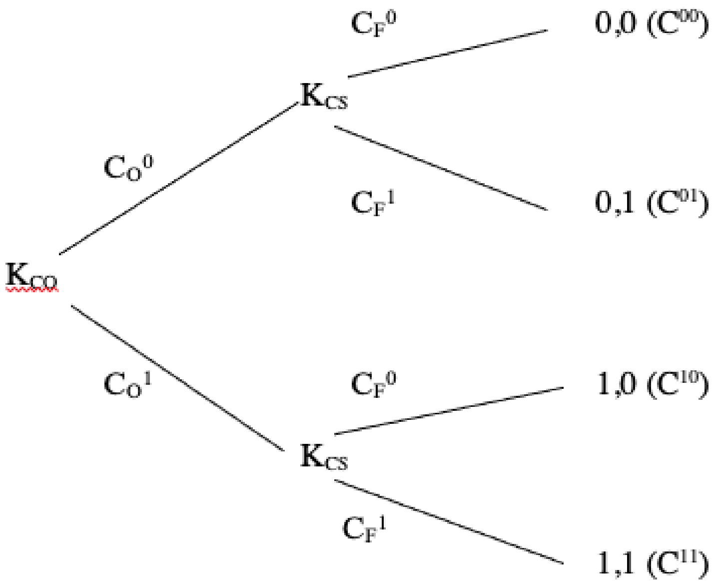


Figure 8: Probability tree, Prisoner´s dilemma (Author)

Figure 8 show a probability tree, developed in order analysis of the prisoner´s dilemma (see table 20 for abbreviations). As figure 8 show, C^1 is the best choice for the commercial operator, as he will either grasp more cargo in the market or increase ship speed equal to the competing fleet. The same logic applies for the competing fleet. The dominant strategy for both commercial operator and the competing fleet is therefore to increase ship speed.

In scenario 0,0 (C^{00}), the commercial operator stays on a low ship speed. The remaining chemical tanker fleet does the same. Demand and supply will in this scenario be in disharmonic, since supply suddenly becomes lower than demand. Each chemical tanker will have fewer trading days. Less ships available to cover the same volume of demand will increase the freight rates. A precondition for this scenario is that all other aspects are unaltered.

In scenario 1,0 (C^{10}), the commercial operator increases the ship speed for the entire fleet, while the competing ship fleet stays on slow ship speed. Because of additional trading days, the commercial operator will be able to grasp more of the cargo volume in the market. High freight rates combined with greater ship speed than the competitors will increase the voyage economic results for the Commercial operator. In scenario 0,1 (C^{01}), the opposite happens, where the competing ship fleet profits from high freight rates combined with greater ship speed. While the commercial operator loses market position and potential profit. Sailing each voyage with slower ship speed than the competing fleet.

If both the commercial operator and the competing ship fleet choose their dominant strategy and increases ship speed, scenario 1,1 (C^{11}), will occur. Increased ship speed will lead to extra trading days for the entire chemical parcel tanker fleet. Extra trading days result in additional ships are in a position where they can bid on different loads. This will eventually drive the freight rates down, as demand surpluses supply. Scenario 1,1 is the only situation among the four scenarios where Nash equilibrium occurs. Neither the commercial operator, nor the remaining chemical tanker fleet would prefer to alter their decision, knowing the choice of the competitors. As none of the players will see a higher profit by individually deciding to reduce ship speed. Kou and Lou’s study in 2016 discovered that individual optimal behaviour would lead to an overcapacity in the market. Even though their study looked at fleet expansion, the concept remains the same as increased ship speed. If both commercial operator and the competing fleet follow their dominant strategy, an overcapacity in the market is expected.

The following subchapter shows scenario 1,1 of the prisoner´s dilemma as numerical experiment. The method is acquired from Kou and Lou’s study regarding Strategic capacity competition and overcapacity in shipping. The total number of ships in the chemical parcel tanker market is 581, whereas the commercial operator manages 100 ships. Giving the commercial operators a market position of 17.2% (100/581). Over a time period of 365 days, the commercial operators’ ships are at port 50 percentage of the time (commercial operator, 2021). An assumption for the experiment is that the remaining fleet has the same port percentage. Indicating that a snapshot of the current marked would show 291 (581/2) ships are currently on a voyage. The distance used in the experiment is the average distance of 5084,1 nm, taken from Table 10. The average ship speed is 12 knots, giving the ships 17,5 days at sea. If each ship increased ship speed by 10 percentage, the average ship speed of the chemical tanker fleet would be 13,2 knots. The designated voyage is now completed in 16,1 days, instead of 17,5. Giving each of the 291 ships 1,4 extra trading days per average voyage. A scenario similar to Kou & Lou´s findings in 2016, where supply and demand no longer where in harmony. Individual optimal behaviour has led to an overcapacity in the market, where several ships are in positions to bid on different cargos (Kou & Lou, 2016). Brokers will try to cover the 1,4 extra trading days by underbidding each other, thus driving the freight rates down to operational costs.

