A decision support tool for the Heavy Lift Shipping Industry

A case study for the fleet composition of Jumbo Maritime

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by

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TU Delft

JUMBO

Preface

The graduate assignment "A Matching Model for the Jumbo fleet in the Heavy Lift Shipping Industry" is performed in order to complete the track Transport Engineering & Logistics of the Mechanical Engineering master degree at the Delft University of Technology. This assignment is commissioned by Jumbo Maritime which is a heavy lift shipping & installation contractor.

I could not have completed this assignment successfully, without the help of employees of Jumbo Maritime, support from my supervisor of the TU Delft and my friends and family. First of all, I would like to thank my company supervisor Kasper van der Heijden for giving me the opportunity of this graduate assignment and his advice and feedback. Subsequently, I would like to thank Jimmy Song, data analyst, for providing the available shipping data from the Jumbo database. I would also like to thank my fellow graduate students Karel, Geert, Job and Sebas for the study related conversations and motivation during the breaks.

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N. Hagen
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Nomenclature

Abbreviations

CMOP	Constrained Multi-objective Operational Problem
CRM	Customer Relationship Management
DP	Dynamic Positioning
DWT	Dead Weight Tonnage
FA	Fleet Assignment
FAM	Fleet Assignment Model
HLCV	Heavy Lift Crane Vessel
KPI	Key Performance Index
LP	Linear Programming
MFRP	Maritime Fleet Renewal Problem
MFSMP	Maritime Fleet Size and Mix Problem
MFSP	Maritime Fleet Size Problem
MILP	Mixed Integer Linear Programming
MOLP	Multi Objective Linear Programming
MPV	Multi Purpose Vessel
PVRP	Periodic Vehicle Routing Problem
SFRPS	Strategic Fleet Renewal Problem in Shipping
SVPP	Supply Vessel Planning Problem
SWL	Safe Working Load
VRP	Vehicle Routing Problem

Symbols

D	Dead weight	kg
H	Hold bale	m^3
K	Cargo gear	kg

Terminology

Air draft	Distance from the waterline to the highest point on a vessel
Dead-weight	A measurement of total contents of a ship including cargo, fuel, crew, passengers, food, and water aside from boiler water. The total weight of the cargo can be a limiting factor for the cargo shipped by the Jumbo fleet [1]
Draft	Vertical distance between the bottom of the hull and the waterline of the vessel (thickness of the hull included) [20]

Fix	A collection of contracted cargoes that are subjected to one booking and will be shipped by Jumbo [20]
Inquiry	A fix, that can be transformed into a booking, if it is possible to be added to the current shipping schedule [20]
Operating costs	Expenses involved in the day-to-day running of the ship and incurred whatever trade the ship is engaged in [33]
Validation	Substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model [27]
Verification	Ensures that the computer programming and implementation of the conceptual model are correct [29]
Voyage	Selection of fixes which are combined into with an identical number per vessel

Abstract

Jumbo Maritime is a company specialized in handling and transporting substantial cargoes which did not fit into a container. To compete in the heavy lift shipping market, a well-balanced fleet composition is essential. In the current situation, the heavy lift cargoes are transported by a fleet consisting of ten vessels, having a varying crane lifting capacity from $3000 * 10^3$ to $650 * 10^3$ kilogram (Class K, H, J and E). However, in the past five years, it has become apparent that the deployment of the vessels based on the heaviest item (between 75-100% of the capacity) has only been needed in a meagre five percent of all transportations. The installed crane capacity on the Jumbo vessels are an overcapacity compared to the demand of the market. During this research, a decision support tool is developed to improve the match between the demand from the market in the heavy lift cargo industry and the supply of the heavy lift shipping vessels. This will result in an improved fleet composition that maximizes profit. Subsequently, the tool has been examined to see whether it can henceforth be applied to the fleet composition to support Jumbo Maritime in its leading role of supplying heavy loads.

The Maritime Fleet Size & Mix Problem model was used to find the optimal fleet composition. The goal of this model is to maximize profit, achieved from transport orders based on reduced cost of the vessels. Considering that the proceeds of a load depend on market demand, the transport data of the past five years has been used as an input parameter. A fleet is chosen by taking into consideration both the technical and financial aspects. The technical aspect is the maximum combined crane capacity installed on the vessels. The financial aspects of the vessels exist of capital costs, labour costs, fuel costs and maintenance costs. The result of this model will lead to an optimization in the distribution of the vessel.

Subsequently, the vessels that are at the end of their life will be replaced in the near future. The Vessels classified under H and E will be replaced by a variety of the newer J-light classes. The decision about the composition of the new vessels in the Jumbo fleet should be supported by the optimization model. The new vessels will be used as input in the model, together with the prediction data of possible future market needs. These future predictions will consist of three scenarios: 1) the demand will stay the same as it has been for the past five years; 2) Demands will rise with 6% due to an increase in the oil and gas industry; 3) a 35% increase in the renewable energy related market. The result of the three scenarios will be a new fleet composition with a corresponding profit.

An optimal fleet composition will be the result when the transport data of the past five years, together with the current fleet characteristics, are used as input for the Maritime Fleet Size & Mix Problem. The current fleet composition [2:4:2:2] is in the optimized situation as followed [1:2:1:8], whereby the theoretical gain increases from 108 million to 181 million. When the future scenarios one, two and three together with the new vessel types (K: J: J-900: J-800: J-700: J-600) are introduced, new optimum fleet compositions arise. The new optimized compositions are as follows: scenario one: [1:1:0:1:0:6] with a profit of 56 million, scenario two: [1:1:0:1:0:6] with a profit of 68 million and scenario three [1:1:0:1:0:6] with a profit of 58 million.

The results of the Maritime Fleet Size & Mix Problem show that the profit can be optimized with an alternative fleet composition. The mathematical model determines the composition of the fleet by using the transport data from the past five years. The optimization model is subjected to a number of assumptions to approach the reality. By also using the Maritime Fleet Size & Mix Problem model with the introduction of the J-light and combining it with the three different future scenarios, the vessel type with a combined crane capacity of 600 tonnes appears to be the most efficient in the J-light class.

Summary (Dutch)

Jumbo Maritime is gespecialiseerd in het verplaatsen van grote ladingen welke niet in een container te vervoeren zijn. Om te kunnen concureren in de markt van zware lading transporten is het van belang om een gebalanceerde vloot samenstelling te hebben. In de huidige situatie worden deze ladingen getransporteerd met een vloot van tien schepen die variëren van 3000 tot 650 ton kraancapaciteit (K, H, J en E klasse). In de afgelopen 5 jaar is gebleken dat de inzet van de schepen gebaseerd op de zwaarste lading (tussen 75-100% van het capaciteit) slechts werd ingezet in 5 procent van de verschepingen. Een beslissingsondersteunend model is ontwikkeld tijdens dit onderzoek om er voor te zorgen dat er een betere overeenkomst behaald kan worden tussen de vraag vanuit de zware ladingen markt en het aanbod van de transport schepen van zware ladingen. Het model zal resulteren in een verbeterde vlootsamenstelling waarbij winst gemaximaliseerd wordt. Vervolgens is gekeken of dit beslissingsondersteunend hulpmiddel kan worden toegepast voor de toekomstige vloot samenstelling van Jumbo in de markt van het transport van zware ladingen.

Voor de optimale vlootsamenstelling is gebruik gemaakt van het Maritime Fleet Size & Mix Problem model. Het doel van dit model is het maximaliseren van de winst die bestaat uit de omzet behaald uit transport opdrachten verminderd met de kosten van de schepen. De opbrengsten van de transportopdrachten zijn afhankelijk van de vraag uit de markt. Hiervoor is de data van de transportopdrachten van de afgelopen vijf jaar gebruikt als input parameter. De eigenschappen van de vloot bestaan uit technische en financiële eigenschappen. De technische eigenschappen gaan om het maximaal gecombineerde kraanvermogen welke op de schepen zijn geïnstalleerd. De kosten van deze schepen zullen bestaan uit kapitale kosten, loonkosten, brandstofkosten en onderhoudskosten. Het resultaat van dit model zal leiden tot een optimalisatie van de verdeling van de vloot.

Vervolgens zullen de huidige schepen die aan het einde van de levensduur zijn vervangen worden. De H- en E-klasse zullen vervangen worden door verschillende varianten van de nieuwe J-light klasse. De keuze welke schepen er in de nieuwe samenstelling van de vloot zouden moeten zitten zal ondersteund worden door het optimalizatie model. Deze nieuwe schepen zullen als input gebruikt worden in het model samen met de voorspellingen van de vraag in de toekomst. Deze toekomstvoorspellingen van de vraag zullen bestaan uit drie scenario's, namelijk: 1) vraag gelijk aan afgelopen vijf jaar; 2) vraag stijgt met 6% door toename in olie en gas industrie; 3) Toename van hernieuwbare energie gerelateerde markt van 35%. Bij deze scenarios zal een nieuwe vlootsamenstelling met een bijhorende winst het resultaat zijn.

Wanneer de transportdata van de afgelopen vijf jaar samen met de huidige vlooteigenschappen als input gebruikt worden voor het Maritime Fleet Size & Mix Problem, resulteert dit in een optimale vloot samenstelling. De huidige vlootsamenstelling (2,4,2,2) wordt in de geoptimaliseerde situatie (1,2,1,8), waarbij de theoretische winst toeneemt van 108 mln naar 181 mln. Wanneer de toekomst scenario's 1, 2 en 3 samen met de nieuwe scheepstypen (K,J, J900, J800 , J700 , J600) worden ingevoerd, ontstaan er nieuwe optimale vlootsamenstellingen, namelijk: scenario 1 (1:1:0:1:0:6), scenario 2, (1:1:0:1:0:6), scenario 3(1:1:0:1:0:6). In deze scenario's is de winst respectievelijk, 56 mln, 68 mln, 58 mln.

Uit de resultaten van het Maritime Fleet Size & Mix Problem blijkt dat de winst kan worden geoptimaliseerd met een alternatieve vlootsamenstelling. Het wiskundige model bepaalt de samenstelling van de vloot aan de hand van de transportgegevens van de afgelopen vijf jaar. Het model is onderhevig aan een aantal aannamens om de werkelijkheid te kunnen benaderen. Door ook het Maritime Fleet Size & MixProblem model te gebruiken bij de introductie van de J-light klasse en deze te combineren met drie verschillende toekomst scenario's, blijkt dat de variant met een gecombineerd kraanvermogen van 600 ton het meest aantrekkelijk is in de J-light klasse.

Contents

List of Figures

List of Tables

1 Introduction

In this chapter the graduate assignment will be introduced. First of all, the background of the company will be discussed supplemented with the relevance of the project in section 1.1. Secondly, the research problem will be explained with a research objective and a research question in section 1.2. Subsequently, in section 1.3, the scope of the project will be formulated to limit the project boundaries. Furthermore, the motivation of the project is described with the research gap in section 1.4. Finally, the structure of the report is explained in section 1.5.

1.1. Background and Relevance

This research is conducted at the company Jumbo Maritime, a heavy lift shipping & offshore transportation and installation contractor. Jumbo is founded in 1968 and is a family owned company. Jumbo is a shipper for pieces that do not fit into a container or on a pallet [22]. For the transportation and lifting of heavy pieces, Jumbo has a fleet which consists of ten specialized Heavy Lift Crane Vessels (HLCV's) that are in-house designed. Each Jumbo vessel has his own characteristics; the type of ship which is preferred depends on the application of the transported and lifted goods. The Jumbo fleet operates with their vessels in the heavy lifting with capacities ranging from 650 to 3,000 $*10^3$ kilograms. Jumbo strives to obtain and maintain a position as the acknowledged leading Maritime Company in Heavy Lift, integrated transportation and offshore installation [23]. The founding principle of Jumbo is as follows: *"Success comes from looking beyond the needs of today, into the possibilities of tomorrow."*

Jumbo is a family owned company in heavy lift transport and integrated offshore transport & installation. The shipping and offshore installation industry is the preferred combination for the business model. The goal of the offshore shipping industry is to maximize the profit in both categories. Although the challenges in both sectors are different, both are complementary and strengthening each other. With a higher utilization of our vessels and a flexible organization we remain active in shipping and offshore installation. The Jumbo organization chart is given in Appendix B.4.

Nowadays, it often occurs that the vessel capacities do not match with the demand of the offshore transportation market. This results in high amounts of redundant running costs and an inefficient way of transportation. There is a lot to gain if there is a better match between the demand of the fluctuating offshore shipping market and the Jumbo vessel capacities. While the demand of maritime transportation reacts quickly to changes in freight rates, the supply adapts slowly to changes in demand, mostly because of the long lead time associated with the acquisition of new ships [25]. To obtain a better match, the fleet should be adapted to the demand in the near future. For this application, a prediction should be made about the demand in the near future to provide a recommendation about the fleet composition of the Jumbo fleet. With the help of a mathematical model, a more strategic decision can be made between the alternative options of the vessel composition for the near future which corresponds to the demand of the offshore shipping market.

1.2. Problem Statement

To participate in the competition of the heavy lift shipping industry, it is important to operate as efficiently as possible. It often occurs that the vessels of Jumbo sail with a load that does not come close to the maximum lifting capacity. Figure 1.1 describes the utilization of the crane capacity per vessel class of the Jumbo fleet. Remarkably, few cargoes use the maximum capacity of the cranes installed on the Jumbo vessels, which means that the crane capacity installed on the vessels are an overcapacity. Especially for the relative expensive K-class vessels, most of the transported cargoes are in the range between 0 and $750*10^3$kg. The result will be a redundant crane capacity corresponding to higher investment costs of the vessels. Increasing fleet size beyond its minimum size is very costly because this will increase the time charter costs as well, this is the majority of the total costs. Therefore, more vessels than really required would never be considered no matter how much this would increase the solution persistence [4]. The costs of the cranes on the vessels are approximately between 25% and 50% of the total costs of acquisition and are highly dependent on the lifting capacity. Therefore, it is essential to use the crane capacity as much as possible to achieve the highest amount of profit. This research will provide a more matching fleet composition to fulfil the demand of the shipping goods. A more matching fleet composition will lead to a competitive market position and can give a profit optimization due to a competitive fleet composition.

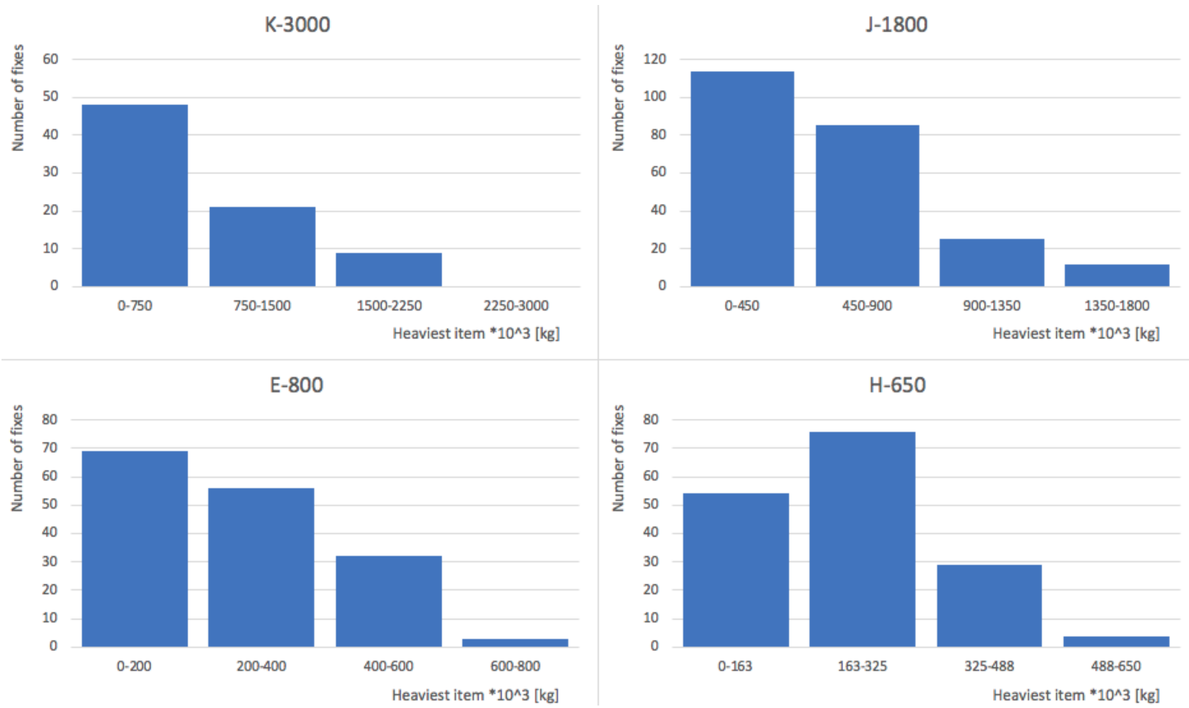

Figure 1.1: Crane utilization per vesselclass

The fleet assignment will be a strategic determination of the vessel type configuration to operate on the heavy lift offshore transportation. A prediction of the demand for the heavy lift shipping market in the near future is done in a few scenarios. Besides the approach of the demand in the heavy lift shipping market, the characteristics of the Jumbo fleet are important as supply side for the fleet composition. The available vessel classes in the near future are different compared to the current vessels in the Jumbo fleet. The current E- and H-classes are substituted by the new J-light vessels. With the help of a mathematical model, a more matching fleet composition will be defined by a better overview of the demand of the Heavy Lift shipping industry and the capacities of the Jumbo fleet.

1.2.1. Research Objectives

The goal of the project is to maximize the vessel performance by a better match between the demand of the Heavy Lift Shipping market and the Jumbo fleet composition.

- Create insight in the demand and supply of the Heavy Lift Shipping industry.

- Develop an optimization model for the recommendation of the Jumbo fleet composition for the near future based on the available shipping data.

1.2.2. Research Question

The project is subjected to a main research question. The main question of the project is:

How to improve the Jumbo fleet composition?

The main question is divided into the following sub-questions:

1. *What are the characteristics of the heavy lift shipping industry?*
2. *Which optimization models are described in literature and which model is most suitable for the Jumbo situation?*
3. *How can the characteristics of the heavy lift shipping industry be implemented in the profit maximization model?*
4. *What is the impact of the improved fleet composition on the profit?*

1.3. Research Scope

The research scope of the project is based on the available data from the past five years. The fix data of the past period are required for a demand forecasting in the near future. The reason of this limitation is the relevance of the data. The fleet distribution for the near future is probably more similar to the past five years compared to earlier datasets. The demand in the near future is an essential input parameter for the mathematical model used to recommend a fleet composition with a maximized profit. The assignment is limited on the strategic level to adjust the fleet composition to the fixes of the past five years.

1.4. Motivation and Research Gap

The research gap for the graduate assignment will be the approach of an optimization for the match between the market and the fleet composition for Jumbo Maritime. This approach will be obtained from an optimization model with exclusively objectives and constraints based on the data of Jumbo Maritime from the past period of five years. In the literature, there are multiple papers available about operation research and optimization models. The research gap for this assignment is the application of an optimization model for the fleet composition of an offshore shipper in the heavy lift crane vessel industry. The output of the model will give an optimal solution for the Jumbo fleet composition in the offshore transport market.

1.5. Outline of the Project

This research is subdivided into phases to create a structured overview of the thesis. It contains the following phases: *Introduction, Theory, Analysis & Methods, Results and Discussion.* The chapters of the thesis belong to one of each phase. In table 1.1, the outline of the project is displayed with the related sub-questions of each chapter. In figure 1.2, the relation between the chapters of this report are given in an overview.

Table 1.1: Outline of the project

Phase	Chapter	Sub-Question
Introduction	1. Introduction	All
Theory	2. Heavy Lift Shipping Market	1
	3. Literature Research	2
Analysis & Methods	4. Model development	3
Results	5. Results	4
Discussion	6. Conclusion and Recommendations	Main question

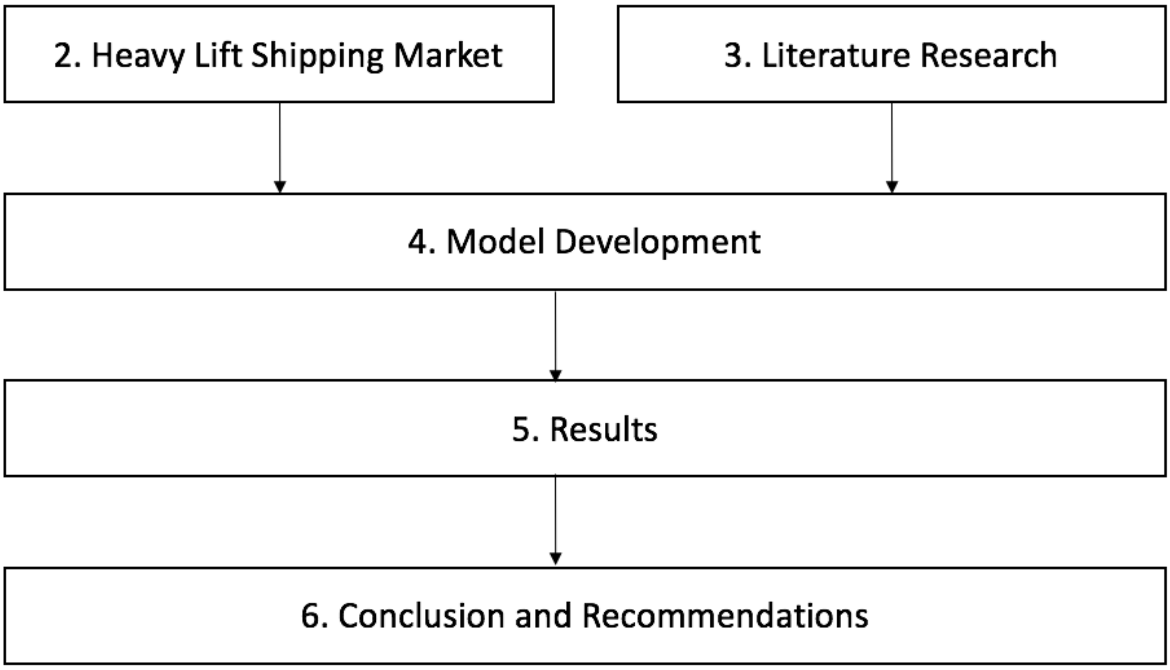

Figure 1.2: Coherence between each chapter in the project

2

Heavy Lift Shipping market

Sea transport can be classified into three cargo types, namely: Bulk Cargo, General Cargo and Specialized Cargo [33]. Jumbo operates with their heavy lift shipping vessels in the Specialized Cargo market. For the specialized shipping market, it is about adapting the shipping operation to the needs of a specific customer group and cargo flow. The disadvantage of the specialized shipping market is that vessels are more expensive and complex compared to normal bulk carriers. In this chapter, the demand and supply side of the heavy lift shipping industry are described in order to understand how to reach a better match between the demand and supply side of the heavy lift shipping industry with an optimal profit. The related sub-question discussed in this chapter is:

- **What are the characteristics of the heavy lifting shipping industry?**

To optimize the profit in the heavy lift shipping industry, it is essential to analyse the characteristics of the demand and supply side of the heavy lift shipping industry. Therefore, section 2.1 will discuss the demand in the heavy lift shipping industry with the characteristics of the charterers in the market and what kind of cargo is shipped by the Jumbo fleet. What are the dependent factors for these charterers and what are the limiting factors for the shipped cargoes? Section 2.2 will give an introduction about three demand scenarios for the near future. In section 2.3, the supply side of the market will be discussed with the characteristics of the vessels in the fleet. Both the historic fleet of Jumbo as well as the present Jumbo fleet will be described including characteristics of these vessels. The properties of the transported cargo from the demand side of the heavy lift shipping market determines the vessel characteristics. For the future situation, the new J-light variants are introduced in section 2.4 to implement in the optimization model for the different demand scenarios. In section 2.5, the situation of the market share and the booking process are shown with the corresponding revenue structure. This chapter is will finish with an intermediate conclusion in section 2.6.

The profit of the fleet depends on the revenue and the costs of the fleet. In this chapter the depending factors for the vessel revenue and costs structure are analysed to indicate the important input parameters for the optimization model to obtain a profit maximization.

2.1. Demand of the Heavy Lift Shipping Market

To obtain a more matching model between the demand and supply in the heavy lift shipping market, it is essential to investigate the most influential parameters. The market of the maritime economics is very complex, therefore this research restricts to the parameters with the most impact [33]. The demand of the heavy lift shipping market is important for the fleet composition of the offshore shippers. This demand is leading for the strategic decisions for the number and types of vessels acting in the fleet.

The most important factor for the demand in the shipping market is the world economy[33]. The economic cycles are divided into internal and external factors. Internal factors are related to the dynamic structure of the world economy and the external factors are a result of random shocks. The cause of a random shock cannot be predicted because of the unique occasion. The result of random shocks will be a deviation from the normal cycle, but according to Stopford [33], the impact of a random shock on the shipping market is often very severe. Examples of random shocks are: weather changes, new resources, wars and commodity price changes. These events are out of the scope of the market analysis for the demand of the heavy lift shipping market. According to Stopford[33], there is a close relationship between the freight rates and the cycles in the economy. These trends caused by an increasing industry result in more products transported over sea. The 'business cycle' of the world industry is the most important cause of short-term fluctuations in seaborne trade and ship demand. Figure 2.1 shows the relationship between the Gross Domestic Product compared and the sea trade.

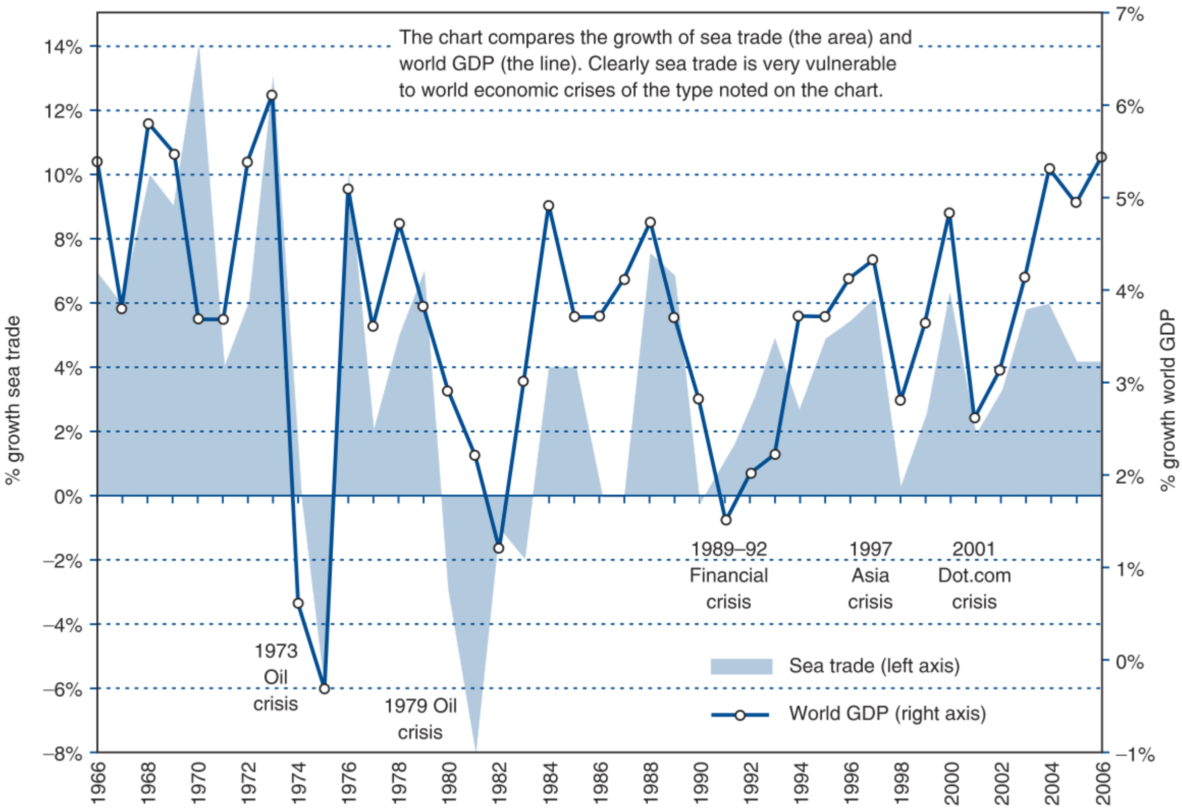

Figure 2.1: World GDP cycles and sea trade [33]

The relationship between the GDP and the sea trade given in figure 2.1 provides a clear view on the overall sea transport. However, the heavy lift shipping market might be divergent from to the overall shipping market. Therefore, this study analyses the reason why the main charterers of the heavy lift shipping market to make an accurate prediction for the near future on this complex market. According to Hagenbeek [11], the main charterers of the Jumbo vessels with examples of the cargoes are given in table 2.1.

Table 2.1: Overview charterers and examples of their cargoes

Charterer	Examples of Cargoes
Major Oil & Gas Companies	Reactors, Refinery Equipment, LNG Modules
EPC companies	Towers, Reels, Mono-piles, Turbines, Mooring Systems
Manufacturers	Generators, Engines, Transformers
Major Mining Companies	Ship-loaders, Locomotives
Other	Yachts, Ferries, Barges, Small Craft

The demand of the major oil and gas companies depends on the oil price. Increasing oil prices will result into more investments for the oil and gas equipment. Engineering Construction Companies can be related to the energy companies or can be contracted by governments to build for example infrastructure projects. The engineering construction companies are the subcontractors between the shipper and the heavy lift operators. The charterer type manufacturers consist of products who need to transport to the end client. The major mining companies transport their utilities that have to be installed at the terminals. The origin of the charterers is important for the prediction in the near future. The most significant drivers of demand for heavy lift shipping are the crude oil price and the viability of renewable energy [11]. The crude oil price is a key indicator for demand of heavy lift shipping industry, as running projects in the oil and gas industry require transportation of project cargo. According to USEIA [35], the future oil prices are highly uncertain and are subject to international market conditions influenced by factors outside of the National Energy Modelling System, which makes it an unpredictable factor for the demand in the heavy lift industry.

Forecast energy consumption The problem for maritime forecasters is that unfortunately Peter Drucker is right – there are important aspects of the future of the maritime industry that are not predictable. Future freight rates depend on how many ships are ordered, a behavioural variable which at the extremes of shipping cycles is totally unpredictable, and developments in the world economy which, with its business cycles and crises, are far too complex for mere mortals to predict with any degree of certainty. In these circumstances even the most sophisticated scientific forecasting methods will have limited success [33].

According to USEIA [35], the projection of the energy consumption for the near future is growing. In figure 2.2, The renewable energy (green line) is the fastest growing percentage compared to the other energy sources given in the figure. Policies have encouraged the use of renewable energy, resulting in an increasing demand for renewable energy sources. The growing market for renewable energy will reduce investment costs for these technologies, this enables the renewable energy to be more competitive compared to other energy sources. Besides the renewable energy source, the consumption of natural gas rises as well. This prediction is driven by a projected low natural gas price. Since natural gas is one of the main charterers of the clients of jumbo, the growing projected consumption of natural gas and renewable energy should be an interesting perspective for the demand of the heavy lift shipping industry.

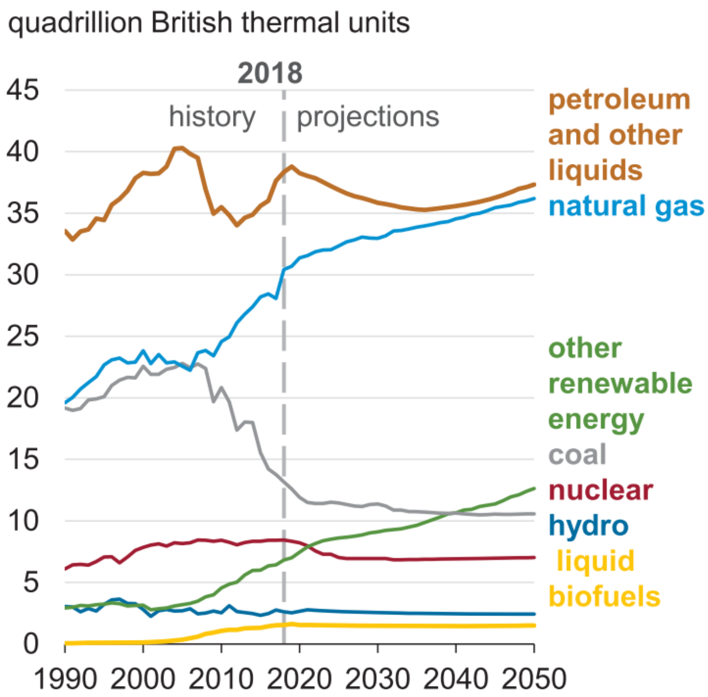

Figure 2.2: Energy consumption by fuel [35]

2.1.1. Cargo characteristics

The possibility of transport is dependent from a few input parameters. The critical parameters of the cargoes should be within the limits of the vessels. In this section the limiting factors of the cargoes are explained. According to Jumbo shipping data of the last five years, the most common reasons why inquiries are cancelled are:

- Port restrictions
- Working radius(outreach)

- Maximum lifting height
- Hoisting capacity
- Dimensions
- Deck strength
- Air draft
- Dead weight

Not every limiting factor can be used for the constraints in the model because of the complexity of the amount of input parameters and the documentation of the used parameters from the Jumbo database. Parameters that are not or less documented are given in the recommendation for a more optimal model which should be closer to the reality compared to this model situation.

Port restrictions The port restrictions are the characteristics of the port that are different for every port. Due to this reason, the port restrictions are out of scope of this assignment. Examples of port restrictions are the length of the quayside and the water depth. The draft of the vessel depends on the water displacement of the vessel. In a critical situation, it can be possible to discharge main or tween decks to minimize the draft of the vessel. Also, the distance between the vessel and the cargo can be a restricting factor due to the limited length of the arm of the crane. The operations department should take these parameters into account.

Working radius The working radius of the cranes installed on each vessel are limited because of the length of the arm. Because of the moment of inertia, the ability to lift a heavy mass on an increasing working radius, the lifting capacity decreases. An overview of the decreasing lifting capacity compared to the radius is given in figure 2.3 for the Jumbo J-class vessels. In this figure, the fly-jib (shown in figure 2.4 is installed to expand the outreach of cranes. The fly-jib should be implemented on the cranes for the J-class vessels. For the other vessel classes, implementation of the fly-jib is not possible. An overview of the load and clearance curve of the Jumbo J-class is given in 2.3. In this figure, the relation between the maximum lifting combined with the working height and the working radius are shown. In addition, the hoist capacity decreases by an increasing outreach.

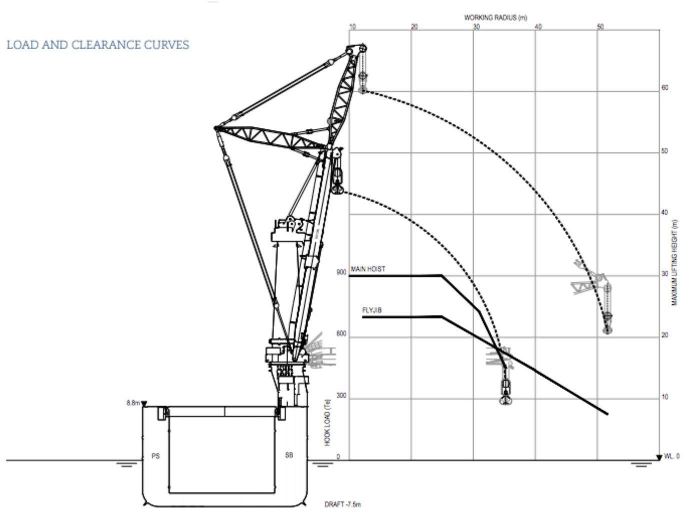

Figure 2.3: Load and clearance curves of the Jumbo J-class

Maximum lifting height Another limiting factor is the maximum lifting height of the cranes. Very large cargo items exceed the maximum lifting height. An option to expand the lifting height of the crane is to install a fly-jib, figure 2.4 displays a fly-jib configuration. But, as aforementioned this is only possible for the J-class vessels. The maximum lifting height depends on the outreach and is given in figure 2.3 for the j-class vessels. For the cranes on the remaining vessel classes, the curves of the maximum lifting height are comparable.

Figure 2.4: Fly-jib installed on the Jumbo J-class vessel

Hoisting capacity The hoisting capacity of the vessels depends on the crane combination installed on a heavy lift vessel. On each vessel of the jumbo fleet, two cranes are installed. They can combine their maximum lifting capacity by summarizing the capacity of both cranes. The advantage of using one crane is the time gain compared to an operation with both cranes that are required for an operation. The hoisting capacity of the crane combination should exceed the weight of the heaviest item of the cargo. In figure 2.3, the hoisting capacity of the J-class vessels is given. The maximum capacity is decreasing for an increasing outreach. In figure 2.5, the heaviest item of the cargo loaded on each vessel class is given. Remarkable is the fact that a few cargoes are above the maximum crane capacity. Probably, this should be an error of the documentation because these cargoes exceed the maximum crane capacity.

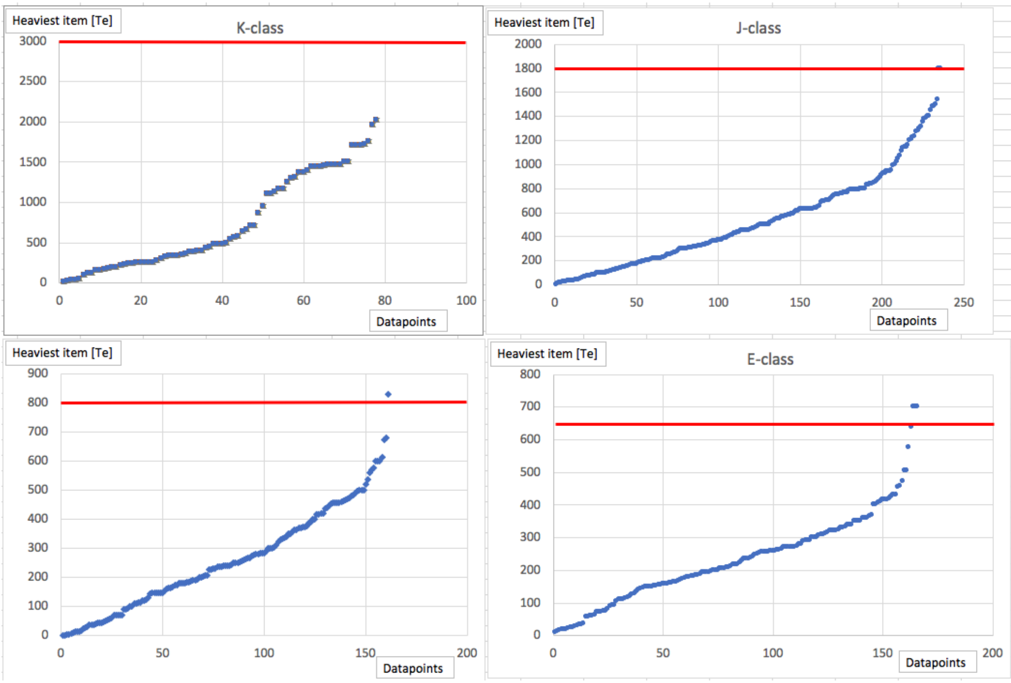

Figure 2.5: Heaviest item on each vessel class of the Jumbo fleet

The cumulative heaviest cargo of the fixes shipped in the past five years over the Jumbo fleet are given in figure 2.6. Most of the cargoes are in the category between 0 and $500 * 10^3$ kilograms. The current challenge is to make a better match between the Jumbo fleet compared to the cargoes of the demand. With a better match between the vessel and the cargo, the crane capacity is close to the weight of the heaviest item of a cargo. A better match can result in a more competitive market position and an increasing profit.

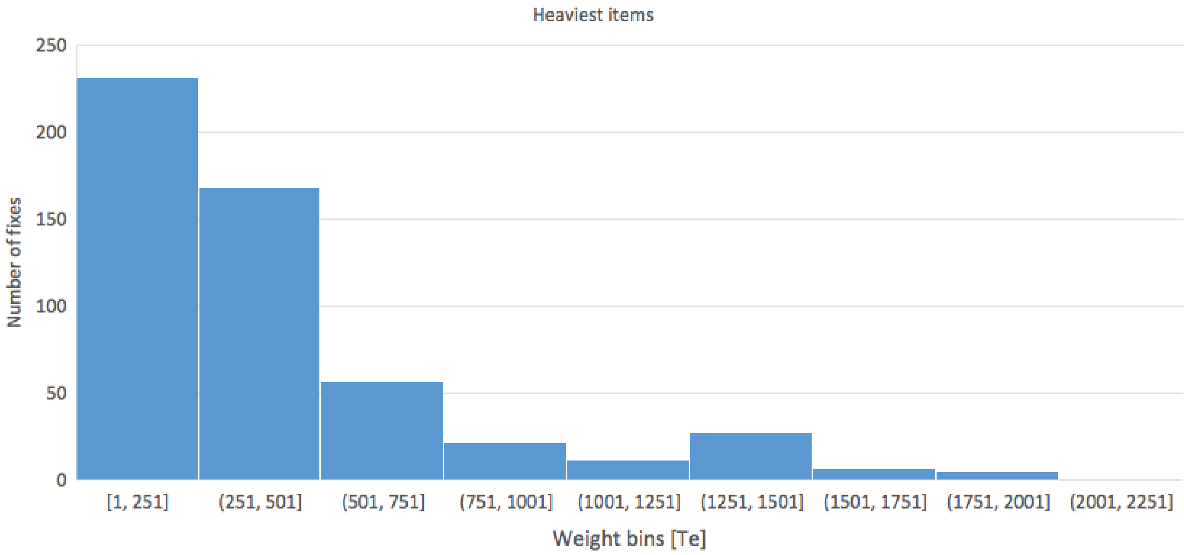

Figure 2.6: Heaviest item shipped by the Jumbo fleet in the past five years

Dimensions The vessel dimensions can also be a limiting factor for the cargo. The cargo can be placed in the hold or on the deck. The volume of the hold is limited and the dimensions of the hold are given in cubicle meters. For the space on deck, the dimensions are given in square meters. The price for the cargo under deck is higher compared to the variant on deck. In the Jumbo database, only the limiting factor 'hold dimensions in cubicle meters' is given. For the engineering department, the deck space can also be a limiting factor. Mostly, the limiting factors are the dimensions instead of the hold volume, because the cargo is too wide or too large and not because it is exceeding the volume of the cargo hold of the vessel.

Deck strength The deck strength is a parameter that defines whether the deck is strong enough for the loaded cargo. This parameter is important for the engineering department of Jumbo. If the cargo exceeds the maximum deck strength, the deck can suffer from minor hull damage to failure and sinking. The deck strength of the tween decks is less compared to the strength of the tank-top. The disadvantage of a stronger ship, which could resist more load per square meter, is a heavy and slow vessel which costs more money to build. A stronger vessel is more expensive to build because of material costs and more expensive to sail because of an increasing draft. The increasing draft is also not desirable due to shallow water depths in a few ports. A balanced combination of the deck strength and the total weight of a vessel is a compromise.

Air draft The air draft is the distance from the waterline to the highest point on a vessel. In case of crossing a bridge on a vessel route, the air draft should be smaller compared to the height of the bridge. For the routing of the vessels, this parameter should be considered. For the capacity utilization, the air draft is out of scope.

Dead-weight Dead-weight tonnage is a measurement of total contents of a ship including cargo, fuel, crew, passengers, food, and water aside from boiler water. The total weight of the cargo can be a limiting factor for the cargo shipped by the Jumbo fleet [1]. For the utilisation of the crane capacity, the summarized number of tonnes transported by the vessel is not relevant for the crane capacity installed on the vessels. A more interesting parameter for the types of cranes installed on the vessel is the total weight of the heaviest item. If the weight of the heaviest item is exceeding the crane capacity of the vessel, a larger crane is required.

Model input parameters For the optimization model of this assignment, the weight of the heaviest item is used as an input parameter for the model. In a more optimal situation, the lifting height and the outreach of the crane would also be implemented as input parameters. These parameters can be combined in the load and clearance curve given in figure 2.3. Because of the limited documentation of the Jumbo database, only the heaviest item of each fix is documented. It is also possible to assume the lifting heights and the outreach of all these cargoes but this is not a reality-based approach.

2.2. Future demand scenario's

In order to take into account the demand expectations for the near future (next 5 years), a number of future scenarios are drafted as input parameters for the optimization model. These scenarios will probably be able to produce divergent fleet compositions. These scenarios will be composed based on expectations in the literature. The different scenarios will be discussed and explained in this chapter. According to Pantuso [25], maritime economics has always been characterized by a cyclic repetition of peaks and troughs in demand and freight rates. The cyclic repetition of peaks and troughs in demand is difficult to follow, because the supply side of the shipping market cannot move fast enough with the demand of the amount of freight rates due to the acquisition time of new vessels.

2.2.1. Scenario 1: Demand is equal to previous five years

In the first forecasting scenario for the demand in the near future, the demand should be equal to the number of fixes loaded and transported in the past five years for Jumbo. This assumption is done because of the limited success of sophisticated scientific forecasting methods according to Stopford [33]. Assumed,the demand of each of the charterers given in table 2.1 will remain the same. The data from the Jumbo database of the past five years can be used as input parameters for the optimization model. In table 2.2, the transport days and the number of fixes of each vessel class are given.

Table 2.2: Situation of the past 5 years for Jumbo shipping

Vesselclass	Transport days	Number of fixes
K-3000	2183	78
J-1800	4831	184
H-800	2680	144
E-650	2625	127
Total:	12319	533

2.2.2. Scenario 2: Increasing demand of 6% compared to previous five years

Drewry's latest expectation for the addressable demand for the MPV fleet is an average annual growth of 1.2% to 2023 [7]. For the situation of a yearly growth of 1.2%, the growth of demand in five years is about 6%. So the second demand scenario for the heavy lift crane vessel industry is assumed to be 6%. In figure 2.7, the increasing charter rate of MPV is given.

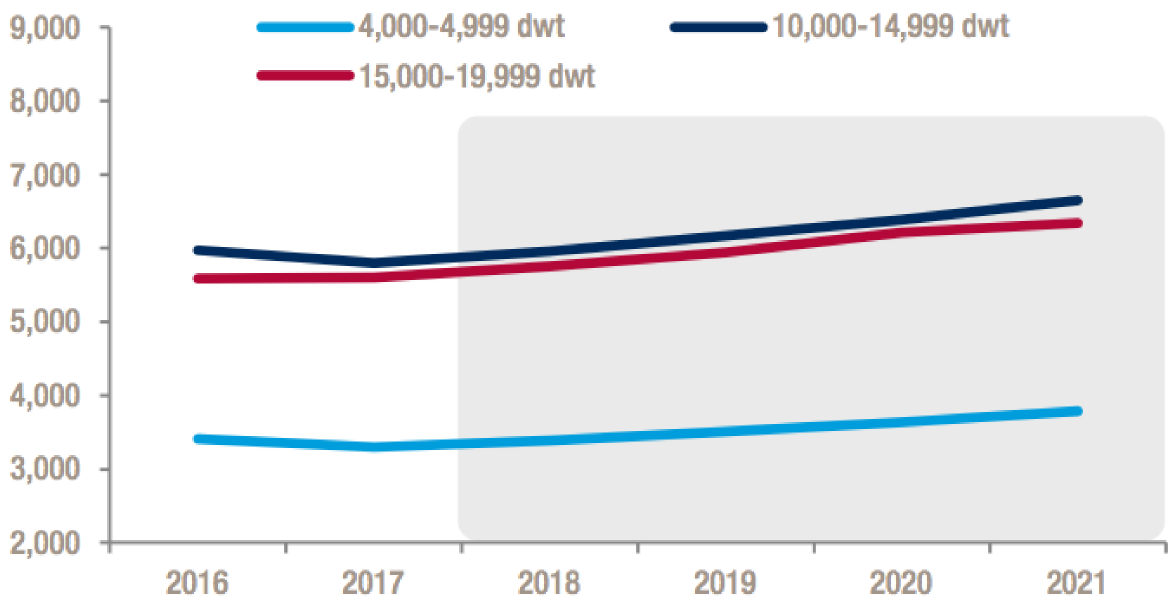

Figure 2.7: Forecast selected MPV period charter rates to 2021 ($ per day) [7]

2.2.3. Scenario 3: Increasing wind energy market

Renewable energy sources are fast growing predicted by Offshore Visie [36]. The installed capacity of wind energy was 7 GW in 2014. The predicted installed amount of wind energy in 2040 is about 140 GW. According to the International Renewable Energy Agency, wind and solar energy will lead the way for the transformation of the global electricity sector. Onshore and offshore wind together would generate more than one-third (35%) of total electricity needs, becoming the prominent generation source by 2050 [15]. The growing renewable energy industry will possibly result in a growing demand in the heavy lift offshore industry. The future projection for the offshore wind market industry is shown in figure 2.8.