Limitations

The thesis has several limitations, which will be presented categorically over the next chapter. The bunker prices for the different fuels are presented in a low – high range, taken form Rotterdam 26. March 2021. Firstly, Bunker prices vary due to e.g., tax regulations and geographical area. Bunker prices in Rotterdam are not the same as in Singapore. Secondly, in future scenarios the bunker prices will fluctuate outside the defined low – high range presented in the analysis. An alternative to the bunker price used in the quantitative model could be a worst – best case scenario. Where historical low and high bunker prices are used as variables for different scenarios. The quantitative model also uses a constant LSMGO price. In reality the bunker price will fluctuate similar to VLSFO.

As explained in table 10, the trading routes created in the scenarios are simplified routes in order to calculate voyage economic results. In reality the trade routes are more dynamic and complex, with loading and discharging cargo at multiple ports. A voyage from Asia to Europe is not characteristically just two stops, but could include several ports (e.g., Singapore, Durban, Antwerp, Rotterdam). The commercial operator constantly bids on cargo in the spot market, in order to utilize ships on different voyages. If the commercial operator is in luck, discharging different types of cargo is done at the same terminal. However, if the cargo is discharged on different terminals, extra costs must be paid (e.g., port costs). In this study the voyage costs, with attention to fuel consumption, fuel prices and freight rates are the variables used in order to calculate the voyage economic results. In reality, there are however five major cost classification from the commercial operator perspective, Operating costs, voyage costs, capital costs, cargo handling costs and periodic maintenance costs. Each of the five major cost classifications have a number of underlying variables. The voyage economic results presented in the analysis could therefore be misleading as the model does not cover essential elements from the parcel tanker market.

What is the value of an extra trading day? Is 1,9 extra trading days the same as potential daily hire for 1,9 days? There can also be limitations at the discharging ports. Having to wait 1,9 days anchored before discharging the cargo. Losing the potential of traveling the entire voyage with increased ship speed. In that regard, productivity ratio could be applied. What is the budget TCE for the specific ship? If a ship is in port 50 percentage per annum, the remaining 182 days are spent on voyages averaging 13 knots. Over a period of 365 days the calculated distance is 56.784 nautical miles. If the ship´s speed increases with 10 percentage, the total distance will increase to 62.462 nm per annum. Giving the ship a productivity ratio of 62.462/56.784 = 1,1. By tying this productivity ratio to budget TCE, the daily hire revenue per annum can rapidly be presented.

Due to economic growth and seaborne transportation, the number of ships in the global market has increased. The process of expanding or establishing new terminals, is however more comprehensive than building new ships. As a result, terminals, berths and channels worldwide cannot sufficiently handle the increased number of ships. Leading to additional time spent in congestion (commercial operator, 2021). The activities in port or terminal have not been prioritized in this thesis. As they were considered constant variables, unaffected by changing the ship speed. Seeing them as constant variables is however a simplified consideration, as they could determine the voyage economic results on multiple voyages. If the commercial operator increases ship speed but ends up in congestion, the surplus of time will be lost. Avoiding terminal queue could also be an incentive for increasing ship speed. If information indicates an accumulation of ships outside a terminal, several days in advance. Similar scenarios as described above have not been prioritized in the study.

There are several safety and security issues linked to chemical tanker business, which are not addressed in the study. Especially regarding loading and discharging the chemical cargos at different terminals. Since the scope of the thesis embrace speed optimization of ship speed, the safety and security aspects have not been prioritized.

In the chemical parcel tanker market, the commercial operator sees increased attention towards ship CO_2 emission (commercial operator, 2021). Lower emissions make the shipowners more attractive to the cargo owner ref. Sea Cargo Charter, chapter 2. Greenhouse gas emissions do not play a significant part in the model, even though it is an incentive to reduce the ship speed. It is however thoroughly discussed in chapter 5.

The quantitative model uses fluctuation in TCE due to changing freight rates. The model thereby excludes oil prices as a variable affecting TCE. Presenting the relationship between freight rates and oil prices was considered in the thesis, but was not prioritized.

Chapter 6 - Conclusion

During the introduction of the thesis, the following research questions were asked: What is the relationship between ships fuel consumption, ships speed and voyage economic results? How could the commercial operator adjust the ships´ speed in order to optimize the voyage economic results? In order to answer the research questions a quantitative model (Appendix A) was developed. Showing possible scenarios and variable sensitivity by adjusting ships speed. Chapter 5 argues that increasing ships speed from budget speed would have a negative effect on the voyage economic results for the commercial operator. As the market conditions seen during Q1 2021 will generate additional bunker costs higher than potential revenue win. The results also show that low ship speeds can have a negative effect on the voyage economic results (table 19).

Seen from a game theoretical perspective, the Prisoner´s dilemma demonstrates that the commercial operator´s dominant strategy is to increase ships speed. And by doing so, possibly contributing to lower freight rates for the entire chemical parcel tanker fleet, ref. table 20. The use of Prisoner´s dilemma and the quantitative model, illustrates that the chemical parcel tanker market is of great complexity. Concluding that looking solely at ship fuel consumption versus potential revenue win and loss, will discriminate other important aspects (e.g., competing fleet´s response by adjusting ship speed). This thesis contributes to current knowledge by exploring industry specific data, using a quantitative model. Furthermore, examining optimal ship speed from a game theoretical perspective.

Issues for further research

The quantitative model compares bunker cost savings versus potential revenue win and loss. The next step in developing the model would be to include a productivity ratio for each ship class, as mentioned in chapter 5. Thereby exploring the potential value of additional trading days even further. A step further would be to include forecasting models for both freight rates and bunker prices. It could also be interesting to further investigate the relationship between ship speed and fuel consumption, using the admiralty coefficient.

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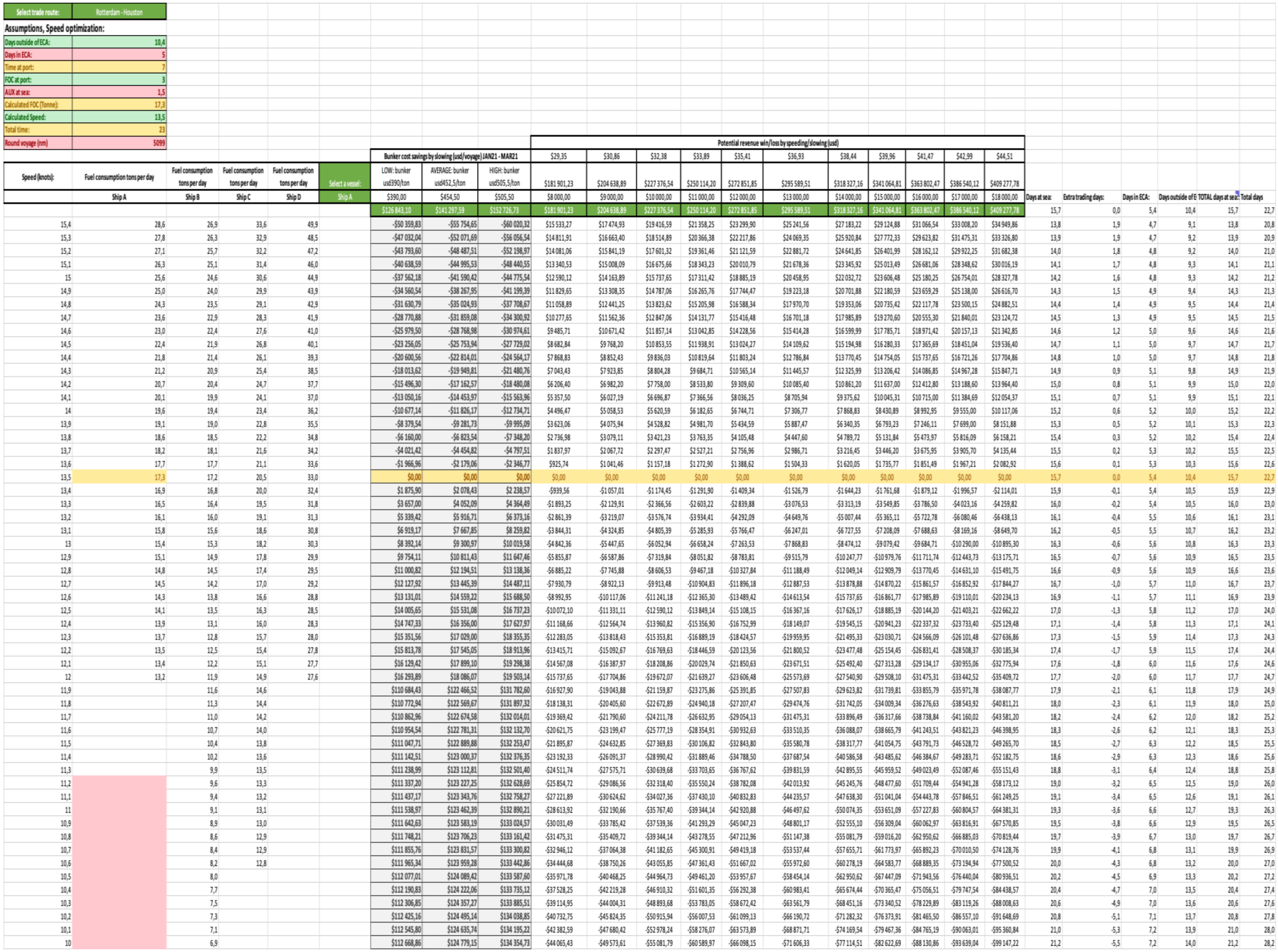
Appendix A: Quantitative model