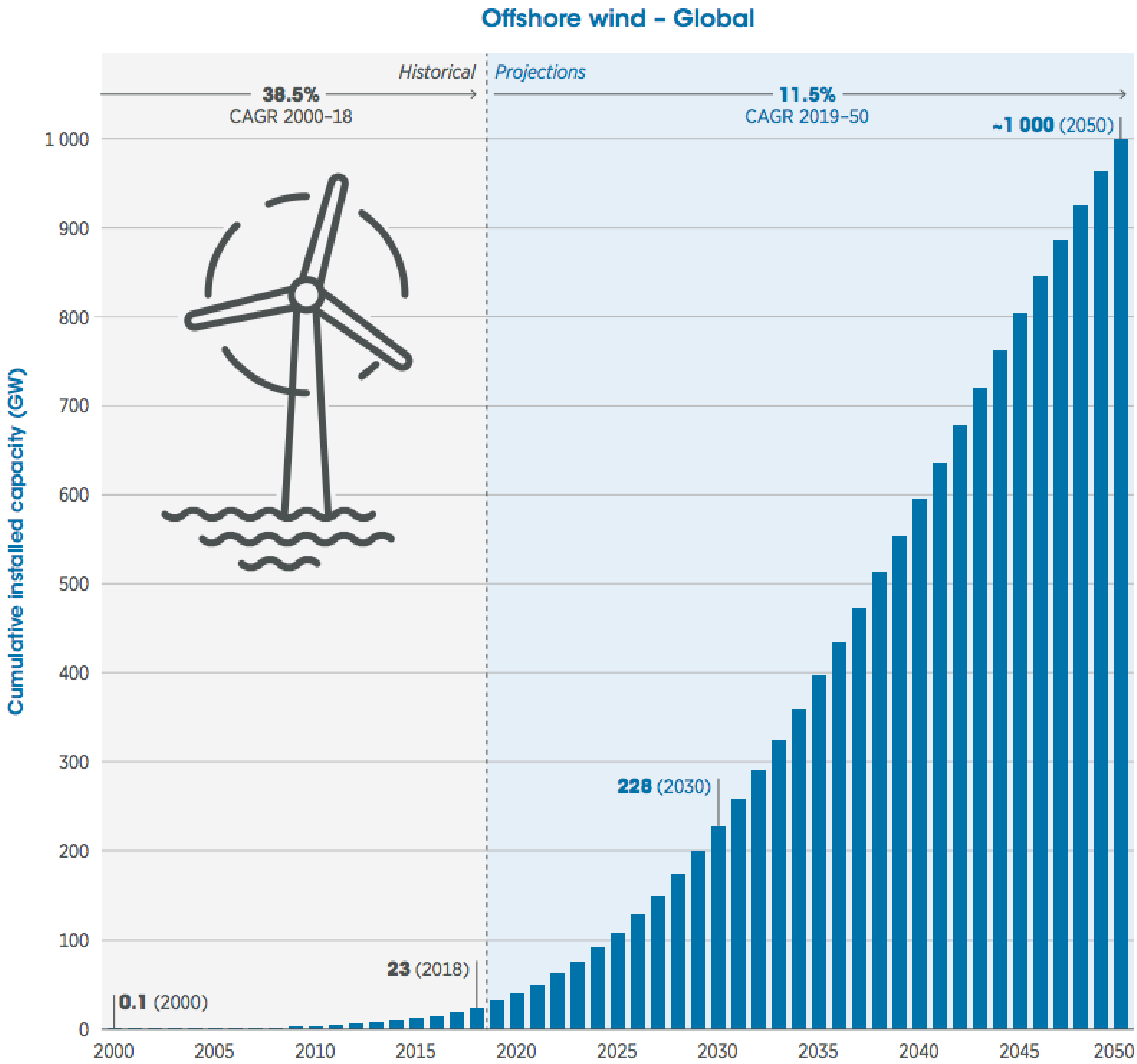

Figure 2.8: Historical values and future projections of the global offshore wind market [15]

It is predicted that the annual offshore wind investments in the period between 2019 and 2030 will be 61 billion USD per year compared to 19 billion USD per year in 2018 [15]. Therefore, investments would need to increase more than three-fold from now until 2030. This should result in an increasing demand for transport of offshore wind turbine parts. The third scenario will consider a 35% increase in demand compared to the period of the past five years.

The shipping for offshore wind turbine parts consists of:

- New offshore wind power installations
- Replacement of existing wind turbine (parts) due to end of their technical lifetime

From the database of Jumbo, the renewable related fixes are selected and increased with 35% for the situation of scenario three. In table 5.9, the prediction of the near future for renewable demand is shown in table 5.9. These data points should be added to the database for this demand scenario of an increasing renewable energy demand. For the new dataset, one fix should be added to the fix data from the past five years with 77 transport days with a revenue of 1.957.770$. This is the difference between the data of the past five years compared to the prediction of the next five years.

Table 2.3: Fixes in the Renewable energy segment

Year	Total Revenue[$]	Total transport days
2015-2019	5 593 630	221
2020-2024	7 551 400	298

2.3. Supply of the Heavy Lift Shipping Market

For the supply side of the heavy lift shipping industry, the vessel characteristics and the market position of Jumbo are important parameters. In subsection 2.3.1, the changes in the fleet composition of the Jumbo fleet are reviewed with the changes of the crane capacities of the different vessel types over time. In subsection 2.3.2, the current Jumbo fleet is described with its characteristics. Subsequently, the market share of Jumbo is given in subsection 2.5.1, to show an overview about the competitors in the heavy lift shipping industry.

2.3.1. Historic Jumbo Fleet

The first vessel of the Jumbo fleet was acquired in 1956, this was the Stellaprima with a crane capacity of $12 * 10^3$ kilograms. Over time, the capacity of the fleet has increased significantly to a maximum capacity of $3000 * 10^3$ kilograms (K-class). Jumbo strives to act in the top segment of the heavy lift shipping industry. There are less competitors in the top segment of the heavy lift crane vessels market compared to the vessel segment with small crane capacity. The disadvantage is the less demand and an increasing venture for very heavy products in comparison with the lower segment. The historical fleet of Jumbo over time is shown in figure 2.9. On the x-axis, from left to right, the names of the different vessels are listed. Remarkable is the increasing maximum crane capacity over time. The result for Jumbo is the focus on the highest segment of the heavy lift crane vessel industry. More information about the Jumbo fleet over time is given in Appendix B.1.

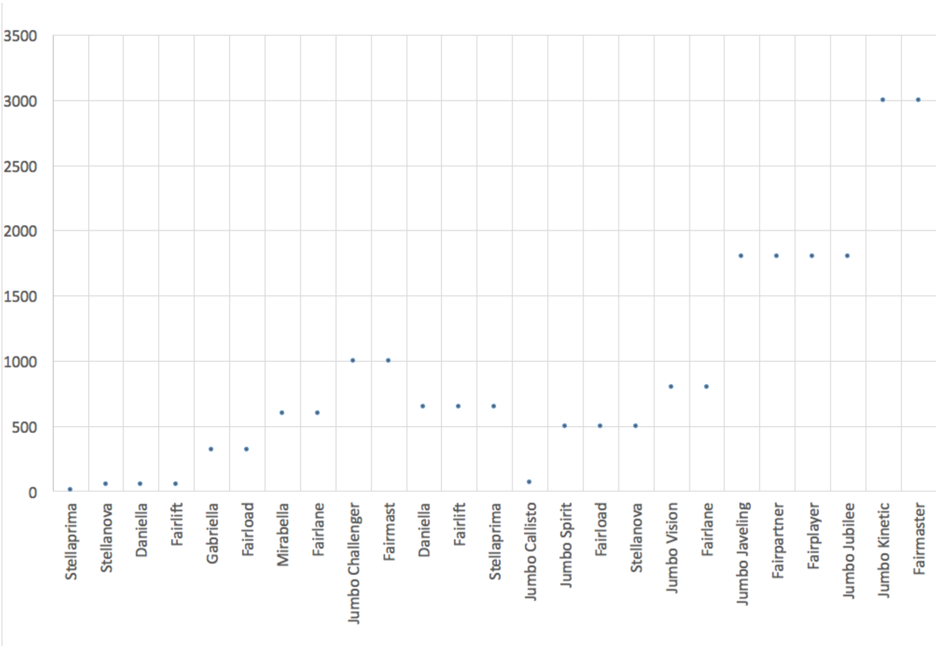

Figure 2.9: Maximum crane capacity of the historical Jumbo fleet

2.3.2. Current Fleet Composition

The current Jumbo fleet is divided into four classes, namely: K-, J-, H- and E- class. All of these classes have their own characteristics. The Jumbo fleet consist of two K-vessel, four J-vessels, two H-vessels and two E-vessels. Two of the four J-class vessels are equipped with a dynamic positioning system. Dynamic positioning (DP) system is a computer-controlled system to automatically maintain a vessel's position and heading which are required for offshore activities. The Fly-Jib is an extra tool to enlarge the lifting radius of the J-class vessels. The characteristics of the current Jumbo fleet are given in table 2.4. A more complete overview about the jumbo fleet is included in Appendix B.2, for more details of each vessel in the current Jumbo fleet the information is given in Appendix B.3. For the assignment, a vessel lifetime is assumed to be fifteen years (based on the Jumbo standards). Table 2.5 displays the characteristics of the Jumbo fleet including their starting year in service. The current E-class vessels are in service since 1990, these vessels are the first in line for replacement. The H-class is in service since 2000 and is therefore also more than fifteen years in operation.

class	Name	Dead weight [$*10^3$ kg]	Hold bale [m^3]	Free deck space [m^2]	Max speed [kn]	Cranes [$*10^3$ kg]	Bunker travel range [nm]	In service since
K	Fairmaster	14000	21000	3250	16	2x1500	10800	2015
	Jumbo Kinetic	14000	21000	3250	16	2x1500	10800	2015
J	Fairpartner	13262	18030	31000	16,5	2x900	9000	2004
	Jumbo Jubilee	13017	18030	31000	16,5	2x900	9000	2008
	Fairplayer	10700	18030	31000	16,5	2x900	9000	2008
	Jumbo Javelin	10942	18030	31000	16,5	2x900	9000	2004
H	Fairlane	7051	10977	1500	15,7	2x400	11000	2000
	Jumbo Vision	6993	10977	1500	15,7	2x400	11000	2000
E	Stellaprima	7572	10902	1375	13	1x250,1x400	TBA	1990
	Fairlift	7561	10902	1375	13	1x250,1x400	TBA	1990

Table 2.4: Specifications Jumbo fleet

2.3.3. Cost structures

For the optimization of the Jumbo fleet, the cost structure of the vessels is required. The cost of the fleet is divided into fixed- and variable costs. The combination of both fixed and variable costs will be included in the optimization model to determine which fleet composition is most suitable with in order to optimize the profit. In this section, the different costs of the Jumbo vessels will be discussed.

For the decision making of the companies to invest in properties, plans and equipment, the analysis of cost structure of the fleet is important. The fixed costs do not change with the increase/decrease of products. The fixed costs are capital costs of the vessels. The variable costs depend on the usage of the vessels, an example of a variable cost is the operating or voyage costs. For the shipping of heavy lift cargoes the costs are divided into three different cost types: capital costs, operating costs and voyage costs. The cost structure is displayed in figure 2.10.

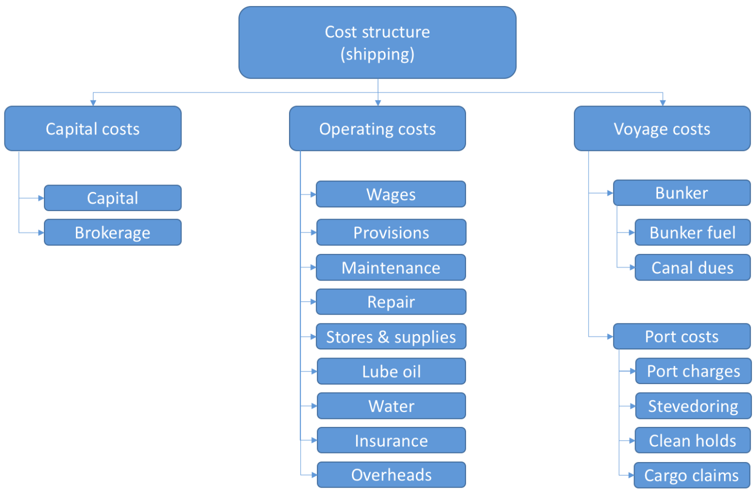

Figure 2.10: Cost structure for shipping in Heavy Lift vessels [33]

Capital costs

In figure 2.10, the capital costs consist of brokerage and capital costs. Capital costs are determined by the way that the ship has been financed.

- **Capital costs**

  The capital costs depend on investment done to purchase the vessel and the way how it is financed. The capital costs account for 42% of the total costs [33]. For the Jumbo vessels, the capital costs are calculated with an interest percentage of 4% and a depreciation of 15 years which results into 6.67% per year. The depreciation is assumed to be on a linear basis, meaning that every year one-fifteenth of the original costs is depreciated. In table 2.5, the capital costs per vessel class are given. Two of the four J-class vessels are equipped with a dynamic positioning system for the offshore installation operations. The difference in the investment between the J-class vessels is about the DP system.

	Investment in mln [USD]	Lifecycle [year]	interest percentage	capital cost/year [USD]
K-class	72	15	4%	$4.992.000
J-class (DP)	37	15	4%	$2.565.333
J-class	32	15	4%	$2.218.667
H-class	19	15	4%	$1.317.333
E-class	12	15	4%	$832.000

Table 2.5: Capital costs of the Jumbo vessel classes

- **Brokerage**

  The brokerage of the capital costs is neglected for the input of this model. Sometimes the broker handles the new building, but it is also possible to deal directly without broker. For the Jumbo situation in case of a new building vessel, Jumbo may deal directly with the shipyard. In case of a second-hand vessel these costs can be included in the model and added to the capital costs.

Operational costs

According to Stopford [33], the definition of operational costs are the expenses involved in the day-to-day running of the ship and incurred whatever trade the ship is engaged in [33]. The operational costs are related to the day-to-day running of the vessel. Fuel and port costs are excluded in these operational costs because these costs items are subdivided to the voyage costs.

- **Wages**

  The greatest part of the operating costs are the wages for the vessel crew. It is not possible to address these costs directly to a voyage. For this assignment, an assumption is made to estimate the wages of the vessel crew per day. These numbers are different for each vessel class, because a larger vessel requires more crew members compared to a smaller vessel. The assumed wages for each vessel are given in table 2.6. The wage costs of the offshore installation are higher compared to the liner shipping wages, because more people are required in the offshore installations. These costs are out of scope, because of the fact that the offshore installations of Jumbo are not included in this assignment. The wages for shipping are about half of the total operating costs [33].

Vessel class	Wages costs/day [USD]
K-class	$3500
J-class	$3500
H-class	$2700
E-class	$2700

Table 2.6: Wages costs of the Jumbo vessel classes

- **Provisions**

  Provisions for dealing with strikes are a relatively small part of the operational costs which should be taken into account for the realised situation. For the scope of the assignment, these costs are not important, since they are similar over different vessel classes. This is the reason why the provision costs are excluded from the assignment.

- **Maintenance & repair**

  For the Jumbo situation, the maintenance costs are subdivided into minor maintenance and major periodic maintenance. Different Jumbo departments are responsible for these costs, this results into a separate documentation of the costs. Small maintenance can be directly attributed to the costs incurred within a certain voyage. This is documented in the disbursement account. Major maintenance activities are considered by the technical service department of Jumbo and a quotation is done by several maintenance ports. The periodic maintenance is calculated in advance and is therefore not directly attributable to a specific voyage, but to a certain period.

  The repair costs in case of a breakdown or spare parts are also calculated in the total maintenance and repair costs. For the model only major periodic maintenance costs are taken into account, assuming that this will account for one million USD per year per vessel. The periodic maintenance costs are calculated for the costs per day. These maintenance costs per day are calculated for a vessel life cycle of 15 years, see 2.7.

Vessel class	Maintenance costs/day [USD]
K-class	$2740
J-class	$2740
H-class	$2740
E-class	$2740

Table 2.7: Periodic maintenance costs of the Jumbo vessel classes

Voyage costs

- **Bunker**

  The voyage costs are given in the disbursement account without the bunkering costs. The bunkering costs are done by the bunker trader that tries to find the best price on the best location along the route with the most lucrative bunker rate. These numbers are hard to find out and assign to a fix or a voyage. The bunker costs are a significant cost item so it is not realistic to neglect this item. The bunker costs depend on the fuel consumption of each vessel. So, this is why the fuel consumption for the model depends on the assumption of the sailing days of the vessel by each fix. This number of vessel days are multiplied by the fuel consumption for each vessel shown in Appendix B.13 up to and including Appendix B.20.

- **Port costs**

  The port charges are a major part of the voyage costs. The services and facilities are included in these port charges. According to Smits [31], "The Port of Rotterdam uses a pilotage base fee based on the draft of the ship plus an additional fee based on the route from sea to the quay location. Port dues are paid over the Gross Tonnage of the ship based on the type of ship/cargo". It is hard to make a prediction of the port costs of a vessel class per day. Furthermore, these costs are not related to the crane capacity. The port costs will be excluded from the optimization model, because these costs are port related and not related to the crane capacity. The port service included the piloting, towage costs and cargo handling. The port costs of the vessel are depending from the pricing policy of the port authority, size of the vessel, time spent in the port and the type of cargo loaded or discharged [33]. The port costs are charged to the owner of the vessel, the owner includes these costs in the price for the client of the cargo. For the Jumbo situation, the costs in the port are given in the disbursement account. From the disbursement account, the following costs are given:

- Cargo costs
- Cash to master
- Lashing material
- Owner's costs
- Port costs
- Various costs

Cargo costs include overtime stevedoring, the handling costs of the cargo and the hired materials such as cranes and gears. The cash to master is the costs for agencies, banks or commissions. Lashing material costs are the welding, cutting, grinding or lashing/unlashing costs. The owner's costs are for example the costs for the crew expenses. Port costs are mainly divided into berth dues and tug towages. The reason why this is divided over two categories is because of the contract of the fixes.

2.4. J-light class

Because the H- and E-class vessels are on the end of the life cycle, these vessel classes are first in for replacement. To fulfil the demand of the market, a number of new vessels are required. For this situation, the J-light class is introduced in the model to give an inside in the future situation. The J-light can be chosen in different crane configurations. The purchase costs of a vessel are largely dependent on the cranes installed on these vessels. Since the E- and H- class Jumbo vessels are in for replacement, it has been decided to equip the J-light configurations with a combined crane capacity of 600-, 700-, 800- and 900 $*10^3$ kilogram. These different configurations are given in table 2.8. These J-light parameters are implemented in the optimization model for the near future compared to the predicted demand scenarios.

	J-600	J-700	J-800	J-900
Purchase vessel [$*10^6$ $]	30	30	30	30
Purchase cranage [$*10^6$ $]	12	15.33	18.67	22
Total Purchase costs [$*10^6$ $]	42	45.33	48.67	52
Capital costs/5 year [$]	14.560.000	15.715.555	16.871.111	18.026.666
Wages/day [$]	2700	2700	2700	2700
Maintenance/5 year [$*10^6$ $]	5	5	5	5
Fuel costs/day [$]	5587	5587	5587	5587

Table 2.8: Characteristics of the J-light vessels

The aforementioned information about the new J-light vessels is provided by Jumbo. The numbers in table 2.8 are assumed to be true because these numbers are according to estimations from Jumbo and quotations. The realised numbers are not available because these vessels are not yet part of the Jumbo fleet. The fuel costs per day are assumed to be half of the fuel costs of the Jumbo Kinetic (Appendix B.13) and Fairmaster (Appendix B.14), because the J-light is sailing with only one power engine. The speed of this vessel should be 14 [kn] instead of 17 [kn] of the K-class vessels.

2.5. Business procedure

To investigate whether a cargo will be transported by the Jumbo fleet, the booking cargo process will be initiated. An overview of the booking cargo process is described in Appendix C.1. Both the technical and the operational parameters should be corresponding to the limitations of the vessels in the Jumbo fleet. The characteristics of the cargo, shown in section 2.1, should comply with the technical specifications of the vessels which are mentioned in section 2.3. For the Jumbo situation, an inquiry is checked according to the booking procedures. If the inquiry complies with these constraints, the inquiry can be booked by the Jumbo booking cargo procedure.

First, the demand of the cargo is in the form of an inquiry. The inquiry is going to the operations department and the engineering department. If it is possible to transport the cargo, the sales department is involved for negotiations. If the offer of the firm is accepted, the inquiry can be converted into a fix, which means that the transportation of the cargo is going to happen. For the cargo characteristics, it is important to figure out which characteristics can lead to an impossible shipping for the Jumbo fleet. So, which requirements should these parameters meet in order to become a fix.

The vessel location is an important parameter for the commercial department. The commercial department makes the planning of the vessels and investigates if it is feasible to load a cargo due to the vessel location and time of the loading/discharge. The vessel location is a crucial parameter for the vehicle routing problem. For the crane capacity utilization, the location of each vessel is neglected. The location of the vessel can be a major factor for the price indication of the transported cargo.

In the commercial planning, the sailing distance for a fix is a known parameter. The sailing speed can be adjusted over different cases. The sailing speed for a larger vessel is higher compared to small heavy lift shipping vessels. The complexity in this case is the deviation in requirements from the clients. For this optimization model, the speed parameter is neglected because the sailing distances of each fix are unknown. So for this reason, the number of days required for the transportation should be implemented in the model.

2.5.1. Market Share

Jumbo is operating with some other competitors in the heavy lift shipping market. Who the competitors are and what kind of ships do these competitors have. Figure 2.11 shows that Jumbo is operating in the top segment of the heavy lift crane vessel industry with the K-class vessels. The $3000 * 10^3$ kilograms combined crane capacity that Jumbo owns is far beyond the capacity limit of the competitors. The two largest competitors are Biglift and Sal. As the crane capacities decreases, competition increases significantly. Jumbo's vision is to profile itself in the top segment of the heavy lift industry. The investment costs of ships with a larger crane capacity increase sharply as the crane capacities increase. Therefore, it might be interesting to invest in the lower weight cargo market to strengthen the market position.