Select trade route:	Rotterdam - Houston

Assumptions, Speed optimization:

Days outside of ECA:	10,4
Days in ECA:	5
Time at port:	7
FOC at port:	3
AUX at sea:	1,5
Calculated FOC (Tonne):	17,3
Calculated Speed:	13,5
Total time:	23
Round voyage (nm)	5099

									Potential revenue win/loss by speeding/slowing (usd)																
						Bunker cost savings by slowing (usd/voyage) JAN21 - MAR21			$29,35	$30,86	$32,38	$33,89	$35,41	$36,93	$38,44	$39,96	$41,47	$42,99	$44,51						
Speed (knots):	Fuel consumption tons per day	Fuel consumption tons per day	Fuel consumption tons per day	Fuel consumption tons per day	Select a vessel:	LOW: bunker usd390/ton	AVERAGE: bunker usd452,5/ton	HIGH: bunker usd505,5/ton	$181 901,23	$204 638,89	$227 376,54	$250 114,20	$272 851,85	$295 589,51	$318 327,16	$341 064,81	$363 802,47	$386 540,12	$409 277,78						
	Ship A	Ship B	Ship C	Ship D	Ship A	$390,00	$454,50	$505,50	$8 000,00	$9 000,00	$10 000,00	$11 000,00	$12 000,00	$13 000,00	$14 000,00	$15 000,00	$16 000,00	$17 000,00	$18 000,00	Days at sea:	Extra trading days:	Days in ECA:	Days outside of E	TOTAL days at sea:	Total days
						$126 843,10	$141 297,59	$152 726,73	$181 901,23	$204 638,89	$227 376,54	$250 114,20	$272 851,85	$295 589,51	$318 327,16	$341 064,81	$363 802,47	$386 540,12	$409 277,78	15,7	0,0	5,4	10,4	15,7	22,7
15,4	28,6	26,9	33,6	49,9		-$50 359,83	-$55 754,65	-$60 020,32	$15 533,27	$17 474,93	$19 416,59	$21 358,25	$23 299,90	$25 241,56	$27 183,22	$29 124,88	$31 066,54	$33 008,20	$34 949,86	13,8	1,9	4,7	9,1	13,8	20,8
15,3	27,8	26,3	32,9	48,5		-$47 032,04	-$52 071,69	-$56 056,54	$14 811,91	$16 663,40	$18 514,89	$20 366,38	$22 217,86	$24 069,35	$25 920,84	$27 772,33	$29 623,82	$31 475,31	$33 326,80	13,9	1,9	4,7	9,2	13,9	20,9
15,2	27,1	25,7	32,2	47,2		-$43 793,60	-$48 487,51	-$52 198,97	$14 081,06	$15 841,19	$17 601,32	$19 361,46	$21 121,59	$22 881,72	$24 641,85	$26 401,99	$28 162,12	$29 922,25	$31 682,38	14,0	1,8	4,8	9,2	14,0	21,0
15,1	26,3	25,1	31,4	46,0		-$40 638,59	-$44 995,53	-$48 440,55	$13 340,53	$15 008,09	$16 675,66	$18 343,23	$20 010,79	$21 678,36	$23 345,92	$25 013,49	$26 681,06	$28 348,62	$30 016,19	14,1	1,7	4,8	9,3	14,1	21,1
15	25,6	24,6	30,6	44,9		-$37 562,18	-$41 590,42	-$44 775,54	$12 590,12	$14 163,89	$15 737,65	$17 311,42	$18 885,19	$20 458,95	$22 032,72	$23 606,48	$25 180,25	$26 754,01	$28 327,78	14,2	1,6	4,8	9,3	14,2	21,2
14,9	25,0	24,0	29,9	43,9		-$34 560,54	-$38 267,95	-$41 199,39	$11 829,65	$13 308,35	$14 787,06	$16 265,76	$17 744,47	$19 223,18	$20 701,88	$22 180,59	$23 659,29	$25 138,00	$26 616,70	14,3	1,5	4,9	9,4	14,3	21,3