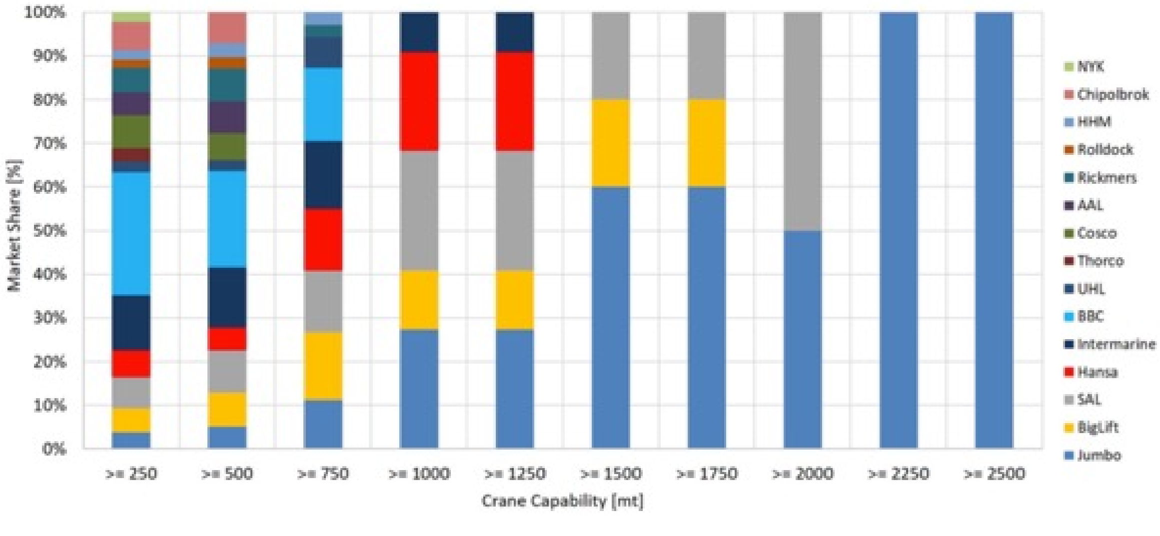

Figure 2.11: Market Share of the Jumbo fleet compared to the competitors categorized in different crane capacity groups [11]

According to figure 2.12, the size distribution of the vessels in the market are given. Most of the competitors are active in the lower segment with a combined crane capacity of less than $750 * 10^3$ kilograms. The number of vessels in the heavy lift shipping market in the lower segment is much bigger compared to the vessels in the higher segment. Jumbo is the only player in the market with vessels who can lift up to $3000 * 10^3$ kilogram. According to figure 2.12, it is clear to see the trend in crane capacities on the vessels in the market. Most of the cargoes do not exceed the $750 * 10^3$ kilogram for the heaviest item which should shipped by a heavy lift crane vessel.

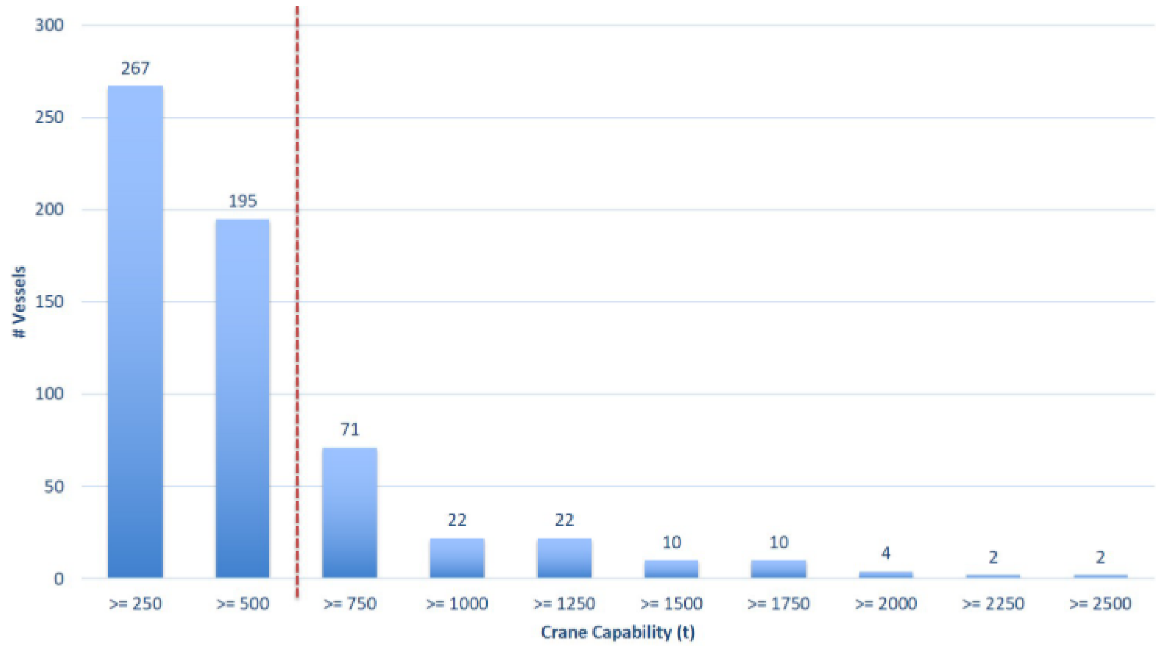

Figure 2.12: Number of vessels for different vessel classes categorized in crane capacity[11]

2.5.2. Revenue structure

For the determination of the revenue of a cargo, there are multiple factors important for the price of a fix. First of all, the commercial department determines how many days it takes to load and discharge the cargo on the vessel. The loading and discharge days depend on the complexity of the cargo. These days, the vessel is in a port which costs money and these costs will be charged by the client. The costs in a port differ for every port, so there is no standard price which will be used for each port. After these port costs, the complexity of the cargo for the engineering department will influence the price. Besides the complexity, it is also dependent if the cargo is loaded under or on deck. The price is more expensive to transport the cargo under deck compared to transportation on deck. The more complex a cargo is on a vessel, the more expensive it is to transport the cargo. In addition, it is important whether the entire ship is fully loaded with this cargo or the space on the vessel is partly in use. When the vessel is partly in use, it can be an option to calculate not the full price for the cargo. It depends on the situation and the opportunity to load other cargoes on the same voyage to make it possible to charge a part of the normal price. The bunker costs of the vessel are also taken into account to the price of the fix. These bunker costs depend on the oil price. The fuel consumption of the vessel is related to the speed of the vessel and the number of engines used during the transport. The location of the vessel also determines the price because it takes time and fuel to reach that location. Also, the location of the competitors is taken into account. Because if there is no competitor close to the location or all the competitors are loaded with other cargo, it is possible to charge a higher price. It is therefore dependent on the costs incurred by Jumbo combined with the willingness to pay of the customer. After all, there is a target price for each vessel class given in table 2.9. If the depending parameters for the price are entered in the computer, a suggested price is provided for the commercial department. The suggested price will be compared to the target price. The commercial department decides whether the price is reasonable and if they expect that the client is willing to pay this price. Once the price is proposed to the customer it is still possible to negotiate.

Table 2.9: Target price per day of each Jumbo vessel class

	Target price/day [$]
K-class	21000
J-class	18000
H-class	8500
E-class	6500

2.6. Conclusions

The main driver for the demand on the heavy lift offshore shipping industry is the oil price. Most of the clients in the heavy lift shipping industry are dependent from the oil price. If the oil price increases, there is more demand in the heavy lift shipping industry. This is because of the increasing investment in oil and gas related industries. Because of strong fluctuations in the demand side of the heavy lift crane vessel industry, it should be interesting to show three possible market scenarios:

- Demand for the near future (coming five years) is equal to the demand in the past five years
- Increasing demand of 6% in the heavy lift crane vessel industry (based on expectations in the literature [7])
- Increasing wind energy market

To be competitive in the heavy lift shipping industry, it is very important to find a profitable fleet composition. The capital costs are related to the installed crane capacity on each vessel, because of the costs of the crane configuration corresponds to between 25 and 50% of the total purchase cost. Important is a matching fleet composition that meets the demand in the market. The cost structure given in this chapter can be used for the optimization model with as goal to reach a more profitable fleet composition on each demand scenario. The cost structures which are implemented in the optimization model are the maintenance, capital, wage and fuel cost.

3
Literature Research

The aim of the literature research is to create a background for the report. Scientific papers were used to give a complete view over the optimization models available in comparable fleet size problems to maximize the profit. With a clear view of the available optimization models, a more matching fleet in the shipping market could be acquired. The sub-question related to this chapter is:

- **Which optimization models are described in literature and which model is most suitable for the Jumbo situation?**

For the scope of the project, the optimization model should be on the strategic level instead of the tactical or operational level. On the strategic level main decisions are made such as what kind of new vehicles should be bought or chartered in, which existing vehicles should be sold or chartered out, and how to cope with demand fluctuations [13]. The strategic decision is made based on the mix and size of the fleet composition. Strategic decisions are long-term decisions, composed of decisions on tactical level. These tactical decisions are medium term decisions for the assignment of vessels to the routes selected by the strategic level[26]. The focus for the operational level is short term, such as sailing dates and demand for service. In this research we only look at long-term decisions and therefore will only take the strategic decisions into consideration.

For the study of Shyshou [30], the optimal fleet size for anchor handling tug supply vessels is analysed. In this study, the two options of long-term owning and short-term hiring on a spot market are compared. They conclude that short-term hiring on a spot market is more expensive. The Jumbo fleet consists only of vessels owned by the company. For this reason, short-term hiring on a spot market is not considered in this research further on.
In case there is an unnecessary large fleet compared to the demand of the market, abundant expenses are made by the shipping fleet. On the other hand, too low a capacity might cause a shipping company to not be able to meet its obligations or that it has to use expensive charter options. It is therefore an important task for shipping companies to continually adjust their fleet composition to meet future transportation requirements [2]. Since profit maximization is the main goal of the company, the most efficient fleet composition should be taken into consideration of this research.

In this chapter, first of all, the solution algorithms of the optimization model are described in section 3.1. Secondly, an analysis about the available optimization models in literature is reviewed in section 3.2. Subsequently, the fleet replacement decision is analysed in section 3.3 and last of all, the intermediate conclusion of this chapter is given in section 3.4.

3.1. Solution algorithms for the optimization problem

In order to solve many optimization problems, both of practical as well as theoretical importance, a search for a most appropriate configuration of a set of variables should be found [3]. The strategy to search for an optimal solution can be obtained by an exact algorithm or an approximation algorithm. The overview is shown in figure 3.1.

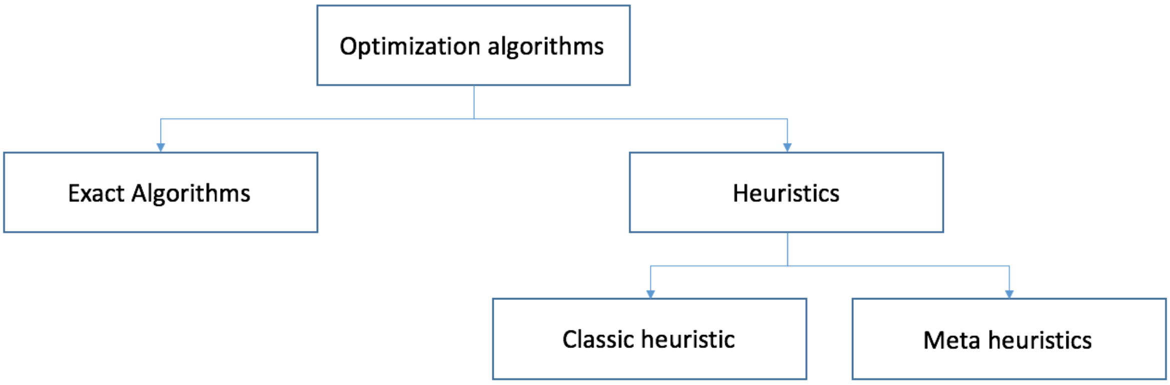

Figure 3.1: Overview of the optimization algorithms

3.1.1. Exact algorithms

An exact algorithm can be used to find an optimal solution in a finite amount of time. For the minimization of the number of vessels in a fleet in order to transport the given cargoes, an exact algorithm can be a suitable solution. The following exact algorithm can be used for this formulation:

- **Integer Programming**

In some optimization problems, it can be hard to solve the problem because the time to solve such a problem is exponentially increased. This kind of problems are NP-hard problems. For these NP-hard problems an exact algorithm is not suitable.

3.1.2. Heuristics

For hard problems such as NP-problems or global optimization, the finite amount of time to find an optimal solution is increasing exponentially. For these problems, the more practical option is to use a heuristic method to find a solution. These methods find a "good" solution in a reasonable amount of time although it is probably not the optimal solution. The heuristic methods are subdivided into classic heuristics and meta heuristics. Heuristic algorithms are very specific and problem dependent instead of meta heuristic algorithms, which are problem independent. According to Stutzle [18], "Metaheuristics are typically high-level strategies which guide an underlying, more problem specific heuristics, to increase their performance. The main goal is to avoid the disadvantages of iterative improvement and, in particular, multiple descent by allowing the local search to escape from local optima. This is achieved by either allowing worsening moves or generating new starting solutions for the local search in a more “intelligent” way than just providing random initial solutions. Many of the methods can be interpreted as introducing a bias such that high quality solutions are produced quickly. This bias can be of various forms and can be cast as descent bias (based on the objective function), memory bias (based on previously made decisions) or experience bias (based on prior performance). Many of the metaheuristic approaches rely on probabilistic decisions made during the search. But, the main difference to pure random search is that in these algorithms’ randomness is not used blindly but in an intelligent, biased form." According to Blum and Roli [3], meta heuristics can be subdivided into a number of algorithm strategies, namely:

- **Basic local search** A solution is only chosen if the resulting solution is better than the current solution. The algorithm stops as soon as it finds a local minimum.

- **Simulated Annealing** An explicit strategy to escape from local minima
- **Tabu Search** This search explicitly uses the history of the search, both to escape from local minima and to implement an exploration strategy

3.2. Optimization Methods

In this section, the optimization models' ability to optimize the Jumbo fleet composition are reviewed in order to maximize the profit. For this goal, the following optimization methods are reviewed:

- *Maritime Fleet Size Problem* 3.2.1
- *Maritime Fleet Size & Mix Problem* 3.2.2
- *Vehicle Fleet Mix* 3.2.3

3.2.1. Maritime Fleet Size problem

In the *Maritime Fleet Size Problem* (MFSP), the fixed vehicle costs and variable routing costs both need to be considered according to Golden[10]. The goal is to determine an economical fleet size with the objective to minimize the total system costs. An example of an MFSP is mentioned in the study of Dantzig [6]. The objective of Dantzig is to minimize the number of tankers in the fleet. This fleet size should meet a fixed schedule. In this problem a *Linear Programming* (LP) model is used to correspond to the scheduling problem including a pick-up point and a discharge point. In the Maritime Fleet Size problem, the vessels used in the problem are assumed to be homogeneous, so there are identical operating characteristics. For the heterogeneous fleet of Jumbo, this optimization method is not applicable, because of the different characteristics of the vessel classes of the Jumbo fleet. A more specialized variant of the MFSP is given in subsection 3.2.2

In the study of Jaikumar and Solomon [17], the minimum number of tugs required to transport a number of barges between different ports in a river is considered. A maritime fleet size problem is applied for this optimization problem. The goal in this study is to minimize the number of vehicles to satisfy the demand requirements. This is a strategic decision in a homogeneous fleet composition with the objective function given in equation 3.1. The number of vessels in the fleet is K.

$$\text{minimize } K \tag{3.1}$$

In this optimization model, the requirement to satisfy the demand of each tug in a limited time slot needs to be met. The optimal solution will result in a minimum fleet size and also in the assignments of ports on the river shown in figure 3.2.

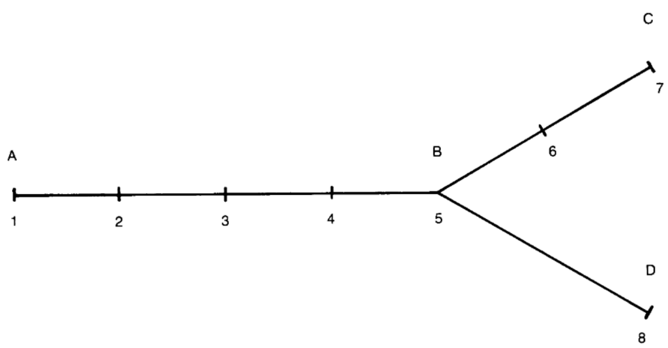

Figure 3.2: The general river structure used in the maritime fleet size problem of Jaikumar and Solomon[17]

The MFSP is also applied in the study of Lai and Lo [19]. In this study the optimal fleet size is considered for a ferry network system. For this problem, a mixed integer multiple origin/destination network flow problem is formulated. The goal of the objective function, shown in equation 3.2, is to minimize the total system costs. The objective function consists of a number of terms. The first term is to minimize the fixed costs associated with owning or hiring a ferry for one day (F). The second term is about operating costs per trip between node i and j. Subsequently, the costs of the waiting time and travel time are included. Finally, the revenue is minimized by the costs, so the sum of all terms is to maximize the profit. For this study, a homogeneous fleet of ferries is used.

$$\begin{aligned}\text{Minimize} \quad Z = &\sum_{i\in N_0'}\sum_{j\in N'\setminus N_b'} Y_{ij}F + \sum_{ij\in S'} Y_{ij}C_{ij} + \sum_{d\in R}\sum_{ij\in(W',O')} X_{ij}^d v_{\mathrm{w}}\beta \\ &+ \sum_{d\in R}\left(\sum_{i=S^*} X_{ij}^d T_{ij} - X_{ij\in D'}^d T^d\right) v_{\mathrm{t}} - \sum_{d\in R}\sum_{ij\in D^*} X_{ij}^d \alpha^d\end{aligned} \tag{3.2}$$

3.2.2. Maritime Fleet Size & Mix Problem

For the decision about the fleet size which would be most corresponding with the demand of the offshore market, a *maritime fleet size and mix problem* (MFSMP) is an option for the heterogeneous fleet of Jumbo. The decision of how many vessels are required in order to meet the demand is a strategic problem. For this problem, the main objective is to minimize the total costs and find the optimal composition of the fleet for a given market condition. According to Pantuso [25], an example of an objective function for the MFSMP is given in formula 3.3. In this objective function, the acquisition of the fleet and the variable costs according to operation of the fleet are included.

$$min \sum_{v\in V} C_v^F y_v + \sum_{v\in V}\sum_{r\in R_v} C_{vr}^V x_{vr} \tag{3.3}$$

In equation 3.3, V is the set of available ship types and R_v represents the set of routes r that a vessel of type v can sail. In the first term of equation 3.3 C_v^F represents the cost of including a vessel of type v in the fleet, while variable y_v represents the number of vessels of type v to include. In the second term, C_{vr}^V stands for the cost of sailing route r with vessels of type v and decision variable x_{vr} represents the number of times route r is sailed by vessel of type v. The first term of the summation corresponds to the fixed costs and the second term corresponds to the variable costs.

The optimal solution of the objective function can be calculated by a *Linear Programming* (LP) model. According to Dantzig[16] the LP model is used to obtain the best ship design and sizes for a fleet of tanker and bulkers. This example is given for a clear view on the objective function. In this objective function, there are three types of costs summarized, the capital costs I_s, total variable costs C_s and the annual fixed operating costs a_s. n_s is the number of vessels of type s. The objective function of the total life-cycle is given in equation 3.4

$$\begin{aligned} lifecyclecost &= \sum_{\mathrm{s}} n_{\mathrm{s}} I_{\mathrm{s}} + \sum_{\mathrm{s}} (C_{\mathrm{s}} + n_{\mathrm{s}} a_{\mathrm{s}}) \sum_{i=1}^{25}\left(\frac{1.04}{1+\alpha}\right)^t \\ &= \sum_{\mathrm{s}} \left[\beta C_{\mathrm{s}} + n_{\mathrm{s}}\left(I_{\mathrm{s}} + \beta a_{\mathrm{s}}\right)\right]\end{aligned} \tag{3.4}$$

where

$$\beta = \sum_{t=1}^{25} \frac{1.04^t}{(1+\alpha)^t}$$

In the formula, α is the discount rate and t is the life cycle of a vessel. Allowing an inflation of 4 percent, which is assumed as a normal inflation rate [16]. In this example, a life cycle t of 25 years is assumed. For the Jumbo situation, further on in this study, a life cycle of 15 years is assumed based on the experience of the heavy lift crane vessels used in the past of the company. In this example an inflation of 4 percent and a discount of 10 percent for a lifetime of 25 years is used, which results in $\beta = 13.0682$.

In the paper of Bronmo [5], another example of an optimal solution for the ship scheduling problem is formulated. This problem can be formulated as an arc-flow model and solved by a *Mixed Integer Linear Programming* model. In this model, the goal of the objective function 3.5 is to maximize the profit. The scheduling method is formulated as a partitioning problem with variables that correspond to vessel schedules.

$$\max \sum_{v \in \mathcal{V}} \sum_{r \in \mathcal{R}_v} P_{vr} y_{vr} + \sum_{i \in \mathcal{N}_C} \pi_i s_i \tag{3.5}$$

In the objective function 3.5, V is the set of vessels indexed by v, the R_v corresponds to the route of vessel v indexed by r. The P_{vr} is the profit of vessel v on route r multiplied by the binary y_{vr}. The value of y_{vr} should be one if vessel v sails route r, otherwise the value is zero. In the second term of the objective function 3.5, N_C is a set of cargoes indexed by i and π_i is the profit of cargo i. The value of profit π_i is multiplied by binary s_i, which is one if the cargo is serviced by a charter, otherwise the value is zero. The terms are divided into a profit from operating the fleet and servicing the cargo. The fixed costs of the fleet are excluded from this optimization function.

To meet the transport demand, the optimum fleet size is determined by Murotsu [24] in an arbritrary route with one port loading and one port discharging. The number of vessels is developed for a case of crude oil carriers. The minimization of the transport costs is subdivided into node costs and link costs as given in figure 3.3. In this mathematic algorithm, a dynamic programming and non-linear programming technique is shown for the solution of the problem.

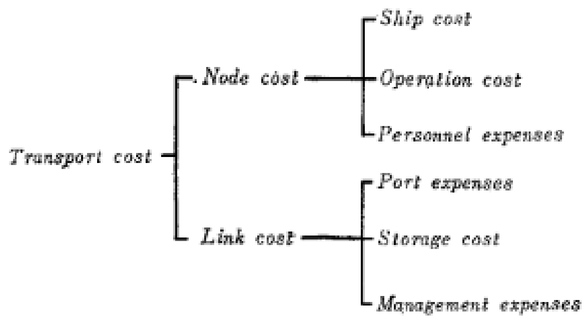

Figure 3.3: Transport costs [24]

According to Fagerholt [9], for an industrial shipping application such as the heavy lift market of Jumbo maritime, the objective is to maximize the profit. Only the cargoes that contribute positively to the profit maximization of the fleet are transported. This is a different view compared to the objective to service all the contract cargoes while minimizing the costs.

Multi-objective optimization problems can be considered equivalent to certain statistical models associated with the specific objectives and constraints [34]. The objectives in this problem are conflicting, so a Pareto optimality is used. Statistical models depending on the structure of the problem are used.

3.2.3. Vehicle Fleet Mix

The vehicle routing problem combined with the vehicle fleet composition problem is also called the Vehicle Fleet Mix [28]. The mathematical formulation of this problem is a linear programming model.

- *Vehicle Routing Problem (VRP)*
  The objective of the classical VRP is to determine a set of optimal routes performed by vehicles with limited capacity to serve a given set of customers [37]. The VRP is a highly abstract model of distances, travel times, travel costs and service times [13]. The application of the VRP in the heavy lift shipping industry is about the optimization of the vessel routes between the port of loading and the port of discharge, both with limited capacity. A special variant of the VRP is the Ship Routing Problem, which needs to be considered as less structural, more complicated and a more conservative operational environment [21].

- *Vehicle fleet composition*
  In the vehicle fleet composition, both the types of vehicles to be used together with the number of each

type should be considered [8]. The vehicle fleet composition can be classified in two categories. In the first category, the total number of vehicles should be determined (vehicle fleet size problems). In the second category, both the type of vehicles to operate and the number of vehicles of each type should be determined (vehicle fleet composition problems). For the situation of Jumbo, the vehicle fleet composition problem is the most suitable, because that would make it possible to variate in different vessel classes.

The model development of the vehicle fleet composition is given by an objective function with a number of constraints. The objective function is about minimalizing the total costs of the fleet which consists of both fixed and variable costs. The objective function given by [8] is:

$$\min \sum_{j=1}^{m} \left(F_j x_j + \sum_{t=1}^{T} f_j y_{jt} \right) + \sum_{j=1}^{m} \sum_{t=1}^{T} \left(V_j z_{jt} + v_j w_{jt} \right) \tag{3.6}$$

The objective function is very similar to the objective function of the MFSMP, the only difference between these functions is the option of rental vessels.