14,8	24,3	23,5	29,1	42,9		-$31 630,79	-$35 024,93	-$37 708,67	$11 058,89	$12 441,25	$13 823,62	$15 205,98	$16 588,34	$17 970,70	$19 353,06	$20 735,42	$22 117,78	$23 500,15	$24 882,51	14,4	1,4	4,9	9,5	14,4	21,4
14,7	23,6	22,9	28,3	41,9		-$28 770,88	-$31 859,08	-$34 300,92	$10 277,65	$11 562,36	$12 847,06	$14 131,77	$15 416,48	$16 701,18	$17 985,89	$19 270,60	$20 555,30	$21 840,01	$23 124,72	14,5	1,3	4,9	9,5	14,5	21,5
14,6	23,0	22,4	27,6	41,0		-$25 979,50	-$28 768,98	-$30 974,61	$9 485,71	$10 671,42	$11 857,14	$13 042,85	$14 228,56	$15 414,28	$16 599,99	$17 785,71	$18 971,42	$20 157,13	$21 342,85	14,6	1,2	5,0	9,6	14,6	21,6
14,5	22,4	21,9	26,8	40,1		-$23 256,05	-$25 753,94	-$27 729,02	$8 682,84	$9 768,20	$10 853,55	$11 938,91	$13 024,27	$14 109,62	$15 194,98	$16 280,33	$17 365,69	$18 451,04	$19 536,40	14,7	1,1	5,0	9,7	14,7	21,7
14,4	21,8	21,4	26,1	39,3		-$20 600,56	-$22 814,01	-$24 564,17	$7 868,83	$8 852,43	$9 836,03	$10 819,64	$11 803,24	$12 786,84	$13 770,45	$14 754,05	$15 737,65	$16 721,26	$17 704,86	14,8	1,0	5,0	9,7	14,8	21,8
14,3	21,2	20,9	25,4	38,5		-$18 013,62	-$19 949,81	-$21 480,76	$7 043,43	$7 923,85	$8 804,28	$9 684,71	$10 565,14	$11 445,57	$12 325,99	$13 206,42	$14 086,85	$14 967,28	$15 847,71	14,9	0,9	5,1	9,8	14,9	21,9
14,2	20,7	20,4	24,7	37,7		-$15 496,30	-$17 162,57	-$18 480,08	$6 206,40	$6 982,20	$7 758,00	$8 533,80	$9 309,60	$10 085,40	$10 861,20	$11 637,00	$12 412,80	$13 188,60	$13 964,40	15,0	0,8	5,1	9,9	15,0	22,0
14,1	20,1	19,9	24,1	37,0		-$13 050,16	-$14 453,97	-$15 563,96	$5 357,50	$6 027,19	$6 696,87	$7 366,56	$8 036,25	$8 705,94	$9 375,62	$10 045,31	$10 715,00	$11 384,69	$12 054,37	15,1	0,7	5,1	9,9	15,1	22,1
14	19,6	19,4	23,4	36,2		-$10 677,14	-$11 826,17	-$12 734,71	$4 496,47	$5 058,53	$5 620,59	$6 182,65	$6 744,71	$7 306,77	$7 868,83	$8 430,89	$8 992,95	$9 555,00	$10 117,06	15,2	0,6	5,2	10,0	15,2	22,2
13,9	19,1	19,0	22,8	35,5		-$8 379,54	-$9 281,73	-$9 995,09	$3 623,06	$4 075,94	$4 528,82	$4 981,70	$5 434,59	$5 887,47	$6 340,35	$6 793,23	$7 246,11	$7 699,00	$8 151,88	15,3	0,5	5,2	10,1	15,3	22,3
13,8	18,6	18,5	22,2	34,8		-$6 160,00	-$6 823,54	-$7 348,20	$2 736,98	$3 079,11	$3 421,23	$3 763,35	$4 105,48	$4 447,60	$4 789,72	$5 131,84	$5 473,97	$5 816,09	$6 158,21	15,4	0,3	5,2	10,2	15,4	22,4
13,7	18,2	18,1	21,6	34,2		-$4 021,42	-$4 454,82	-$4 797,51	$1 837,97	$2 067,72	$2 297,47	$2 527,21	$2 756,96	$2 986,71	$3 216,45	$3 446,20	$3 675,95	$3 905,70	$4 135,44	15,5	0,2	5,3	10,2	15,5	22,5
13,6	17,7	17,7	21,1	33,6		-$1 966,96	-$2 179,06	-$2 346,77	$925,74	$1 041,46	$1 157,18	$1 272,90	$1 388,62	$1 504,33	$1 620,05	$1 735,77	$1 851,49	$1 967,21	$2 082,92	15,6	0,1	5,3	10,3	15,6	22,6
13,5	17,3	17,2	20,5	33,0		$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	$0,00	15,7	0,0	5,4	10,4	15,7	22,7
13,4	16,9	16,8	20,0	32,4		$1 875,90	$2 078,43	$2 238,57	-$939,56	-$1 057,01	-$1 174,45	-$1 291,90	-$1 409,34	-$1 526,79	-$1 644,23	-$1 761,68	-$1 879,12	-$1 996,57	-$2 114,01	15,9	-0,1	5,4	10,5	15,9	22,9
13,3	16,5	16,4	19,5	31,8		$3 657,00	$4 052,09	$4 364,49	-$1 893,25	-$2 129,91	-$2 366,56	-$2 603,22	-$2 839,88	-$3 076,53	-$3 313,19	-$3 549,85	-$3 786,50	-$4 023,16	-$4 259,82	16,0	-0,2	5,4	10,5	16,0	23,0
13,2	16,1	16,0	19,1	31,3		$5 339,42	$5 916,71	$6 373,16	-$2 861,39	-$3 219,07	-$3 576,74	-$3 934,41	-$4 292,09	-$4 649,76	-$5 007,44	-$5 365,11	-$5 722,78	-$6 080,46	-$6 438,13	16,1	-0,4	5,5	10,6	16,1	23,1
13,1	15,8	15,6	18,6	30,8		$6 919,17	$7 667,85	$8 259,82	-$3 844,31	-$4 324,85	-$4 805,39	-$5 285,93	-$5 766,47	-$6 247,01	-$6 727,55	-$7 208,09	-$7 688,63	-$8 169,16	-$8 649,70	16,2	-0,5	5,5	10,7	16,2	23,2
13	15,4	15,3	18,2	30,3		$8 392,14	$9 300,97	$10 019,58	-$4 842,36	-$5 447,65	-$6 052,94	-$6 658,24	-$7 263,53	-$7 868,83	-$8 474,12	-$9 079,42	-$9 684,71	-$10 290,00	-$10 895,30	16,3	-0,6	5,6	10,8	16,3	23,3
12,9	15,1	14,9	17,8	29,9		$9 754,11	$10 811,43	$11 647,46	-$5 855,87	-$6 587,86	-$7 319,84	-$8 051,82	-$8 783,81	-$9 515,79	-$10 247,77	-$10 979,76	-$11 711,74	-$12 443,73	-$13 175,71	16,5	-0,7	5,6	10,9	16,5	23,5
12,8	14,8	14,5	17,4	29,5		$11 000,82	$12 194,51	$13 138,36	-$6 885,22	-$7 745,88	-$8 606,53	-$9 467,18	-$10 327,84	-$11 188,49	-$12 049,14	-$12 909,79	-$13 770,45	-$14 631,10	-$15 491,75	16,6	-0,9	5,6	10,9	16,6	23,6
12,7	14,5	14,2	17,0	29,2		$12 127,92	$13 445,39	$14 487,11	-$7 930,79	-$8 922,13	-$9 913,48	-$10 904,83	-$11 896,18	-$12 887,53	-$13 878,88	-$14 870,22	-$15 861,57	-$16 852,92	-$17 844,27	16,7	-1,0	5,7	11,0	16,7	23,7
12,6	14,3	13,8	16,6	28,8		$13 131,01	$14 559,22	$15 688,50	-$8 992,95	-$10 117,06	-$11 241,18	-$12 365,30	-$13 489,42	-$14 613,54	-$15 737,65	-$16 861,77	-$17 985,89	-$19 110,01	-$20 234,13	16,9	-1,1	5,7	11,1	16,9	23,9
12,5	14,1	13,5	16,3	28,5		$14 005,65	$15 531,08	$16 737,23	-$10 072,10	-$11 331,11	-$12 590,12	-$13 849,14	-$15 108,15	-$16 367,16	-$17 626,17	-$18 885,19	-$20 144,20	-$21 403,21	-$22 662,22	17,0	-1,3	5,8	11,2	17,0	24,0
12,4	13,9	13,1	16,0	28,3		$14 747,33	$16 356,00	$17 627,97	-$11 168,66	-$12 564,74	-$13 960,82	-$15 356,90	-$16 752,99	-$18 149,07	-$19 545,15	-$20 941,23	-$22 337,32	-$23 733,40	-$25 129,48	17,1	-1,4	5,8	11,3	17,1	24,1