3.3. Fleet Replacement Decision

The fleet of Jumbo is divided into ten offshore shipping and installation vessels. The decision of the required vessel types and quantity depends on the demand of heavy lifting inquiries, mentioned in section 2.1. Important financial considerations of the replacement of a vessel is the cost for a new vessel compared to the costs of refit for a vessel. Besides the acquisition and refit costs, the running costs in case of replacement should also be considered. According to Zheng and Chen [38], the replacement decision of the fleet depends on three main questions:

1. How can a shipowner's fleet replacement decisions be analysed if the future demand on routes and fuel prices are uncertain and dynamically volatile?
2. How can the impacts of parameter changes, e.g., cargo demand and fuel price volatilities, on shipowner fleet replacement decisions be evaluated?
3. How can the performance of government policies (e.g., the subsidy for building new energy vessels or the subsidy for using LNG fuel) be compared under different scenarios?

The uncertainty of the demand in the heavy lift shipping market is the reason why it is challenging to predict the fleet composition and replacement decisions. As in the strategic setting, main decisions are which new vehicles should be bought or chartered, which existing vehicles should be sold or chartered out, and how to cope with demand fluctuation [13]. In formula 3.7, the first term is about the total fixed costs and the second term gives the total variable routing costs. The formula is an example of a *fleet size and mix vehicle routing problem*.

$$\text{Minimize} \sum_{k \in V} \sum_{j \in N} f_k x_{0j}^k + \sum_{k \in V} \sum_{(i,j) \in A} c_{ij} x_{ij}^k \tag{3.7}$$

3.3.1. Fleet Deployment model

The fleet deployment model is an optimization model for the minimization of the operational costs given a fixed fleet composition and a fixed sailing route. For this optimization model it is possible to apply a heterogeneous fleet composition. The shipowner needs to decide the annual fleet deployment plan to fulfil her shipping business at several routes [38]. The goal of the objective function is to find an optimal pattern with a minimization of these variable costs. The optimization is subjected to a number of constraints. An example of the constraints used in the optimization model of Steffensen [32] are:

- Continuity and vessel capacity constraints
- Demand constraints
- Cargo capacity constraints

- Integer and non-negative constraints

The fleet deployment model is not applicable for the Jumbo situation since the fixed fleet composition and the fixed routes are not suitable as input parameter for this optimization model. Furthermore, the fleet deployment model is an operational optimization instead of a strategic optimization model.

3.4. Conclusions

For the strategic decision about the fleet composition on the long term, different variants of the fleet size problems are analysed in the paragraphs above. For Jumbo, the objective is to maximize the profit instead of minimization of the total cost. This is also done by the objective function of Lai and Lo for their MFSP. The Jumbo fleet consists in the current situation of different vessel classes. So, a heterogeneous fleet composition should be taken into account for an optimization model. This is the reason why a MFSMP is more favourable in this situation. The revenue of each fix should be implemented into the optimization formula to give the profit maximization instead of the total cost minimization. The best optimization formula for the Jumbo situation is shown in formula 3.8.

$$max \quad \sum_{i\in I}\sum_{j\in J} R_j x_{ij} - (\sum_{i\in I}\sum_{j\in J} x_{ij}(d_j(W_i + B_i)) + \sum_{i\in I} b_i(C_i + M_i)) \tag{3.8}$$

4
Model development

According to chapter 3, the MFSMP is the best model to optimize the Jumbo fleet composition. The model reviewed in this chapter is subjected to input parameters depending on the demand from the market and the characteristics of the Jumbo vessel. The output of the model provides a fleet composition with the maximum possible profit. For this optimization method, an objective function with a number of constraints are used to formulate the model. For this model, it is possible to change the input parameters which will result in a deviation of the fleet composition and the profit. The input for this model has been obtained by the Jumbo database. For the missing data due to a lack of information or forecasts about the near future, assumptions have been made. The sub-question related to this chapter is:

- **How can the characteristics of the heavy lift shipping industry be implemented in the profit maximization model?**

The input parameters for the optimization model of the fleet composition consist of the demand of the Heavy Lift Market and the vessel characteristics. The output of the model will be the optimal fleet composition in order to obtain the maximum profit. To be able to achieve the above-mentioned results from the formula, data from the past five years of shipping will be used as input. The overview about the optimization model is given in figure 4.1. In this chapter the problem representation is discussed in section 4.1. After this problem representation, the optimization model is described in section 4.2.

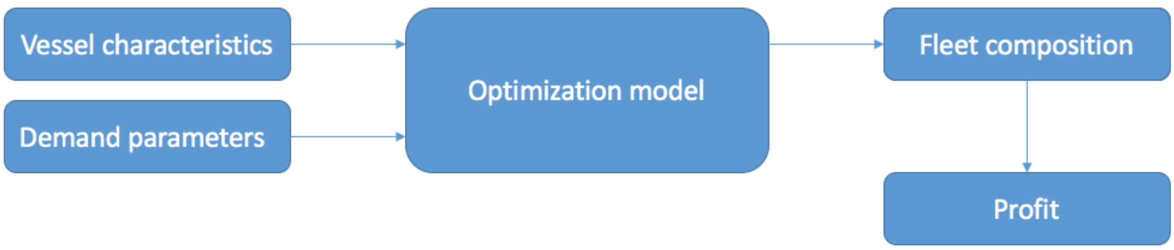

Figure 4.1: Input and output parameters on the optimization model

4.1. Problem representation

For a shipping company such as Jumbo, the company's aim is to make as much profit as possible. For the model, the challenge is to find the fleet composition that makes it possible to maximize the profit. To formulate this problem into a mathematical model, the revenue of each fix and the cost structure of the fleet are required. Next to the revenue of the fix, the technical aspects of the cargo are of importance. The weight of the heaviest item that needs to be transported has to weigh less compared to the combined crane capacity of the vessel. These data will result in a vessel configuration which is suitable to ship these fixes. For the formulation of this mathematical model an objective function with a number of constraints are implemented.

This will be reviewed later on in this chapter. Different demand scenarios should give several output results for the profit and the fleet composition. The results of the optimal fleet composition will be compared to the present Jumbo fleet composition.

4.2. Model description

The input parameters for the model consist of the fix data and the vessel characteristics. The overview of the model is given in figure 4.1. From the fix data, the most important parameter for this optimization model is the heaviest item of the cargo which should be shipped by the Jumbo fleet. This parameter is important because the combined capacity of the cranes should be more compared to the weight of the heaviest cargo item. Besides the heaviest item, the number of days a vessel is used is important, because the vessel can only be used for a limited amount of days in a year. Also, the revenue per fix is an important parameter, because the revenue is the leading factor in the objective function.

The formulation of the mathematical model is according to the overview of the Operational Research Modelling Approach of Hillier [12], which consists of decision variables, objective function, constraints and parameters.

For the optimization of the fleet composition the GUROBI mathematical solver is used. The MILP problem is a general problem solved by the branch-and-bound algorithm. GUROBI is chosen because the optimizer is compatible with the python programming language. Besides the compatibility, GUROBI claims to be the most powerful mathematical optimization solver.

Objective function

The objective for the linear programming model is to find the most profitable fleet composition of the Jumbo fleet. The total revenue is the sum of the revenues obtained by each fix. The total cost of the fleet is the sum of each cost item. The cost items which are included in the objective function will be described further on. To find the maximum profit, the total revenue is minimized by the total costs.

Model assumptions

- **Vessel utilization** Assumed for the model situation, the vessel availability is 75% of the total days each year. This number is resulting from the actual occupation of the past five years of each vessel class. This is due to maintenance time and time to travel from destination to origin for the next cargo. The routing of the vessels is a complex parameter which is described in section 2.5. The numbers of the vessel utilization of each vessel class in the past five years are shown in table 4.1. The same percentage is chosen for this model because of the plausibility of this occupation percentage being the same in the foreseeable future. This results for each vessel to be available for 273 days per year for shipping and 1369 in a period of five years.

Table 4.1: Occupation of the fleet in the past five year

Class	Vessels in class	days in 5 year	total days in each class	realised transport days in 5 year	occupation
K-3000	2	1825	3650	2183	59,8%
J-1800	4	1825	7300	4831	66,2%
H-800	2	1825	3650	2680	73.4%
E-650	2	1825	3650	2625	71,9%

- **One fix per vessel at the same time** Combined fixes on a vessel are possible in the real Jumbo situation, but because of a lack of documentation of data, the fixes cannot be assigned to a voyage. This is the reason that combined cargoes on the vessel are not possible for the optimization model.
- **Heaviest item less or equal to combined crane capacity** If the weight of the heaviest item is less or equal to the combined crane capacity of the Jumbo vessel, it is possible for the optimization model to load the cargo on the vessel. In real situation, the outreach of the crane is an important parameter,

because in case of an increasing outreach, the crane capacity will decrease, because of the moment of inertia. The complexity of the outreach combined with the maximum lifting height and the hoisting capacity are described in section 2.1.1. The used outreach of the lifted cargo is not documented in the Jumbo database so it is not possible to implement these parameters in the optimization model.

- **Bunker costs** The bunker costs in the optimization model are based on a calculation. This fuel consumption calculation is based on 85% of the used engine power combined with a vessel draft of 6.6 meter. In the calculation, a sailing time of 67% of each day is assumed as normal. The fuel consumptions of each vessel can be found in Appendix B.5.

- **Wages** The wages of the crew on each vessel are assumed by the supervisor from Jumbo who gives an indication of the wage costs for each vessel. In table 4.2, the wage cost per vessel class are shown. These wage costs are only given for the shipping wages. For the offshore installation, more employees are required, but for the optimization of the shipping industry only these numbers are given in this report.

Table 4.2: Wage costs per vessel class included in the mathematical model

Vessel class	$/day
K	3500
J	3500
H	2700
E	2700

- **Location** The location of each vessel is neglected, because the focus of this assignment is on the crane capacity instead of a location problem, which is very complex to combine. For the commercial department, mentioned in section 2.5, the vessel location and location of the inquiry are essential parameters for the routing and planning.

- **Routing** The routing of the vessel is out of scope, according to the model each cargo is loaded on location A and discharged on location B. This is because the whole location of each vessel is not taken into consideration.

- **Canal fees** Normally, canal fees should be taken into consideration. But because the routing in this problem is neglected, the canal fees are also neglected. For the Jumbo situation, clients are responsible for canal fees.

- **Jumbo vessel** Only the vessels which are owned by Jumbo are implemented in the model. In real life, rented vessels can be used to serve a fix. But because of the complexity of these transactions, this should be neglected for the optimization model. Fixes which are served by a rented vessel are filtered out from the input database.

- **Fix date** The date of the fix is neglected. In the optimization model only the 365 days per year are implemented and it is not possible to use a vessel more than 365 days per year. The maximum occupation percentage, mentioned above is multiplied by the 365 days of a year. In some cases it is required to sail in a certain period of time from A to B. This constraint is neglected because this research focuses on the optimization of the crane utilisation and not on the optimization of the location problem.

Input

For the optimization model of the Jumbo shipping fleet, the data from the shipped cargo of the past five years and the vessel characteristics are used. From the characteristics of the cargo, the following data points are useful for the optimization model:

- Transport days per fix
- Revenue per fix
- Heaviest cargo item per fix

For the supply side of the optimization model, the Jumbo fleet characteristics are important. The vessel characteristics are used as input parameters, which consist of a technical and a financial parameter. The used characteristics for the optimization model are:

- Combined crane capacity installed per vessel class
- Cost structures of each vessel class

Output

The output of the model consists of two main elements:

1. *Profit*, consisting of revenue per fix minimized by the total vessel cost.
2. *Fleet composition*, divided into a number of vessels per vessel class.

The profit of the model is the key indicator and the fleet composition is the recommendation for the optimal fleet composition according to the input data from the past five years combined with the assumptions done to make the model possible.

4.3. Illustrative example

For the illustrative example, a small data set combined with a limited fleet composition is shown to give a view about the complexity of the decision which vessel should be assigned to a fix. The consideration depends on the objective function which should try to find the solution with the optimal profit. The solution is subjected to a number of constraints. In this illustrative example, a time period of one year is chosen with three fixes and two vessels.

Table 4.3: Example fix data

	fix 1	fix 2	fix 3
Transport days	100	300	200
Revenue [$*10^6$$]	6	12	10
Heaviest item [$*10^3 kg$]	1200	600	800

Table 4.4: Example vessel data

	Vessel A	Vessel B
Crane capacity	2000	1000
Total costs/day	45000$	30000$

In this example, the various fixes, given in table 4.3 are distributed among the vessels given in table 4.4, so that the most profitable combination can be made. This optimization will automatically make use of the cheapest ship if it complies with the constraints of the crane capacity and the max number of transport days on a vessel in one year. In this case fix 1 will be shipped by vessel A, due to the constraint over the crane capacity. Furthermore, it is not possible to ship both fix 2 and fix 3 on vessel B, because the max number of transport days on one vessel will be exceeded. This results in the fact that fix 3 will also be shipped by vessel A. The difference with the optimization model made in this assignment will be a lot more fix data compared with a larger fleet composition.

4.4. Mathematical model

The used indices and sets can be found in table 4.5. The used parameter variables are given in table 4.6. The decision variables used in the mathematical model are given in subsection 4.4.3.

4.4.1. Indices and sets

In table 4.5, the indices and sets used in the mathematical model are given with their values and description.

Table 4.5: Indices and sets for the mathematical model

Index	Definition	Values	Description
i	Vessel class	$i \in I = 1, ..., i_{max}$	I refers to the number of vessel classes in the Jumbo fleet
j	Fix number	$j \in J = 1, ..., j_{max}$	J refers to the number of fixes in the database of the past five years

4.4.2. Parameter variable

Table 4.6: Input parameters for the mathematical formulation

Parameter	Unit	Definition	Value [E,H,J,K]
R_j	\$	Revenue per fix	input data
C_i	\$/5 year	Capital costs per vessel	[2279,3609,6079,13677]
M_i	\$ /5 year	Maintenance costs per vessel	[2740,2740,2740,2740]
W_i	\$ /day	Wages per vessel class	[2700,2700,3500,3500]
B_i	\$ /day	Fuel costs per vessel class	[5490,5490,11399,11173]
K_i	$*10^3 kg$	Combined crane capacity of each vessel class	input data
G_j	$*10^3 kg$	Heaviest item on a fix	input data
a_i	days	Vessel availability in five years	1369
F_i	vessels	Number of vessels in a vessel class in the initial situation	[2,2,4,2]
d_j	days	Transport days per fix	input data
b_i	vessels	Number of vessels in vessel class i	output data
U	%	Occupation gradient of each vessel in the fleet	75

4.4.3. Decision variables

The first decision variable used in the optimization model is a binary:

$$x_{ij} = \begin{cases} 1, & \text{if fix } j \text{ is shipped by vesselclass } i. \\ 0, & \text{otherwise.} \end{cases}$$

The second decision variable used in the optimization model is an integer variable about the number of vessels in each vessel class:

b_i = Number of vessels in vesselclass i.

4.4.4. Objective function

The objective function used in the optimization model is given in equation 4.1. The goal of the objective function is to maximize the total of the profit from the fleet.

$$max \quad \sum_{i\in I}\sum_{j\in J} R_j x_{ij} - (\sum_{i\in I}\sum_{j\in J} x_{ij}(d_j(W_i + B_i)) + \sum_{i\in I} b_i(C_i + M_i)) \tag{4.1}$$

The objective function is subdivided into a revenue part, which is minimized by the two vessel related cost items. The summarized revenue over the fixes are calculated by the first part of the objective function:

$$\sum_{i\in I}\sum_{j\in J} R_j x_{ij}$$

The cost items are divided in variable and constant costs. The variable costs are only included in case the vessel is used for a fix multiplied by the number of transport days. The variable cost item is given in the second part of the objective function:

$$\sum_{i\in I}\sum_{j\in J} x_{ij}(d_j(W_i + B_i))$$

The constant costs of a vessel are calculated over a number of years the vessel is in use. This is because the capital costs and the maintenance costs do not depend on the number of days the vessel is in use. The depreciation of each vessel cannot directly be assigned to a number of fixes but over a period of time. The last item of the objective function is related to the constant costs:

$$\sum_{i\in I} b_i(C_i + M_i)$$

4.4.5. Constraints

The constraints for the linear programming model depend on the limiting factors of the vessels. The limiting factors are given in the fact sheet of every vessel or can be analysed from the data of the previous five years. In equation 4.2, the constraint ensures that exactly one vessel is used for each fix. This is required because of the fact that one vessel can only be used for one fix.

$$\sum_{i \in I} x_{ij} = 1 \quad \forall j \in J \tag{4.2}$$

The constraint given in equation 4.3, ensures the max number of transport days in the period of five years cannot be exceeded for each vessel in the fleet.

$$\sum_{j \in J} x_{ij} d_j \leq b_i a_i \quad \forall i \in I \tag{4.3}$$

The cargo shipped by a vessel class cannot exceed the combined crane capacity of the chosen vessel class. The constraint in equation 4.4 is to ensure that the weight of the heaviest cargo of a fix is less or equal to the crane capacity of the used vessel.

$$\sum_{i \in I} \sum_{j \in J} x_{ij} G_j \leq K_i \tag{4.4}$$

Because it is not possible to exceed the maximum number of vessels in a vessel class, the constraint to maintain this limitation is given in equation 4.5. This constraint should not be used in the optimal solution but only for the possibility to divide the cargoes over the current vessels in the fleet.

$$b_i \leq F_i \quad \forall i \in I \tag{4.5}$$

4.4.6. Verification and validation

The verification and validation of the model is a tool to check whether the results from the model are correct. The verification is to figure out if the model is right and the validation is for the check if it is the right model which is used for this optimization assignment. In figure 4.2 the relation between reality, computerized model and conceptual model is given. The difference between the reality and the conceptual model is the fact that in reality actual data are used and in the conceptual model assumptions are used.

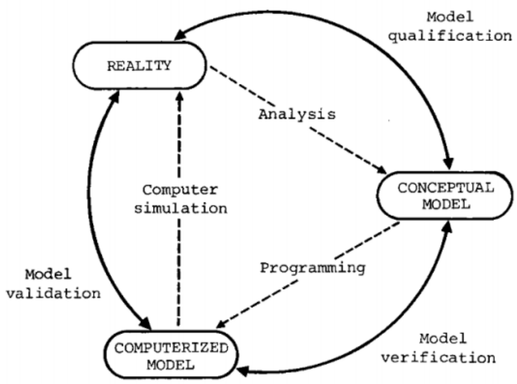

Figure 4.2: Basic elements to provide a proper framework to review the credibility of a simulation [27]

Model verification

Verification ensures that the computer programming and implementation of the conceptual model are correct [29]. Is the model implemented accordingly to the specifications? For the verification of the optimization model, a number of experiments should be done to check if the model gives output values which are equal to the expected output values. In these experiments extreme conditions are implemented as input parameters.

The first experiment for the verification is to increase the capital costs of the smallest vessel class of the Jumbo fleet to a very large value. The capital costs per day of the E-class vessel are equal to 10^{10} \$. The expected number of fixes on these vessel class should be zero and the number of vessel days should also be zero. The output of the mathematical model is given in figure 4.3. Both the number of fixes, revenue and transport days of the E-class vessel are zero which are equal to the expected value of zero.

```
fixes on K type vessel:        58
fixes on J type vessel:         0
fixes on H type vessel:       475
fixes on E type vessel:         0

Rev on K type vessel:   73421088
Rev on J type vessel:          0
Rev on H type vessel:  289066412
Rev on E type vessel:          0

days on K type vessel:      1567
days on J type vessel:         0
days on H type vessel:     10752
days on E type vessel:         0
```

Figure 4.3: Zero fixes on the E-class vessel for an expensive capital costs input

The second experiment for the verification of the conceptual model into the computerized model is to set a constraint of the availability of vessels in each vessel class which is equal to one. This constraint should not be possible in combination with a constraint regarding that each fix should be shipped by the vessels in the fleet. The result of the optimization model is: AttributeError: b"Unable to retrieve attribute 'x'". This is equal to the expectation of the conflicting constraints. If the constraint of equal fixes compared to the realized situation is dropped out, an output is given which is also presumable.

The third experiment is the case of an equal crane capacity of each vessel type in the fleet. The difference in costs per vessel class are still present in the model. In this case, it should be expected that all the fixes are shipped by the E class vessel because of the lower capital and operational costs compared to the other vessel classes. In figure 4.4 is shown that all the fixes are shipped by the E class vessels which is equal to the expectation.

```
fixes on K type vessel:         0
fixes on J type vessel:         0
fixes on H type vessel:         0
fixes on E type vessel:       533

Rev on K type vessel:          0
Rev on J type vessel:          0
Rev on H type vessel:          0
Rev on E type vessel:  362487500

days on K type vessel:         0
days on J type vessel:         0
days on H type vessel:         0
days on E type vessel:     12319
```

Figure 4.4: Crane capacity of each vessel class is equal to $3000 * 10^3$ [kg]

Model validation

The definition of validation is substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model [27]. For this optimization model it is hard to validate the model with the real situation, because real numbers are used as input parameters combined with some assumed values of the vessel characteristics. Besides these assumptions of the vessel characteristics, there are also assumptions done about the location of the vessel which should result in deviation compared to the realised situation. Fixes which do not contain the weight of the heaviest item, transport days, vessel name are filtered, because these parameters are required for the optimization model. A one hundred percent equality compared to the realised situation does not exist for the validation but trying to come close is preferred.

4.5. Conclusions

In this chapter, the representation of the problem is converted into a mathematical model. The problem is converted into a model description including an objective function, assumptions made for the model and an enumeration of the input and output parameters. The objective of the mathematical model is to maximize the profit with respect to the linear constraints implemented into the optimization model. The MILP of the GUROBI optimization algorithm is used to solve the problem of the assignment with output parameters about the fleet composition and the maximum profit.

5 Results

The results obtained by the model formulated in chapter 4, are described in this chapter. The aim of this chapter is to optimize the fleet composition for Jumbo to enable profit maximization in different demand scenarios. The experiments of various demand scenarios are used as input to give a recommendation about the fleet composition in the near future. In section 5.1, the results from the realised Jumbo shipping situation are shown as comparison with other results later on in this chapter. Subsequently, in section 5.2 the realised shipping data combined with the present vessel classes are used as input parameters. The output of the fleet composition should be compared to the realised situation. Subsequently, the new J-light vessel classes are introduced in section 5.3 as input parameter which should be interesting for the different demand scenarios of the near future. In section 5.5, an evaluation about the results of the optimization are done and at last, the conclusion of this chapter is given in section 5.6. The sub-question related to this chapter is:

- **What is the impact of the improved fleet composition on the profit?**

The optimal fleet composition mentioned in the sub-question is focused on the near future with the new J-light vessels. The fleet for the next years consists of the current K- and J-class vessels combined with the new J-light vessels. This optimal fleet composition should be shown in different demand scenarios for the near future.

5.1. Results from realised situation

First of all, the results of the realised period of the past five years combined with the vessel characteristics of the current Jumbo fleet (K-, J-, H- and E-class vessels) are shown. The realised number of fixes on each vessel class are given in table 5.1. From the database of Jumbo, the price of each fix is known, so this realised price is linked to these fixes and the total revenue of each vessel class in the past five years is summarized. The revenue realised in the past five years are minimized by the cost structure implemented in the model to calculate the total profit. The reason why the realised situation is analysed combined with the cost structure applied in the mathematical model is to compare the situation of the current Jumbo fleet with other (future) fleet compositions. For each fleet optimization, the number of fixes in the database should be equal to 533 to compare the optimized fleet composition with the realised situation.

	Realised situation								
Vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	2	2183	78	74.948.149	29.856.263	7.640.500	24.390.477	5.981.420	7.079.489
J	4	4831	184	195.804.422	29.365.421	16.908.500	55.068.368	13.236.940	81.225.193
H	2	2680	144	49.674.040	9.672.475	7.236.000	14.712.083	7.343.200	10.710.282
E	2	2625	127	42.060.889	5.983.562	7.087.500	14.410.156	7.192.500	7.387.171
	10	12.319	533	362.487.500	74.877.721	38.872.500	108.581.084	33.754.060	
								Total profit:	106.402.135

Table 5.1: Profit calculation with the initial fleet composition and the realised transportation of the fixes in the past five years

For the capital cost calculation of a usage of a vessel per day, the method in table 5.1 satisfies. This method can be used when the price of a fix should be determined. To calculated the costs of the fleet, the capital cost per period of time is used because it is not possible to own a vessel for one day for example. This is the reason why the capital costs are calculated over a period of five year, because the input data is also in a time span of five year. In table 5.2, the calculation of the capital costs is the depreciation and interest costs calculated per used vessel day shown in table 2.5. Now, the capital costs are calculated over five years instead of the number of used vessel days and are shown in table 5.2. Remarkable is the decreasing total profit, because of the increasing capital costs.

Vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	2	2183	78	74.948.149	49.920.000	7.640.500	24.390.477	10.001.000	- 17.003.828
J	4	4831	184	195.804.422	44.373.333	16.908.500	55.068.368	20.002.000	59.452.221
H	2	2680	144	49.674.040	13.173.333	7.236.000	14.712.083	10.001.000	4.551.623
E	2	2625	127	42.060.889	8.320.000	7.087.500	14.410.156	10.001.000	2.242.233
	10	12.319	533	362.487.500	115.786.667	38.872.500	108.581.084	50.005.000	
								Total Profit:	49.242.249

Table 5.2: Capital costs calculated over a period of time

The revenue, wages, bunker and maintenance costs are equal to output of table 5.1. This is because the number of transport days on each vessel are unchanged. The only difference is the capital cost calculation which result in a decreasing profit of 40.9 mln $. This calculated should be compared to other optimized fleet compositions.

5.2. Results from the optimized situation

Now in this section, the mathematical model will be used to give an optimized fleet composition. For the input of the model, the shipping data from the past five years is used as input from the demand side of the market. This data is used as input to compare the optimized situation with the realised situation. The parameters of this data are given in a heaviest item that should be lifted by the Jumbo crane vessels, an estimated price for which the cargo is transported and a number of transport days. The number of transport days are the days used for the shipping from origin to destination. The transport days are required to calculate the cost of the vessel during this period. The transport days are multiplied by the wage costs per day, bunker costs per day and the maintenance costs per day. The output parameters of the model consist of the fleet composition and the total profit. The optimized situation will be compared to the realised situation given in table 5.1 to evaluate if the fleet composition was close to the optimal solution. An infinite availability of each transport class is assumed because the most profitable vessels are used according to the demand of the market. The number of vessels should be minimized to meet the objective function. The increase in profit by this calculation is 75 mln dollars compared to the realised situation. In table 5.3, the more expensive vessels such as the K- and J-class are only used to ship the heavy cargo fixes. For most of the fixes, the smallest vessel class (E-class) satisfies, which will result is a lot of cost savings and in the end should be more profitable. The capital costs are calculated over the number of days the vessel is in use. The result will be a higher number of vessels used for an equal number of fixes and transport days compared to current fleet composition.

vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	121	4	1.250.000	1.654.882	423.500	1.351.923	331.540	- 2.511.845
J	2	1446	54	72.171.088	8.789.567	5.061.000	16.482.894	3.962.040	37.875.587
H	1	834	35	27.022.775	3.010.016	2.251.800	4.578.313	2.285.160	14.897.486
E	8	9918	440	262.043.637	22.607.605	26.778.600	54.445.688	27.175.320	131.036.424
	12	12.319	533	362.487.500	36.062.071	34.514.900	76.858.817	33.754.060	
								Total profit:	181.297.652

Table 5.3: Optimized model calculated with capital costs per days the vessel is in use

For the optimization model, the capital costs are calculated over the period of five years. This will prevent the model from the possibility to use a vessel for a very short time. In the realised situation, this is a more applicable approach, because the vessel is purchased and the vessel is depreciating over a period of fifteen years.This is the reason why in table 5.4, the capital costs are calculated over the period of five year. Remarkable is the fact that the J-class vessels are not used any more. The reason of the zero used J-class vessel is because of the constraint to transport each fix of the input data. There are a number of fixes which exceed to capacity of the J-class vessel, so the K-class are required to satisfy this constraint. This model can be compared to the realised situation given in table 5.2. The difference in profit is 80.4 mln dollars.

vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	50	66.186.088	24.960.000	4.788.000	15.284.550	5.000.500	16.153.038
J	1	199	8	7.235.000	11.093.333	696.500	2.268.393	5.000.500	- 11.823.726
H	1	1190	45	32.629.775	6.586.667	3.213.000	6.532.604	5.000.500	11.297.004
E	7	9562	430	256.436.637	29.120.000	25.817.400	52.491.396	35.003.500	114.004.341
	10	12.319	533	362.487.500	71.760.000	34.514.900	76.576.943	50.005.000	
									129.630.657

Table 5.4: Optimized model calculated with capital costs in period of time

For a company like Jumbo, the main goal is the profit maximization. In case of profit maximization, only the profitable fixes should be shipped. This is the reason that the non-profitable orders will be ignored by the model if the constraint of shipping each fix is removed. For this model situation, not every fix should be transported any more. The results are given in table 5.5. The shipping fleet does not have to satisfy all the fixes transported by the realised situation with as goal to optimize the profitability of the fleet. Remarkable for this optimization is the K-class vessels are not used any more. This is because the crane capacity of the K-class vessels are not very oft required by the transported cargoes of the demand and these vessels are relatively expensive compared to the other vessel classes. This model can be compared to the realised situation given in table 5.2. The profit is increasing with 140.3 mln dollars.

Model situation (number of fixes not equal to realized situation)									
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	0	0	0	-	-	-	-	-	-
J	1	1367	54	90.998.649	11.093.333	4.784.500	15.582.376	5.000.500	54.537.940
H	0	0	0	-	-	-	-	-	-
E	5	6843	315	236.838.649	20.800.000	18.476.100	37.565.219	25.002.500	134.994.830
		8.210	369	327.837.298	31.893.333	23.260.600	53.147.595	30.003.000	
									189.532.770

Table 5.5: Optimized model without a fixed number of fixes

5.3. Future Fleet Composition

The future fleet composition is an output parameter which depends on the input parameters in the model. The first set of parameters depends on the different demand scenarios. The second set of input parameters are related to the vessel characteristics of the fleet. Because the relative old H- and E-class vessel are soon in for replacement, new vessel classes are to be considered for the near future. The main question of the new vessel configuration is the crane capacity installed on these vessels. The capacity of the cranes is directly related to the capital costs, because of the investment of these crane set-up. According to the results in section 5.2, the J-light vessels are given in four crane capacity groups, 600-, 700-, 800- and 900- $*10^3$ kilogram. The J-light vessels are implemented in the model for a new fleet composition. The cost structures of these J-light vessels are given in table 5.6. Because these vessels are not yet in operation, the costs structures are estimated by Jumbo.

These new J-light vessels should be purchased to meet the demand of the near future. Unfortunately, the future is unknown, but it is possible to make a number of predictions of the demand in the next five year according to expectations of the demand scenarios. This is the reason why the demand scenarios given in section 2.2, are used as input parameters to find the optimized fleet composition for these situations.

5.3.1. Demand scenario 1

For the first demand scenario, the fix data predicted for the next five year is equal to the data in the past five years. The new fleet configuration is implemented into the optimization model. To compare the situation

	J-600	J-700	J-800	J-900
Capital costs per day in [$]	7978	8611	9245	9878
Capital costs per 5 year [$]	14.56 mln	15.71 mln	16.87 mln	18.03 mln
Maintenance costs per day [$]	2740	2740	2740	2740
Maintenance costs per 5 year [$]	5 mln	5 mln	5 mln	5 mln
Wages per day [$]	2700	2700	2700	2700
Fuel costs per day [$]	5587	5587	5587	5587

Table 5.6: Characteristics of the J-light vessels

of the new fleet composition with the J-light, the number of cargoes transported by the fleet should be equal to the realised situation. The result of this optimization is given in table 5.7. Compared to the profit given in table 5.1, the total profit decreases with 4.4 mln $. This is caused by a more expensive capital costs of the J-light fleet compared to the low-priced H- and E- class in the realised situation.

Demand Scenario 1									
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	53	64.828.946	24.960.000	4.788.000	15.284.550	5.000.000	14.796.396
J	1	199	5	8.592.142	11.093.333	696.500	2.268.393	5.000.000	- 10.466.084
J-900	0	0	0	-	-	-	-	-	-
J-800	1	1362	57	38.741.075	16.222.222	3.677.400	7.609.494	5.000.000	6.231.959
J-700	0	0	0	-	-	-	-	-	-
J-600	7	9390	418	250.325.337	98.000.000	25.353.000	52.461.930	35.000.000	39.510.407
	10	12.319	533	362.487.500	150.275.556	34.514.900	77.624.367	50.000.000	50.072.678

Table 5.7: Profit calculation with the future fleet possibilities and demand scenario 1, all fixes served

To optimize the result of the profit, only the profitable fixes are analyzed in the model and the number of fixes transported by the fleet should not be equal to the realised situation.

5.3.2. Demand scenario 2

The second demand scenario is about the increasing oil and gas industry, which are the main drivers for the demand in the heavy lift shipping industry. This scenario is discussed in section 2.2.1. Assumed in this scenario is an increase of the total demand of 6%. The input data is from the database of Jumbo from the past five years multiplied by 6%. The new J-light vessels combined with the current K- and J-class vessels are the input from the supply side of the model. The fleet composition in case of this demand scenario is shown in table 5.8.

Model situation (fix not equal initial situation, cap/vessel)									
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	55	33.975.096	24.960.000	4.788.000	15.284.550	5.000.000	- 16.057.454
J	1	860	29	62.699.267	11.093.333	3.010.000	9.803.104	5.000.000	33.792.830
J-900	0	0	0	-	-	-	-	-	-
J-800	0	0	0	-	-	-	-	-	-
J-700	1	1292	30	38.025.150	15.111.111	3.488.400	7.218.404	5.000.000	7.207.235
J-600	7	9538	420	249.582.237	98.000.000	25.752.600	53.288.806	35.000.000	37.540.831
	10	13058	534	384.281.750	149.164.444	37.039.000	85.594.864	50.000.000	62.483.442

Table 5.8: Profit calculation with the future fleet possibilities and demand scenario 2, all fixes served

5.3.3. Demand scenario 3

For demand scenario 3, only the renewable energy related cargoes which are shipped in the past five year are analysed. According to section 2.2.3, the demand of renewable related cargoes should increase by 35%. The renewable related data from the past is multiplied by 1.35 to get a new input dataset for the optimization model. The new renewable energy related revenue and transport days are given in table 5.9.

It is clear to see in the results of demand scenario 3, shown in table 5.10, that the preference is for the J-light variant of 600 $*10^3$ kilogram crane capacity. The profit in this optimization is comparable to the profit achieved in the optimization of demand scenario 1.

Table 5.9: Fixes in the Renewable energy segment

Year	Total Revenue[$]	Total transport days
2015-2019	5 593 630	221
2020-2024	7 551 400	298

vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	50	69.287.588	24.960.000	4.788.000	15.284.550	5.000.000	19.255.038
J	1	199	8	4.133.500	11.093.333	696.500	2.268.393	5.000.000	- 14.924.726
J-900	0	0	0	-	-	-	-	-	-
J-800	1	1257	51	37.406.275	16.222.222	3.393.900	7.022.859	5.000.000	5.767.294
J-700	0	0	0	-	-	-	-	-	-
J-600	7	9572	425	253.617.907	98.000.000	25.844.400	53.478.764	35.000.000	41.294.743
	10	12396	534	364.445.270	150.275.556	34.722.800	78.054.566	50.000.000	51.392.349

Table 5.10: Profit calculation with the future fleet possibilities and demand scenario 3, all fixes served

5.4. Sensitivity analysis

The demand scenarios used as input parameters for the sensitivity analysis are based on the input from the three demand scenarios in this assignment. The sensitivity analysis is applied for the optimization to figure out what the deviations in the fleet compositions are. This are consequences of the various input parameters. The second and third demand scenario from this assignment are adjusted to another number of increasing demand. The results in the fleet composition will be compared to the difference in input to check the robustness of the mathematical model. First of all, the increasing demand in the renewable energy sector are 20%, 50% and 70% instead of an increase of 35%. Subsequently, the demand in the heavy lift shipping industry will increase 8% and 10% due to a rise in the oil price. Finally, the rise in the renewable energy of 35% (demand scenario 2) is combined with the increasing demand due to the rise of the oil price (demand scenario 3). In table 5.11, the results of the optimized fleet composition are given due to the various input parameters. An extensive overview of all costs and revenues in the variants is shown in Appendix D .

	Renewable				Oil	
Vesselclass	20%	50%	70%	35% ; 6%	8%	10%
K	1	1	1	1	1	1
J	1	1	1	1	1	1
J-900	0	0	0	0	0	0
J-800	1	1	1	0	0	0
J-700	0	0	0	1	1	0
J-600	7	7	7	7	7	8
total	10	10	10	10	10	10

Table 5.11: Optimized fleet composition in various input scenarios

Remarkable from the results given in 5.11 are the comparable fleet compositions in different demand situations. The J-600 class are in every situation most attractive because the heaviest item of the cargoes are lighter than 600 tonnage. The results of the different scenarios are not very different from each other, which means that the model is robust. It is also noticeable that at least one K-class vessel is used to transport the cargoes in the highest segment of the heavy lift shipping industry.

5.5. Evaluation

The overview about the fleet composition at each demand scenario mentioned in section 5.3 is shown in table 5.12. In this section, the results achieved in the various demand scenarios for the future are put side by side in table 5.12. In this optimization model it is possible to choose the current K- and J-class vessels and the new J-light vessels. These vessels are configured in different crane capacities. The costs structures of these vessels are also divergent, which makes it more attractive to take the smallest possible crane capacity over an unnecessarily large crane configuration. Remarkable, that the smallest variant of the J-light is the most preferred. This is because very often cargoes are lifted with a heaviest item of less than $600 * 10^3$ kilogram.

	Demand scenario 1	Demand scenario 2	Demand scenario 3
K	1	1	1
J	1	1	1
J-900	0	0	0
J-800	1	0	1
J-700	0	1	0
J-600	7	7	7
vessels in fleet	10	10	10
Profit *mln	$50	$62	$51

Table 5.12: Overview of the optimized fleet composition at different future demand scenario's

5.6. Conclusions

The result of the optimization model is a fleet composition were the profit is maximized for the situation were all the fixes of the shipping data are served. In the optimization model, the capital costs and maintenance costs are divided over a period of five years instead of counting these per day that a vessel is in operation. This is more in line with the real situation. Subsequently, the vessels which are soon in for replacement removed as input vessels and substituted by the new J-light vessels. These new vessel classes are combined with the three future demand scenarios. Remarkable, that the smallest variant of the J-light in all demand scenarios are the most attractive for profit maximization according to the robust optimization model.

6
Conclusion and Recommendations

The goal of this research project is to find a fleet composition for a profit maximization in the heavy lift shipping industry. It is therefore very important to find a fleet composition which is as efficient as possible. The costs of these vessels are highly dependent on the installed crane configuration.

6.1. Conclusion

During this research, an optimization model to assemble a fleet composition in which profit maximization can be realized was successfully developed. The goal of this research has been to answer the following main question:

> **How can a model be developed for the optimization of Jumbo's fleet composition in order to maximize their profit in the heavy lift shipping industry?**

In order to achieve the best possible match between demand and supply, it is essential to find out in detail which characteristics determine both the demand from the market and the supply of vessel classes and the matching business procedure with the market share and the revenue structure in the heavy lift shipping market. Therefore, data from the cargoes of the past five years has been selected on what these applications and what the limiting factors were. Based on this knowledge, three different market scenarios have been developed. The scenarios are as follows: 1) equal to the demand in the past five years, 2) increase of 6% due to an improving oil and gas industry, 3) increase of 35% in the renewable energy market. For the supply side, the current vessels have been used to analyze what the most efficient fleet distribution would be. For the future scenarios, the vessels that are going to be replaced are omitted and the new J-light class will be introduced with various crane capacities in the optimization model. For the supply, costs are divided into capital costs, operational costs and voyage costs.

A *Maritime Fleet Size & Mix Problem* was used to optimize the fleet composition. This model was chosen because the composition of the Jumbo fleet consists of a variety of vessel classes. The decision of the optimized fleet composition is a strategic long-term decision were the goal of the objective function is to maximize the profit. The optimization model uses the following objective function:

$$max \quad \sum_{i\in I}\sum_{j\in J} R_j x_{ij} - (\sum_{i\in I}\sum_{j\in J} x_{ij}(d_j(W_i + B_i)) + \sum_{i\in I} b_i(C_i + M_i)) \tag{6.1}$$

In this objective function, the revenues from the fixes are reduced by cost items that are included in the optimization model. The model will be subject to a number of functional constraints to get the model as close to reality as possible. The mathematical model used for this optimization is a mixed integer linear programming model. The GUROBI solver is used to implement the mathematical algorithm into an optimization model.

It will always be difficult to predict the future. Unfortunately, the vessels must be purchased on the basis of future predictions. In addition, vessels can only be delivered after a considerable time due to the production.

That is why the three aforementioned scenarios have been used. The results of the robust optimization model clearly show that the current vessels with large capacities are too expensive and relatively unprofitable. It is therefore striking that the smallest variant of the J-light vessels is used the most in every scenario. It will therefore be recommended to purchase cheaper and smaller variants, because most of the loads can be conveyed with these. Jumbo strives to operate in the top segment of the heavy lift shipping market, but according to the optimization model this is not the most profitable. A disadvantage of smaller vessels is that the number of competitors will increase.

6.2. Recommendations for future research

When making an optimization model, the aim is always to get as close to reality as possible. In practice, this model will always deviate from reality. If assumptions are made in an optimization model to approximate reality, this will result in not being entirely consistent. Assumptions have been made for this model that could be inserted in more detail for further research.

This model does not include the possibility of renting vessels. This may be a possibility in the future, but is highly dependent on the length of time that a vessel is needed, the market that currently prevails and the location from where the vessel is needed and can be rented. This makes it very complex to implement this in the model.

It might be interesting to add the aspect of the location problem to the model to base it more on reality. This will result in a very complex model. This is not possible within a graduation assignment. It is also very difficult to predict this for the future.

For this research assignment, the main objective was to investigate the crane configuration of the vessel. It would be interesting to add other technical characteristics of the vessels to get a total picture.

In reality it happens that different cargoes are transported in combination. For the model it is only possible to serve fixes one by one. This is not equal to the real situation, but it is not possible to add this constraint without location problem.

When the location problem is added, it would also be interesting to find out the complete routes. Hereby it will be interesting to include the total distance travelled and the costs of canal fees in the cost calculation.

To get the model closer to reality, the complete costs overview should be taken into account. These costs would also have to be adjusted because port costs, for example, depend on the length of a vessel.

The maintenance costs are based on an assumption by Jumbo. To add this in more detail, the entire maintenance program would have to be traced and added to the optimization model.

Port costs are port related and will therefore not be included in the optimization model. For a scheduling problem this would be of great importance since it contains a large part of the costs.

6.3. Recommendations for Jumbo Maritime

In addition to the crane capacity, the outreach and the maximum lifting height should be interesting to implemented into the optimization model. The data of the outreach and lifting height to transport a cargo are essential for the crane capacity. Because these aspects were not documented in the Jumbo database, the outreach and lifting height parameters were neglected.

In the Jumbo database, properties of loads such as dimensions, volume, weight of the total load, maximum required deck strength and the port restrictions are not or hardly documented. To prepare this model, it will be necessary to fully document the data.

The recommendation is to purchase relatively smaller vessels. The results from the model have not considered the competition from the shipping market. In practice, the current high competition in the market for relatively smaller vessels must be considered because it could be less profitable than the model suggested. When considering a new fleet, this aspect will also have to be considered.

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A

Paper

A Decision Support Tool for the Heavy Lift Shipping Industry*

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A decision support tool is used to find the optimal fleet composition in the heavy lift shipping market. Many challenges were faced to find the optimal solution for the Jumbo fleet in the heavy lift crane vessel industry. First of all, it is important to find out which characteristics of the market determine the demand in the heavy lift shipping market. Thereafter, it is required to match the vessels of the Jumbo fleet with the market demand. This paper presents a Maritime Fleet Size Mix Problem (MFSMP) to optimize the Jumbo fleet composition in order to maximize the profit. This optimization model is based on a Mixed Integer Linear Programming algorithm. Three demand scenarios are introduced to optimize the fleet in the near future. Both the market scenarios and the new optimal vessels are included in the optimization model, which results in an optimized fleet composition and a maximized profit. The optimal fleet composition will be the result when, both the transport data of the past five years and the current fleet characteristics are used as input for the Maritime Fleet Size & Mix Problem. The results show that the Maritime Fleet Size & Mix Problem is a good mathematical model to determine the composition of the fleet by using the transport data of the past five years. The results show that with an optimal fleet composition the profit is increased.

I. INTRODUCTION

In the heavy lift shipping industry, it often occurs that the vessels sail with a load that does not come close to the maximum lifting capacity of the crane vessels. The result will be a redundant crane capacity which corresponds with higher investment costs of the vessels. According tot he Jumbo shipping data from the past five years, it has become apparent that the deployment of the vessels, based on the heaviest item (between 75-100% of the capacity) have only been needed in a meagre five percent of all transportations. Therefore, a decision support tool was examined by using the data collected in those years. This will result in an optimal fleet composition that maximizes profit whilst diminishing losses.

For the optimization of the fleet, the cost structure of the vessels is very important. A major cost item is the capital cost which depend on the new price of a vessel. The crane configuration has a direct effect on the purchase expenses with a contribution of 25% to 50% of the new price of a heavy lift crane vessel.

It is very costly to increase the fleet size beyond its minimum size since time charter costs will increase with it, which are the majority of the total costs. Therefore, there will never be more vessels considered than required; not even if this would increase the solution persistence.

An optimal fleet composition with the intention of maximizing the profit, could be achieved by using a decision support tool. Various demand scenarios will be presented for this, so they can be linked to the updated vessels. Based on the above, a recommendation is made for the Jumbo fleet in the future.

II. LITERATURE REVIEW

The strategic decisions for the fleet in the heavy lift shipping industry form the basis of this research project. The most important decisions are made on the strategic level, such as what kind of new vehicles should be bought or chartered in, which one of the existing vehicles should be sold or chartered out, and how to cope with demand fluctuations [1]. The strategic decision is made, based on the mix and size of the fleet composition. These strategic decisions are medium-term decision for the assignment of vessels to the routes selected by the strategic level [2]. The focus for the operational level is short-term, such as sailing dates and service demand. Only long-term decisions and therefore only strategic decision have been considered for this research. The optimization models' ability to optimize the Jumbo fleet composition have been assessed in order to maximize the profit. To do so, the following optimization methods have been assessed:

- *Maritime Fleet Size Problem*
- *Maritime Fleet Size & Mix Problem*
- *Vehicle Fleet Mix*

Various *Maritime Fleet Size Problems* (MFSP) have been examined in the literature. An example of Jaikumar and Solomon [3] was used for the optimization model of this research. In this example, the goal is to minimize the number of vessels in the fleet. Another example of such a MFSP is given in the Lai and Lo study [4]. In this study the size of the optimal fleet is considered for a ferry network system. For this problem, a mixed integer multiple origin/destination network flow problem

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is formulated. However, the abovementioned is homogeneous. The Jumbo vessels are not all identical hence not homogeneous.

Therefore, an MFSMP was subsequently examined. In this optimization model it is possible to optimize a heterogeneous fleet that applies to Jumbo. The decision on the required number of vessels to meet the demand is a strategic problem. According to Pantuso [5], an example of an objective function for the MFSMP is given in formula 1. In this objective function, both the acquisition of the fleet and the variable costs according to operation of the fleet are included.

$$min \sum_{\nu \in V} C^F_\nu y_\nu + \sum_{\nu \in V} \sum_{r \in R_\nu} C^V_{\nu r} x_{\nu r} \tag{1}$$

The objective of the classical *Vehicle Routing Problem* (VRP) is to determine a set of optimal routes performed by vehicles with limited capacity to serve a given set of customers [6]. The VRP is a highly abstract model of distances, travel times, travel costs and service times [1]. The application of the VRP in the heavy lift shipping industry is about the optimization of the vessel routes between the port of loading and the port of discharge; both with limited capacity.