12,3	13,7	12,8	15,7	28,0		$15 351,56	$17 029,00	$18 355,35	-$12 283,05	-$13 818,43	-$15 353,81	-$16 889,19	-$18 424,57	-$19 959,95	-$21 495,33	-$23 030,71	-$24 566,09	-$26 101,48	-$27 636,86	17,3	-1,5	5,9	11,4	17,3	24,3
12,2	13,5	12,5	15,4	27,8		$15 813,78	$17 545,05	$18 913,96	-$13 415,71	-$15 092,67	-$16 769,63	-$18 446,59	-$20 123,56	-$21 800,52	-$23 477,48	-$25 154,45	-$26 831,41	-$28 508,37	-$30 185,34	17,4	-1,7	5,9	11,5	17,4	24,4
12,1	13,4	12,2	15,1	27,7		$16 129,42	$17 899,10	$19 298,38	-$14 567,08	-$16 387,97	-$18 208,86	-$20 029,74	-$21 850,63	-$23 671,51	-$25 492,40	-$27 313,28	-$29 134,17	-$30 955,06	-$32 775,94	17,6	-1,8	6,0	11,6	17,6	24,6
12	13,2	11,9	14,9	27,6		$16 293,89	$18 086,07	$19 503,14	-$15 737,65	-$17 704,86	-$19 672,07	-$21 639,27	-$23 606,48	-$25 573,69	-$27 540,90	-$29 508,10	-$31 475,31	-$33 442,52	-$35 409,72	17,7	-2,0	6,0	11,7	17,7	24,7
11,9		11,6	14,6			$110 684,43	$122 466,52	$131 782,60	-$16 927,90	-$19 043,88	-$21 159,87	-$23 275,86	-$25 391,85	-$27 507,83	-$29 623,82	-$31 739,81	-$33 855,79	-$35 971,78	-$38 087,77	17,9	-2,1	6,1	11,8	17,9	24,9
11,8		11,3	14,4			$110 772,94	$122 569,67	$131 897,32	-$18 138,31	-$20 405,60	-$22 672,89	-$24 940,18	-$27 207,47	-$29 474,76	-$31 742,05	-$34 009,34	-$36 276,63	-$38 543,92	-$40 811,21	18,0	-2,3	6,1	11,9	18,0	25,0
11,7		11,0	14,2			$110 862,96	$122 674,58	$132 014,01	-$19 369,42	-$21 790,60	-$24 211,78	-$26 632,95	-$29 054,13	-$31 475,31	-$33 896,49	-$36 317,66	-$38 738,84	-$41 160,02	-$43 581,20	18,2	-2,4	6,2	12,0	18,2	25,2
11,6		10,7	14,0			$110 954,54	$122 781,31	$132 132,70	-$20 621,75	-$23 199,47	-$25 777,19	-$28 354,91	-$30 932,63	-$33 510,35	-$36 088,07	-$38 665,79	-$41 243,51	-$43 821,23	-$46 398,95	18,3	-2,6	6,2	12,1	18,3	25,3
11,5		10,4	13,8			$111 047,71	$122 889,88	$132 253,47	-$21 895,87	-$24 632,85	-$27 369,83	-$30 106,82	-$32 843,80	-$35 580,78	-$38 317,77	-$41 054,75	-$43 791,73	-$46 528,72	-$49 265,70	18,5	-2,7	6,3	12,2	18,5	25,5
11,4		10,2	13,6			$111 142,51	$123 000,37	$132 376,35	-$23 192,33	-$26 091,37	-$28 990,42	-$31 889,46	-$34 788,50	-$37 687,54	-$40 586,58	-$43 485,62	-$46 384,67	-$49 283,71	-$52 182,75	18,6	-2,9	6,3	12,3	18,6	25,6
11,3		9,9	13,5			$111 238,99	$123 112,81	$132 501,40	-$24 511,74	-$27 575,71	-$30 639,68	-$33 703,65	-$36 767,62	-$39 831,59	-$42 895,55	-$45 959,52	-$49 023,49	-$52 087,46	-$55 151,43	18,8	-3,1	6,4	12,4	18,8	25,8
11,2		9,6	13,3			$111 337,20	$123 227,25	$132 628,69	-$25 854,72	-$29 086,56	-$32 318,40	-$35 550,24	-$38 782,08	-$42 013,92	-$45 245,76	-$48 477,60	-$51 709,44	-$54 941,28	-$58 173,12	19,0	-3,2	6,5	12,5	19,0	26,0