III. RESEARCH

To be able to apply the MFSMP model to the heavy lift shipping industry of Jumbo, it is necessary to find out what the demand and supply in the market of the heavy lift shipping industry depend on. Technical limitations of the vessels and the cost structures of the vessel are categorized under the supply side of the market. The demand from the market is difficult to predict, but according to Hagenbeek [7], the most significant drivers of demand for heavy lift shipping are the crude oil price and the viability of renewable energy. The demand from the market and the supply from the Jumbo fleet are the input parameters in the model. An overview is given in the following figure 1:

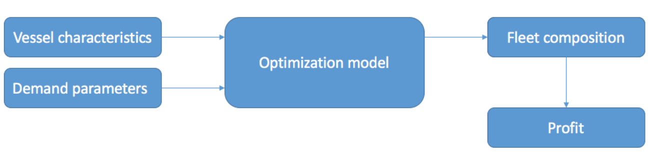

FIG. 1. Optimization in the Heavy Lift Shipping market

It is important to make an estimate of future demand, in order to be able to make a recommendation for the fleet distribution in the near future. Various scenarios are designed to answer this question. By using both, the new vessel classes and the demand scenarios as input, it will result in an optimized fleet for the future. These various fleet compositions will lead to an optimized profit for the various demand scenarios.

A. Research Question

During this research, an optimization model to assemble a fleet composition in which profit maximization can be realized was successfully developed. The goal of this research has been to answer the following main question:

> *How can a model be developed for the optimization of Jumbo's fleet composition in order to maximize their profit in the heavy lift shipping industry?*

B. Assumptions

The aim with an optimization model is to approach reality as closely as possible. Unfortunately, it is not possible to get the model exactly the same as the actual situation. Because it is very complex to translate all parameters from reality into the optimization model, assumptions will have to be made. Various assumptions have been made for this model, namely:

- *Vessel utilization grade* For the model situation, a vessel utilization of 75% is assumed. This result is an availability of 256 days in a year. This number is compared to the shipping data over the previous five years.
- *One fix per vessel at the same time* For the optimization model, it is not possible to combine multiple cargoes on a vessel at the same time. This is because the location problem is neglected.
- *Heaviest item less or equal to combined crane capacity* It is possible for the optimization model to load the cargo on the vessel if the weight of the heaviest item is less or equal to the combined crane capacity of the Jumbo vessel.
- *Bunker costs* The fuel consumption calculation is based on 85% of the used engine power combined with a vessel draft of 6.6[m].
- *Rental vessels* This model does not include the possibility of renting vessels.
- *Vessel location* The location of the vessels are neglected because the aim is to optimize the crane configurations installed on each vessel and not an optimized location problem.
- *Fix data* The loading and discharge date of the cargoes are neglected because these data will be client dependent. These parameters are not included in the model, only the number of days required to transport a cargo from origin to destination are inserted.

IV. MATHEMATICAL MODEL

The model is formulated as a linear programming formulation. The aim of the *Mixed Integer Linear Programming* model is to give an optimized fleet composition to maximize the profit.

A. Indices and sets

In table I, the indices and sets which are used in the mathematical model are shown.

TABLE I. Indices and sets

Index	Description	Range
i	Vessel class	$i \in I$ =1, ..., i_{max}
j	Fix number	$j \in J$ =1, ..., j_{max}

The fix data over the past five years are inserted from a shipping database from Jumbo. The numbers from vessel characteristics are calculated or figured out by the fact sheets of the vessels in the current fleet and subsequently inserted in the model.

B. Parameter variable

For the optimization model, the revenue per fix j is minimized by the cost structure of vessel i. The costs which are calculated in the optimization are the capital costs, maintenance costs, wage costs and fuel costs. The capital and maintenance costs are calculated over a period of five years, because the vessel is in operation for a period of time. The wages and fuel costs are calculated over the number of days that a vessel is in operation. The parameters used for the optimization model are shown in table IV B.

Parameter	Definition
R_j	Revenue per fix
C_i	Capital costs per vessel
M_i	Maintenance costs per vessel
W_i	Wages per vessel class
B_i	Fuel costs per vessel class
K_i	Combined crane capacity of each vessel class
G_j	Heaviest item on a fix
a_i	Vessel availability in five years
n_i	Number of vessels in a vessel class
d_j	Vessel days per fix
b_i	Number of vessels in vessel class
U	Occupation gradient of each vessel in the fleet

C. Decision variables

The model uses a binary decision variable where one of the fix j is served by vessel i, otherwise the decision variable should be zero and the revenue and costs of this vessel and fix combination are multiplied by zero. The decision variable used in the model is shown in equation IV C.

$$x_{ij} = \begin{cases} 1, & \text{if fix } j \text{ is shipped by vesselclass } i. \\ 0, & \text{otherwise.} \end{cases}$$

[]

$$b_i =$$

Number of vessels in vessel class$i$.

D. Objective function

The objective for the linear programming model is to find the most profitable fleet composition of the Jumbo fleet. The total revenue is the sum of the revenues obtained by each fix. The total cost of the fleet is the sum of each cost item. The cost items that are included in the objective function will be described further on. To find the maximum profit, the total revenue is minimized by the total costs. The objective function for this assignment is shown in equation 2.

$$max \quad \sum_{i \in I} \sum_{j \in J} R_j x_{ij} - (\sum_{i \in I} \sum_{j \in J} x_{ij}(d_j(W_i + B_i)) + \sum_{i \in I} b_i(C_i + M_i)) \tag{2}$$

E. Constraints

The constraints for the linear programming model depend on the limiting factors of the vessels.

$$\sum_{i \in I} x_{ij} = 1 \quad \forall j \in J \tag{3}$$

$$\sum_{j \in J} x_{ij} d_j \leq n_i a_i \quad \forall i \in I \tag{4}$$

$$\sum_{i \in I} \sum_{j \in J} x_{ij} G_j \leq K_i \tag{5}$$

$$b_i \leq F_i \quad \forall i \in I \tag{6}$$

In equation 3, the constraint ensures that exactly one vessel is used for each fix. Equation 4 ensures the max number of vessel days in the period of five years cannot be exceeded for each vessel in the fleet. The cargo shipped by a vessel class cannot exceed the combined crane capacity of the chosen vessel class. The constraint in equation 5 is to ensure that the weight of the heaviest cargo of a fix is less or equal to the crane capacity of the used vessel. Since it is not possible to exceed the maximum number of vessels in a vessel class, the constraint to maintain this limitation is given in equation 6. Constraint 6 is to divide the cargoes over the current vessels in the fleet.

V. OPTIMIZATION SOLVER

This chapter will discuss which type of the mathematical model will be solved with the formulation in the previously discussed chapter. It will also briefly discuss which solver has been used for this.

A. Mathematical Problem: Linear Programming

For a linear programming model, the real situation should be translated by a number of linear functions. It will be more complex if the model is given in a quadratic programming formulation. In the case of the optimization problem, the objective function and all the accessory constraints can be written as linear functions.

B. GURBOI Optimizer

The branch-and-bound method of the GUROBI solver is used for the mathematical formulation. This optimizer is suitable for Linear Programming models and Mixed Integer Linear Programming models, which should meet the requirements of this formulation.

VI. RESULTS

In this section, the model input, model output and the verification & validation of the model are shown. The results of the model given in this previous chapter are based on the different input parameters.

A. Model input

The model input is based on the vessel characteristics which consist of the financial and the technical parameters. The financial parameters of the vessels are subdivided in a cost structure which is mentioned above. The technical parameters of the vessel depend on the crane configuration which is installed on each vessel. In the first situation the current Jumbo fleet is used as input fleet. For the fleet composition in the near future, the current H- and E-class vessels are removed and the new variants of the J-light class are introduced. Subsequently, the second model input depends on the fix data. The input parameters origination from the shipping data of Jumbo consist of a number of vessel days that are required to ship the cargo from origin to the destination, the price and the heaviest item of the cargo which should be transported. For the fix data, three different demand scenarios for the near future are determined, which depend on the future predictions of the demand in the heavy lift shipping market. The demand scenarios for the near future are:

- Demand is equal to previous five years
- Increasing demand of 6% compared to previous five years
- Increasing wind energy market

B. Model output

The output of the optimization model will give an optimal fleet composition which contribute to a maximized profit. First of all, the current situation is used as input parameter for the model. Secondly, both the future vessel configurations and the future demand scenarios are inserted.

1. *Realized situation* The realized situation should be compared to the optimization of the fleet combined with the realized shipping data. For this optimization, the same vessel classes can be used but in another composition. The optimized situation will give a fleet composition shown in table II

TABLE II. Fleet composition of previous five year

	Realized situation	Optimized configuration
K-3000	2	2
J-1800	4	0
H-800	2	1
E-650	2	7
Profit	49.2 mln $	115.8 mln $

2. *Future fleet composition* In the future fleet composition, the J-light vessels are introduced in four variants with a combined crane capacity of 600, 700, 800 and 900 tonnes. These new vessels combined with the current J- and K-class vessels are the vessel that are used for the optimization in the future fleet composition. This fleet is combined with the different demand scenarios. The results of the optimization are shown in figure VI B.

C. Validation and verification

Verification ensures that the computer programming and implementation of the conceptual model are correct [8]. Is the model implemented accordingly to the specifications? For the verification of the optimization model, a

	Demand scenario 1	Demand scenario 2	Demand scenario 3
K	1	1	1
J	1	1	1
J-900	0	0	0
J-800	1	0	1
J-700	0	1	0
J-600	6	6	6
vessels in fleet	9	9	9
Profit	56.5 mln $	68.7 mln $	57.6 mln $

FIG. 2. Overview of the optimized fleet composition at different future demand scenario's

number of experiments should be done to check whether the model gives output values that are equal to the expected output values. In these experiments extreme conditions are implemented as input parameters. The definition of validation is substantiating that a computerized model possesses a satisfactory range of accuracy within its domain of applicability that is consistent with the intended application of the model [9]. For this optimization model it is hard to validate the model with the real situation, because real numbers are used as input parameters combined with some assumed values of the vessel characteristics. A one hundred percent equality compared to the realized situation does not exist for the validation but trying to come close is preferred.

VII. CONCLUSIONS

The results show that the Maritime Fleet Size & Mix Problem is a good mathematical model to determine the composition of the fleet by using the transport data from the past five years. The result show that an optimal fleet composition will increase the profit. By also using the Maritime Fleet Size & Mix Problem model with the introduction of the J-light and combining it with the three different future scenarios, the vessel type with a combined crane capacity of 600 tonnes appears to be the most attractive in the J-light class.

VIII. RECOMMENDATIONS

When making an optimization model, the aim is always to get as close to reality as possible. In practice, this model will always deviate from reality. If assumptions are made in an optimization model to approximate reality, this will result in not being entirely consistent. Assumptions have been made for this model that could be inserted in more detail for further research.

ACKNOWLEDGMENTS

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B

Jumbo Maritime

B.1. The Historic and Current Fleet of Jumbo [11]

Vessel	Class	Crane Capability [t]	In service since	Status
Stellaprima	-	12	1956	Out of service
Stellanova*	A	55-70	1968	Out of service
Daniella	A	55	1969	Out of service
Fairlift	A	55	1969	Out of service
Gabriella	B	320	1974	Out of service
Fairload	B	320	1974	Out of service
Mirabella	C	600	1977	Out of service
Fairlane	C	600	1974	Out of service
Jumbo Challenger	D	1000	1983	Out of service
Fairmast	D	1000	1983	Out of service
Daniella**	E	500-650	1989	Out of Service
Fairlift**	E	500-650	1990	Currently employed
Stellaprima	E	650	1990	Currently employed
Jumbo Callisto***	N/A	70	1990	Out of service
Jumbo Spirit	G	500	1994	Out of service
Fairload	G	500	1994	Out of service
Stellanova	G	500	1995	Out of service
Jumbo Vision	H	800	2000	Currently employed
Fairlane	H	800	2000	Currently employed
Jumbo Javeling	J	1800	2004	Currently employed
Fairpartner	J	1800	2004	Currently employed
Fairplayer	J	1800	2008	Currently employed
Jumbo Jubilee	J	1800	2008	Currently employed
Jumbo Kinetic	K	3000	2015	Currently employed
Fairmaster	K	3000	2015	Currently employed

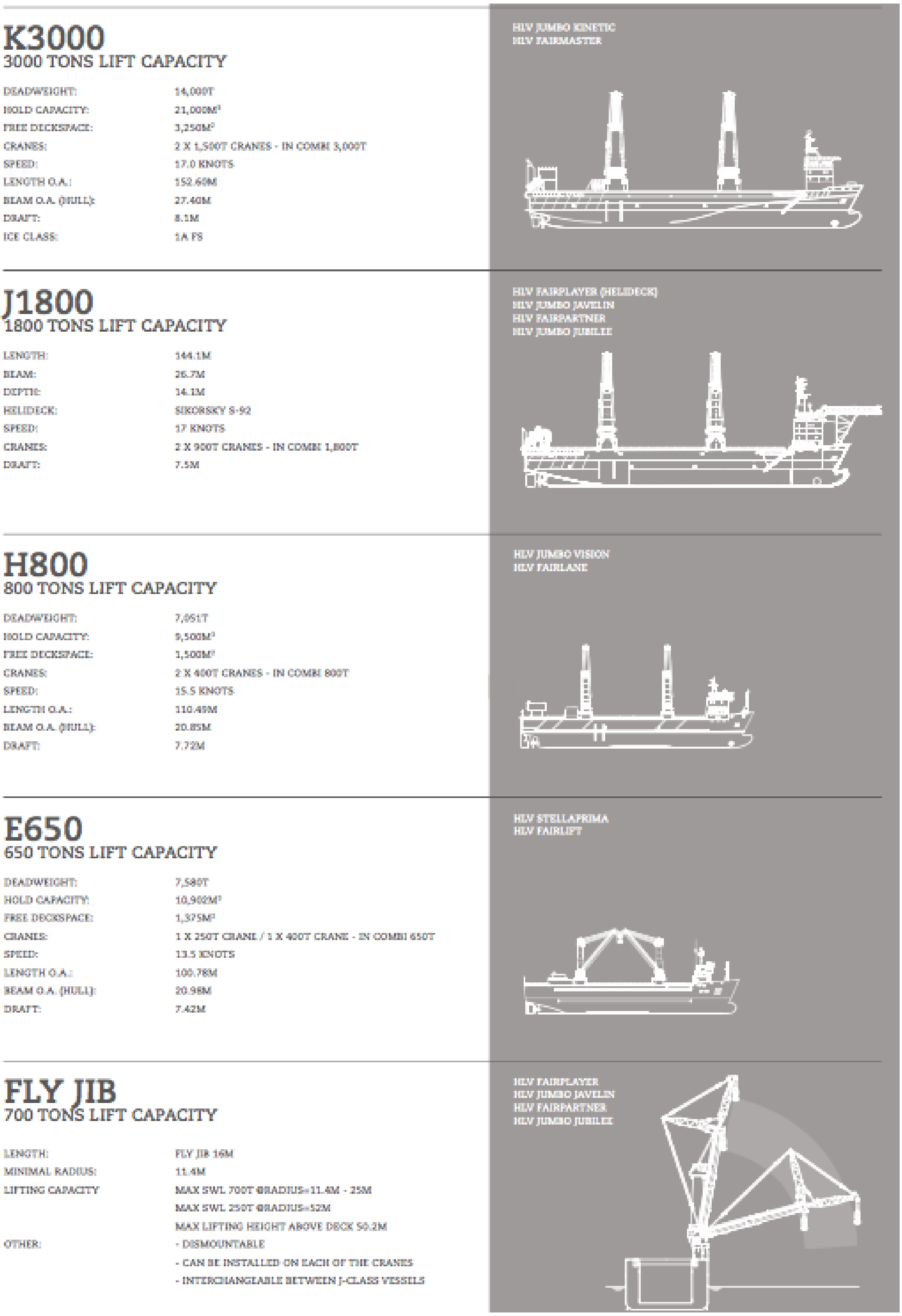
* The lifting capability the Stellanova has been upgraded from 55 to 70 tons

** One of the 250 tons cranes has been upgraded to a 400 tons crane

*** No class is known, because this vessel had been bought in 1990

Figure B.1: The Historic and Current Fleet of Jumbo [11]

B.2. The Current Fleet of Jumbo



K3000
3000 TONS LIFT CAPACITY

DEADWEIGHT:	14,000T
HOLD CAPACITY:	21,000M³
FREE DECKSPACE:	3,250M²
CRANES:	2 X 1,500T CRANES - IN COMBI 3,000T
SPEED:	17.0 KNOTS
LENGTH O.A.:	152.60M
BEAM O.A. (HULL):	27.40M
DRAFT:	8.1M
ICE CLASS:	1A FS

HLV JUMBO KINETIC
HLV FAIRMASTER

J1800
1800 TONS LIFT CAPACITY

LENGTH:	144.1M
BEAM:	26.7M
DEPTH:	14.1M
HELIDECK:	SIKORSKY S-92
SPEED:	17 KNOTS
CRANES:	2 X 900T CRANES - IN COMBI 1,800T
DRAFT:	7.5M

HLV FAIRPLAYER (HELIDECK)
HLV JUMBO JAVELIN
HLV FAIRPARTNER
HLV JUMBO JUBILEE

H800
800 TONS LIFT CAPACITY

DEADWEIGHT:	7,051T
HOLD CAPACITY:	9,500M³
FREE DECKSPACE:	1,500M²
CRANES:	2 X 400T CRANES - IN COMBI 800T
SPEED:	15.5 KNOTS
LENGTH O.A.:	110.49M
BEAM O.A. (HULL):	20.85M
DRAFT:	7.72M

HLV JUMBO VISION
HLV FAIRLANE

E650
650 TONS LIFT CAPACITY

DEADWEIGHT:	7,580T
HOLD CAPACITY:	10,902M³
FREE DECKSPACE:	1,375M²
CRANES:	1 X 250T CRANE / 1 X 400T CRANE - IN COMBI 650T
SPEED:	13.5 KNOTS
LENGTH O.A.:	100.78M
BEAM O.A. (HULL):	20.98M
DRAFT:	7.42M

HLV STELLAPRIMA
HLV FAIRLIFT

FLY JIB
700 TONS LIFT CAPACITY

LENGTH:	FLY JIB 16M
MINIMAL RADIUS:	11.4M
LIFTING CAPACITY	MAX SWL 700T @RADIUS=11.4M - 25M
	MAX SWL 250T @RADIUS=52M
	MAX LIFTING HEIGHT ABOVE DECK 50.2M
OTHER:	- DISMOUNTABLE
	- CAN BE INSTALLED ON EACH OF THE CRANES
	- INTERCHANGEABLE BETWEEN J-CLASS VESSELS

HLV FAIRPLAYER
HLV JUMBO JAVELIN
HLV FAIRPARTNER
HLV JUMBO JUBILEE

Figure B.2: The Current Fleet of Jumbo

B.3. Factsheets

Call sign	PCFO	G.T. Panama:	61201
IMO NO.:	9634165	N.T. Panama:	15131
Port of Registry:	Rotterdam	No. of holds:	1
Flag:	Netherlands	No. of hatches:	1
Classification:	Lloyd's Register +100 A1	Bale capacity:	20,700 m^3 (with tweendecks
	strengthened for heavy		fitted)
	cargoes +LMC, UMS, CG, LI,	Hold: dimensions lower hold:	83,2 x 17,0 x 5,6 m
	IWS	Hold: dimensions upper hold:	108,8 x 17,0 x 7.0 m
General agent:	Kahn Scheepvaart B.V.	Hold: total height:	12,6 m
Ice Class:	1A Finnish Swedish	Strenght of tanktop:	12 T/m^2
Deadweight (summer) abt:	14,000 T	Strenght of tweendecks:	7 T/m^2
Draft (above bottom of keel):	8,1 m	Strenght of hatchcovers:	6 x 8,7 T/m^2 and 3 x 12 T/m^2
Length o.a.:	152,60 m	No. of tweendecks:	1 (flush) adjustable in height
Beam moulded:	27,4 m	Cargo gear:	2 x 1,500 T mastcrane,
Beam overall (hull);	27,75 m		combinable to 3,000 T
Air draft (above keel, jibs &	51,55 m	Main engine(s):	2 x CPP/ME with MAK 9M32C
derricks down):			engines, total of 9,000 kW
Free deck space:	3,250 m^2	Thruster(s):	Bowthruster: Berg – 1,500 kW
G.T.:	18099	Speed:	17.00 kn
N.T.:	5844	Bunker capacity:	1499 t I.F.O. / 301 t M.G.O.
G.T. Suez Canal:	17620	Fresh water capacity:	298 t
N.T. Suez Canal:	14476 (Danube rule)		

Figure B.3: Jumbo Kinetic

Call sign	PCYQ	G.T. Panama:	61201
IMO NO.:	9650585	N.T. Panama:	15131
Port of Registry:	Rotterdam	No. of holds:	1
Flag:	Netherlands	No. of hatches:	1
Classification:	Lloyd's Register +100 A1	Bale capacity:	19,191 m³ (with tweendecks
	strengthened for heavy		fitted)
	cargoes +LMC, UMS, CG, LI,	Hold: dimensions lower hold:	82,9 x 17,0 x 5,6 m
	IWS	Hold: dimensions upper hold:	108,6 x 17,0 x 7,0 m
General agent:	Kahn Scheepvaart B.V.	Hold: total height:	12,6 m
Ice Class:	1A Finnish Swedish	Strenght of tanktop:	12 T/m²
Deadweight (summer) abt:	14,000 T	Strenght of tweendecks:	7 T/m²
Draft (above bottom of keel):	8,65 m	Strenght of hatchcovers:	6 x 8,7 T/m² and 3 x 12 T/m²
Length o.a.:	152,9 m	No. of tweendecks:	1 (flush) adjustable in height
Beam moulded:	27,4 m	Cargo gear:	2 x 1,500 T mastcrane,
Beam overall (hull);	27,74 m		combinable to 3,000 T
Air draft (above keel, jibs &		Main engine(s):	2 x CPP/ME with MAK
derricks down):	51,55 m		9M32C engines, total of
Free deck space:	3,183 m²		9,000 kW
G.T.:	18099	Thruster(s):	Bowthruster: Berg – 1,500 kW
N.T.:	6397	Speed:	17.00 kn
G.T. Suez Canal:	17620	Bunker capacity:	1499 t. I.F.O / 301 t M.G.O.
N.T. Suez Canal:	14476	Fresh water capacity:	162,7 t

Figure B.4: Fairmaster

J1800 Class

HLV Fairpartner

Call sign:	PHEC
IMO no.:	9243849
Port of registry:	Willemstad
Flag:	Netherlands
Classification:	Lloyd's Register 100 A1, LI, CG, +LMS, UMS, with descriptive note
	SCM regarding loading and unloading aground during crane
	operations, class contemplated. vessel can sail with weather deck
	hatchcovers omitted
Built:	2004
Owner:	Fairpartner N.V.
Charterers:	Fairplay Heavy Lift B.V. Rotterdam
General agent:	Kahn Scheepvaart B.V. Rotterdam
Owners P.I. club:	Gard A.S. Arendal, Norway
Deadweight (summer) abt:	11,281 T (7,5 m) / 13,262 T (8.1 m) all told
Draft (above bottom of keel):	7.5 m (open condition) / 8,1 m
Length o.a.:	144.21 m
Beam o.a. (hull):	26.60 m
Air draft (above keel, jibs & derricks down):	47.32 m
G.T.:	15,022 T
N.T.:	4,506 T
G.T. Suez Canal:	14,672 T
N.T. Suez Canal:	10,926 T
G.T. Panama:	
N.T. Panama:	12,592 T
Number of holds:	1
Number of hatches:	1
Bale capacity (with tweendecks in holds) abt.:	18,030 m³
Free deckspace abt.:	3,100 m²
Hold: dimensions lowerhold:	82.65 x 17.00 m
Hold: dimensions tweendeck:	101.95 x 17.00 m
Hold: total height:	12.50 m
Strength of tanktop:	12.00 T/m²
Strength of tweendecks:	7.00 T/m²
Strength of hatchcovers:	5 x 8.7 T/m² + 3 x 12 T/m²
Number of tweendecks:	1 (flush) adjustable in height
Cargo gear:	2 cranes 900 T / combined 1,800 T
	Auxiliary hoist 2 x 37.5 T (traveling trolley)
	Manriding approved
	2 x 10 T slinghandling hoist
Main engine(s):	2 x Man/B&W 9L 32/40 (8,640 kW total)
Thrusters:	Bowthruster: Lips CPP 1,450 kW
Speed about:	17.00 knots
Bunker capacity:	1,368 T HFO / 164 T MGO
Fresh water capacity:	140.82 T
No. insulated cargo spaces:	
No. cargo tanks:	
Container intake (sub weight):	192 FEU in hold w/o tweendeck hatchovers / 426 TEU