11,1		9,4	13,2			$111 437,17	$123 343,76	$132 758,27	-$27 221,89	-$30 624,62	-$34 027,36	-$37 430,10	-$40 832,83	-$44 235,57	-$47 638,30	-$51 041,04	-$54 443,78	-$57 846,51	-$61 249,25	19,1	-3,4	6,5	12,6	19,1	26,1
11		9,1	13,1			$111 538,97	$123 462,39	$132 890,21	-$28 613,92	-$32 190,66	-$35 767,40	-$39 344,14	-$42 920,88	-$46 497,62	-$50 074,35	-$53 651,09	-$57 227,83	-$60 804,57	-$64 381,31	19,3	-3,6	6,6	12,7	19,3	26,3
10,9		8,9	13,0			$111 642,63	$123 583,19	$133 024,57	-$30 031,49	-$33 785,42	-$37 539,36	-$41 293,29	-$45 047,23	-$48 801,17	-$52 555,10	-$56 309,04	-$60 062,97	-$63 816,91	-$67 570,85	19,5	-3,8	6,6	12,9	19,5	26,5
10,8		8,6	12,9			$111 748,21	$123 706,23	$133 161,42	-$31 475,31	-$35 409,72	-$39 344,14	-$43 278,55	-$47 212,96	-$51 147,38	-$55 081,79	-$59 016,20	-$62 950,62	-$66 885,03	-$70 819,44	19,7	-3,9	6,7	13,0	19,7	26,7
10,7		8,4	12,9			$111 855,76	$123 831,57	$133 300,82	-$32 946,12	-$37 064,38	-$41 182,65	-$45 300,91	-$49 419,18	-$53 537,44	-$57 655,71	-$61 773,97	-$65 892,23	-$70 010,50	-$74 128,76	19,9	-4,1	6,8	13,1	19,9	26,9
10,6		8,2	12,8			$111 965,34	$123 959,28	$133 442,86	-$34 444,68	-$38 750,26	-$43 055,85	-$47 361,43	-$51 667,02	-$55 972,60	-$60 278,19	-$64 583,77	-$68 889,35	-$73 194,94	-$77 500,52	20,0	-4,3	6,8	13,2	20,0	27,0
10,5		8,0				$112 077,01	$124 089,42	$133 587,60	-$35 971,78	-$40 468,25	-$44 964,73	-$49 461,20	-$53 957,67	-$58 454,14	-$62 950,62	-$67 447,09	-$71 943,56	-$76 440,04	-$80 936,51	20,2	-4,5	6,9	13,3	20,2	27,2
10,4		7,7				$112 190,83	$124 222,06	$133 735,12	-$37 528,25	-$42 219,28	-$46 910,32	-$51 601,35	-$56 292,38	-$60 983,41	-$65 674,44	-$70 365,47	-$75 056,51	-$79 747,54	-$84 438,57	20,4	-4,7	7,0	13,5	20,4	27,4
10,3		7,5				$112 306,85	$124 357,27	$133 885,51	-$39 114,95	-$44 004,31	-$48 893,68	-$53 783,05	-$58 672,42	-$63 561,79	-$68 451,16	-$73 340,52	-$78 229,89	-$83 119,26	-$88 008,63	20,6	-4,9	7,0	13,6	20,6	27,6
10,2		7,3				$112 425,16	$124 495,14	$134 038,85	-$40 732,75	-$45 824,35	-$50 915,94	-$56 007,53	-$61 099,13	-$66 190,72	-$71 282,32	-$76 373,91	-$81 465,50	-$86 557,10	-$91 648,69	20,8	-5,1	7,1	13,7	20,8	27,8
10,1		7,1				$112 545,80	$124 635,74	$134 195,22	-$42 382,59	-$47 680,42	-$52 978,24	-$58 276,07	-$63 573,89	-$68 871,71	-$74 169,54	-$79 467,36	-$84 765,19	-$90 063,01	-$95 360,84	21,0	-5,3	7,2	13,9	21,0	28,0
10		6,9				$112 668,86	$124 779,15	$134 354,73	-$44 065,43	-$49 573,61	-$55 081,79	-$60 589,97	-$66 098,15	-$71 606,33	-$77 114,51	-$82 622,69	-$88 130,86	-$93 639,04	-$99 147,22	21,2	-5,5	7,2	14,0	21,2	28,2