Figure B.5: Fairpartner

J1800 Class
HLV Jumbo Jubilee

Call sign:	PBSA
IMO no.:	9371581
Port of registry:	Rotterdam
Flag:	Netherlands
Classification:	Lloyd's Register +100 A1 strengthened for heavy cargoes +LMC, UMS, CG, LI, IWS, with the descriptive note SCM and loading & unloading aground during crane operations, with hatchcovers omitted draught restricted to 7.5 m
Built:	2009
Owner:	Jumbo Jubilee N.V.
Charterers:	Kahn Special Transport B.V. Rotterdam
General agent:	Kahn Scheepvaart B.V. Rotterdam
Owners p.i. club:	Gard A.S. Arendal, Norway
Deadweight (summer) abt:	11,036 T (7.5 m) / 13,017 T (8.1 m) all told
Draft (above bottom of keel):	7.5 m (open condition) / 8.1 m
Length o.a.:	144.80 m
Beam o.a. (hull):	26.84 m
Air draft (above keel, jibs & derricks down):	47.32 m
G.T.:	15,012 T
N.T:	4,503 T
G.T. Suez Canal:	15,229.22 T
N.T. Suez Canal:	12,581.29 T
G.T. Panama:	
N.Y. Panama:	12,584 T
Number of holds:	1
Number of hatches:	1
Bale capacity (with tweendecks in holds) abt.:	18,130 m³
Free deckspace abt.:	3,100 m²
Hold: dimensions lowerhold:	82.70 x 17.00 x 5.65 m
Hold: dimensions tweendeck:	102.00 x 17.00 x 6.85 m
Hold: total height:	12.50 m
Strength of tanktop:	12.00 T/m²
Strength of tweendecks:	7.00 T/m²
Strength of hatchcovers:	5 x 8.7 T/m² + 3 x 12 T/m²
Number of tweendecks:	1 (flush) adjustable in height
Cargo gear:	2 cranes each 900 T / combined 1,800 T Auxiliary hoist 2 x 37.5 T (traveling trolley) Manriding approved 2 x 10 T slinghandling hoist
Main engine(s):	2 x CPP/ME with MAK 9M32C engines (9,000 kW total)
Thrusters:	Bowthruster: Wartsila 1,500 kW
Speed about:	17.00 knots
Bunker capacity:	1,340 T HFO / 290 T MGO
Fresh water capacity:	140.00 T
No. insulated cargo spaces:	
No. cargo tanks:	
Container intake (sub weight):	192 FEU in hold w/o tweendeck hatchovers / 426 TEU

Figure B.6: Jumbo Jubilee

SPECIFICATIONS

General	
Call sign	PHPU
IMO no.	9371579
Built	2008
Flag	The Netherlands
Port of Registry	Rotterdam
Classification	Lloyd's Register+ 100A1,
	Strengthened for Heavy Cargos
	LMC, UMS, CG, LI, DP (AA), IWS

Principal Dimensions/Tonnage	
Length o.a.	144.1 m
Length b.p.p	133.8 m
Breadth moulded	26.7 m
Depth to Main Deck	14.1 m
Draft (bottom keel)	6.0 m / 8.1 m
Displacement (at 7.5m)	20,120 t
Deadweight (at 7.5m)	10,700 t
GRT	15,027 t
NRT	5,244 t

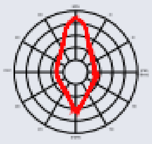
Main Deck/Cargo Hold	Area	Strength
Main Deck	3,100 m²	9-12 t/m²
Tween Deck	1,700 m²	7 t/m²
Lower Hold/Tank top	1,400 m²	12 t/m²

Power Plant	
Main Engines	2 x MAK 9M 32C 4,500 kW
Auxiliary Engines	2 x Caterpillar 3516B 1,824 kW/ea
Shaft Generators	2 x AEM SE 630 M4 3,000 kW/ea
Emergency Generator	1 x 465 kW

Propulsion Plant	
Stern Main Thrusters	2 x Wartsila CPP
Bow Tunnel Thrusters	2 x Wartsila 1,500 kW
Retractable Azimuth	1 x Wartsila 1,700 kW
Thrusters	

Service Speed	
Transit average	17 Knots
Economical	14 Knots

Dynamic Positioning System	
DP System	Kongsberg K-pos2 system
Reference Systems	2 x Seatex 116 DPS
	1 x Veripos Verify DGPS
	1 x HiPAP 501
	1 x LTW (tautwire system)
	RADius/Fanbeam



Cranage	
Cranes/Type	Huisman Mast Cranes
	2 x 900 t Revolving
Heavy Lift Capacity	1,000 t (Offshore)
	1,800 t (Calm Water/Harbor)
Subsea Lift Capacity	1,000 t at 1,000 m water depth
	660 t at 1,500 m water depth
	280 t at 2,000 m water depth
	200 t at 3,000 m water depth
Heave Compensation	Passive Heave Compensators
	project specific/tailor made
Ancillary Lifting	Auxiliary Hoists: 2 x 37,5 t
	Travel Trolley
	Sling Handling Hoists: 2 x 10 t
	Tugger Winches: 2 x 25 t / crane
	(constant tension)
	1 x 700 t Fly-Jib

Capacities	
Fuel Oil	1,340 t I.F.O/290 Te M.G.O
Fresh water	200 t

Accommodation/Helideck	
Accommodation	up to 75 persons
	13 x single cabins,
	31 x double cabins
Helideck	12.8 t (Sikorsky S-92-CAP437)

Figure B.7: Fairplayer

SPECIFICATIONS

General	
Call sign	PHEG
IMO no.	9243837
Built	2004
Flag	The Netherlands
Port of Registry	Willemstad
Classification	LLOYD'S REGISTER 100 A1, LI, CG,
	+LMC, UMS, DP AA

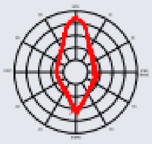
Principal Dimensions/Tonnage	
Length o.a.	144.1 m
Length b.p.p	133.8 m
Breadth moulded	26.7 m
Depth to Main Deck	14.1 m
Draft (bottom keel)	6.0 m / 8.1 m
Displacement (at 7.5m)	20,120 Te
Deadweight (at 7.5m)	10,942 Te
GRT	15,022 Te
NRT	4,506 Te

Main Deck/Cargo Hold	Area	Strength
Main Deck	3,100 m^2	9-12 Te/m^2
Tween Deck	1,700 m^2	7 Te/m^2
Lower Hold/Tank top	1,400 m^2	12 Te/m^2

Power Plant	
Main Engines	2x MAN 9L 32/40 4,320 kW
Auxiliary Engines	1 x Caterpillar 3516B 1,824 kW/ea
	1 x Caterpillar 3508B 740 kW/ea
Shaft Generators	2 x AEM SE 630 M4 3,000 kW/ea
Emergency Generator	1 x 280 kW

Propulsion Plant	
Stern Main Thrusters	2 x Wartsila CPP
Bow Thrusters	1 x Wartsila 1,450 kW
	1 x Rolls Royce 1500 kW
Retractable Azimuth	1 x Wartsila 1,700 kW
Thrusters	

Service Speed	
Transit average	17 Knots
Economical	14 Knots

Dynamic Positioning System	
DP System	Kongsberg SDP 21
Reference Systems	2 x Seatex 116cm DGPS
	1 x Veripos Verify DGPS
	1 x HiPAP 501
	1 x LTW (tautwire system)
	RADius/Fanbeam

Cranage	
Cranes/Type	Huisman Mast Cranes
	2 x 900 Te Revolving
Heavy Lift Capacity	1,000 Te (Offshore)
	1,800 Te (Calm Water/Harbor)
Subsea Lift Capacity	1,000 Te at 1,000 m water depth
	660 Te at 1,500 m water depth
	280 Te at 2,000 m water depth
	200 Te at 3,000 m water depth
Heave Compensation	Passive Heave Compensators
	project specific/tailor made
Ancillary Lifting	Auxiliary Hoists: 2 x 37,5 Te
	Travel Trolley
	Sling Handling Hoists: 2 x 10 Te
	Tugger Winches: 2 x 25 Te / crane
	(constant tension)
	1 x 700 Te Fly-Jib

Capacities	
Fuel Oil	1,270 Te I.F.O/209 Te M.G.O
Fresh water	141 Te

Accommodation	
Accommodation	up to 80 persons (incl. hospital 2 pers)
	10 x single cabins
	34 x double cabins

Figure B.8: Jumbo Javelin

H800 Class
MV Fairlane

Call sign:	PBFW
IMO no.:	9153654
Port of registry:	Rotterdam
Flag:	Netherlands
Classification:	Llloyd's Register +100 A1, strengthened for heavy
	cargoes, bottom strengthened for loading / unloading
	aground CG, LMS, UMS, SCM, class contemplated
Built:	2001
Owner:	Fairlane B.V.
Charterers:	N/A
General agent:	Kahn Scheepvaart B.V. Rotterdam
Owners P.I. club:	Gard A.S. Arendal, Norway
Deadweight (summer) abt:	7,051 T all told
Draft (above bottom of keel):	7.72 m
Length o.a.:	110.49 m
Beam o.a. (hull):	20.85 m
Air draft (above keel, jibs & derricks down):	36.40 m
G.T.:	7,971 T
N.T.:	2,391 T
G.T. Suez Canal:	8,116 T
N.T. Suez Canal:	6,723 T
G.T. Panama:	
N.T. Panama:	6,744 T
Number of holds:	1
Number of hatches:	1
Bale capacity (with tweendecks in holds) abt.:	10,977 m^3
Free deckspace abt.:	1,500 m^2
Hold: dimensions lowerhold:	58.65 x 15.18 x 7.28 m
Hold: dimensions tweendeck:	72.75 x 15.18 x 4.09 m
Hold: total height:	12.17 m
Strength of tanktop:	12.00 T/m^2
Strength of tweendecks:	4.25 T/m^2
Strength of hatchcovers:	4.25 T/m^2
Number of tweendecks:	1 (flush) adjustable in height
Cargo gear:	2 cranes each 400 T / combined 800 T
	Auxiliary hoist 2 x 25 T
Main engine(s):	MAN/B&W 7S 35MC, 4,900 kW
Thrusters:	Bowthruster: Lips, 610 kW
Speed about:	14.50 knots
Bunker capacity:	800 T HFO 380/115 T MGO
Fresh water capacity:	167.00 T
No. insulated cargo spaces:	
No. cargo tanks:	
Container intake (sub weight):	340 TEU
	Lakes fitted

Figure B.9: Fairlane

H800 Class

MV Jumbo Vision

Call sign:	PBBG
IMO no.:	9153642
Port of registry:	Rotterdam
Flag:	Netherlands
Classification:	Lloyd's Register 100 A1, strengthened for heavy cargoes, bottom strengthened for loading / unloading aground CG, LMS, UMS, SCM
Built:	2000
Owner:	Jumbo Vision B.V.
Charterers:	N/A
General agent:	Kahn Scheepvaart B.V. Rotterdam
Owners P.I. club:	Gard A.S. Arendal, Norway
Deadweight (summer) abt:	6,993 T all told
Draft (above bottom of keel):	7.72 m
Length o.a.:	110.49 m
Beam o.a. (hull):	20.85 m
Air draft (above keel, jibs & derricks down):	36.40 m
G.T.:	7,966 T
N.T.:	2,389 T
G.T. Suez Canal:	8,111 T
N.T. Suez Canal:	6,726 T
G.T. Panama:	
N.T. Panama:	6,741 T
Number of holds:	1
Number of hatches:	1
Bale capacity (with tweendecks in holds) abt.:	10,977 m^3
Free deckspace abt.:	1,500 m^2
Hold: dimensions lowerhold:	58.65 x 15.18 x 7.28 m
Hold: dimensions tweendeck:	72.75 x 15.18 x 4.09 m
Hold: total height:	12.17 m
Strength of tanktop:	12.00 T/m^2
Strength of tweendecks:	4.25 T/m^2
Strength of hatchcovers:	4.25 T/m^2
Number of tweendecks:	1 (flush) adjustable in height
Cargo gear:	2 cranes 400 T / combined 800 T
	Auxiliary hoist 2 x 25 T
Main engine(s):	MAN/B&W 7S 35MC, 4,900 kW
Thrusters:	Bowthruster: Lips, 610 kW
Speed about:	14.50 knots
Bunker capacity:	800 T IFO 380/115 T MGO
Fresh water capacity:	168.00 T
No. insulated cargo spaces:	
No. cargo tanks:	
Container intanke (sub weight):	340 TEU
	Lakes fitted

Figure B.10: Jumbo Vision

E650 Class
MV Fairlift

Call sign:	PEBM
IMO no.:	8806905
Port of registry:	Willemstad
Flag:	Netherlands
Classification:	Lloyd's Register 100 A1, LMC
	Strengthened for heavy cargoes, CG, UMS
Built:	1990
Owner:	Fairlift N.V.
Charterers:	Fairplay Heavy Lift BV Rotterdam
General agent:	Kahn Scheepvaart BV Rotterdam
Owners P.I. club:	Gard A.S. Arendal, Norway
Deadweight (summer) abt:	7,561 T all told
Draft (above bottom of keel):	7.42 m
Length o.a.:	100.78 m
Beam o.a. (hull):	20.98 m
Air draft (above keel, jibs & derricks down):	36.00 m
G.T.:	6,953 T
N.T.:	2,085 T
G.T. Suez Canal:	7,089 T
N.T. Suez Canal:	5,894 T
G.T. Panama:	7,182 T
N.T. Panama:	4,859 T
Number of holds:	1
Number of hatches:	1
Bale capacity (with tweendecks in holds) abt.:	10,902 m^3
Free deckspace abt.:	1,375 m^2
Hold: dimensions lowerhold:	49.57 x 15.18 x 3.795 m
Hold: dimensions tweendeck:	71.48 x 15.18 x 7.585 m
Hold: total height:	12.18 m
Strength of tanktop:	12.00 T/m^2
Strength of tweendecks:	3.50 T/m^2
Strength of hatchcovers:	3 x 4.5 T/m^2 + 5 x 2.8 T/m^2
Number of tweendecks:	1 (flush) adjustable in height
Cargo gear:	1 crane 250 T / 1 crane 400 T / combined 650 T
	auxiliary hoist 2 x 25 T
Main engine(s):	MAK 9M 453 c. 3,300 kW
Thrusters:	N/A
Speed about:	13,00 knots
Bunker capacity:	614 T HFO 380/110 T MGO
Fresh water capacity:	92.00 T
No. insulated cargo spaces:	
No. cargo tanks:	
Container intake (sub weight):	370 TEU
	Lakes fitted
	Standard stores / equipment / lub oil: 150 T
	Compensation for cranes: 3,180 Tm

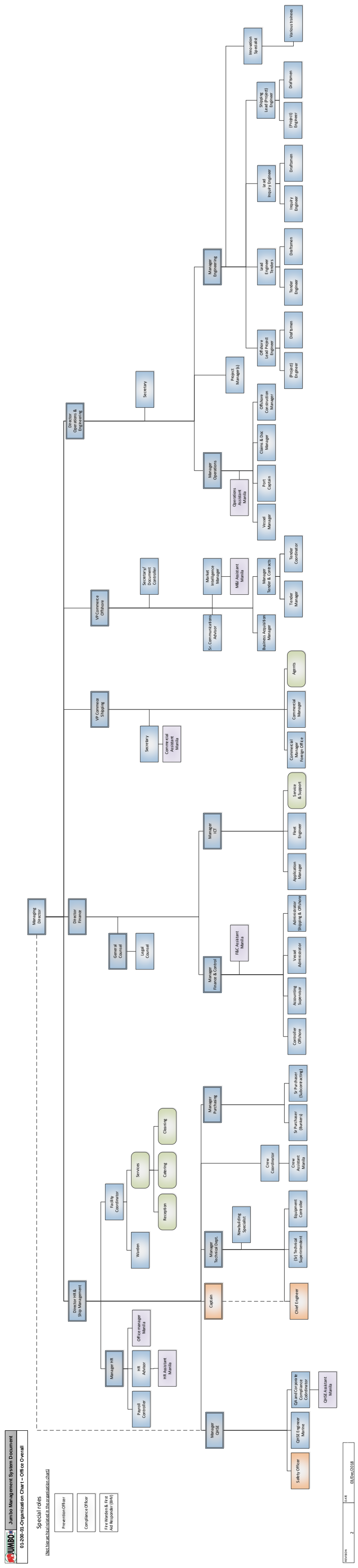
Figure B.11: Fairlift

E650 Class
MV Stellaprima

Call sign:	PHEA
IMO no.:	8912326
Port of registry:	Willemstad
Flag:	Netherlands
Classification:	Llloyd's Register 100 A1, LMC
	Strengthened for heavy cargoes, CG, UMS
Built:	1991
Owner:	Stella Navigation N.V.
Charterers:	Scheepvaart My Stella V.O.F. Rotterdam
General agent:	Kahn Scheepvaart B.V. Rotterdam
Owners P.I. club:	Gard A.S. Arendal, Norway
Deadweight (summer) abt:	7,572 T all told
Draft (above bottom of keel):	7.42 m
Length o.a.:	100.78 m
Beam o.a. (hull):	20.98 m
Air draft (above keel, jibs & derricks down):	36.00 m
G.T.:	6,902 T
N.T.:	2,070 T
G.T. Suez Canal:	7,089 T
N.T. Suez Canal:	5,894 T
G.T. Panama:	7,181 T
N.T. Panama:	4,559 T
Number of holds:	1
Number of hatches:	1
Bale capacity (with tweendecks in holds) abt.:	10,902 m³
Free deckspace abt.:	1,375 m²
Hold: dimensions lowerhold:	49.57 x 15.18 x 3.795 m
Hold: dimensions tweendeck:	71.48 x 15.18 x 7.585 m
Hold: total height:	12.18 m (11.98 m below hatchcovers 4, 5 & 6)
Strength of tanktop:	12.00 T/m²
Strength of tweendecks:	3.50 T/m²
Strength of hatchcovers:	3 x 4.5 T/m² + 5 x 2.8 T/m²
Number of tweendecks:	1 (flush) adjustable in height
Cargo gear:	1 crane 250 T / 1 crane 400 T / combined 650 T
	Auxiliary hoist 2 x 25 T
Main engine(s):	MAK 9M 453 c. 3,300 kW
Thrusters:	n.a.
Speed about:	13.00 knots
Bunker capacity:	614 T HFO 380/110 T MGO
Fresh water capacity:	92.00 T
No. insulated cargo spaces:	
No. cargo tanks:	
Container intake (sub weight):	340 TEU
	Lakes fitted
	Standard stores / equipment / lub oil: 150 T
	Compensation for cranes: 3,180 Tm

Figure B.12: Stellaprima

B.4. Organisation Chart



B.5. Fuel Consumption

Jumbo Kinetic

Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag	Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag
2-Engines							1-Engine						
100%	5,8	-30	39,8	16,8	99	403	100%	5,8	-30	20,3	11,7	72	281
	6,5	-30	39,8	16,4	101	394		6,5	-30	20,3	11,4	74	274
	7,5	-30	39,8	15,9	104	382		7,5	-30	20,3	11,0	77	264
	8,1	-60	39,8	15,2	109	365		8,1	-60	20,3	10,5	81	252
95%	5,8	-30	36,8	16,7	92	401	95%	5,8	-30	18,7	11,8	66	283
	6,5	-30	36,8	16,3	94	391		6,5	-30	18,7	11,5	68	276
	7,5	-30	36,8	15,8	97	379		7,5	-30	18,7	11,1	70	266
	8,1	-60	36,8	15	102	360		8,1	-60	18,7	10,6	74	254
90%	5,8	-30	35,7	16,4	91	394	90%	5,8	-30	18,2	11,5	71	281
	6,5	-30	35,7	16	93	384		6,5	-30	18,2	11,2	72	276
	7,5	-30	35,7	15,4	97	370		7,5	-30	18,2	10,8	73	271
	8,1	-60	35,7	14,8	101	355		8,1	-60	18,2	10,3	79	252
85%	5,8	-30	34,6	15,8	91	379	85%	5,8	-30	17,6	11,1	69	271
	6,5	-30	34,6	15,5	93	372		6,5	-30	17,6	10,8	71	264
	7,5	-30	34,6	15	96	360		7,5	-30	17,6	10,4	74	254
	8,1	-60	34,6	14,5	99	348		8,1	-60	17,6	9,9	77	242
80%	5,8	-30	30,8	15,5	83	372	80%	5,8	-30	15,7	10,7	61	257
	6,5	-30	30,8	15,2	84	365		6,5	-30	15,7	10,4	63	250
	7,5	-30	30,8	14,8	87	355		7,5	-30	15,7	10,0	65	240
	8,1	-60	30,8	14,3	90	343		8,1	-60	15,7	9,5	69	228
75%	5,8	-30	28,9	15,2	79	365	75%	5,8	-30	14,5	10,0	60	240
	6,5	-30	28,9	14,9	81	358		6,5	-30	14,5	9,7	62	233
	7,5	-30	28,9	14,5	83	348		7,5	-30	14,5	9,3	65	223
	8,1	-60	28,9	14,1	85	338		8,1	-60	14,5	8,8	68	211

Figure B.13: Fuel consumption of the Jumbo Kinetic on different power settings

Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag	Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag
2-Engines							1-Engine						
100%	5,8	-30	39,8	16,8	99	403	100%	5,8	-30	20,3	11,7	72	281
	6,5	-30	39,8	16,4	101	394		6,5	-30	20,3	11,4	74	274
	7,5	-30	39,8	15,9	104	382		7,5	-30	20,3	11,0	77	264
	8,1	-60	39,8	15,2	109	365		8,1	-60	20,3	10,5	81	252
95%	5,8	-30	36,8	16,7	92	401	95%	5,8	-30	18,7	11,8	66	283
	6,5	-30	36,8	16,3	94	391		6,5	-30	18,7	11,5	68	276
	7,5	-30	36,8	15,8	97	379		7,5	-30	18,7	11,1	70	266
	8,1	-60	36,8	15	102	360		8,1	-60	18,7	10,6	74	254
90%	5,8	-30	35,7	16,4	91	394	90%	5,8	-30	18,2	11,5	71	281
	6,5	-30	35,7	16	93	384		6,5	-30	18,2	11,2	72	276
	7,5	-30	35,7	15,4	97	370		7,5	-30	18,2	10,8	73	271
	8,1	-60	35,7	14,8	101	355		8,1	-60	18,2	10,3	79	252
85%	5,8	-30	34,6	15,8	91	379	85%	5,8	-30	17,6	11,1	69	271
	6,5	-30	34,6	15,5	93	372		6,5	-30	17,6	10,8	71	264
	7,5	-30	34,6	15	96	360		7,5	-30	17,6	10,4	74	254
	8,1	-60	34,6	14,5	99	348		8,1	-60	17,6	9,9	77	242
80%	5,8	-30	30,8	15,5	83	372	80%	5,8	-30	15,7	10,7	61	257
	6,5	-30	30,8	15,2	84	365		6,5	-30	15,7	10,4	63	250
	7,5	-30	30,8	14,8	87	355		7,5	-30	15,7	10,0	65	240
	8,1	-60	30,8	14,3	90	343		8,1	-60	15,7	9,5	69	228
75%	5,8	-30	28,9	15,2	79	365	75%	5,8	-30	14,5	10,0	60	240
	6,5	-30	28,9	14,9	81	358		6,5	-30	14,5	9,7	62	233
	7,5	-30	28,9	14,5	83	348		7,5	-30	14,5	9,3	65	223
	8,1	-60	28,9	14,1	85	338		8,1	-60	14,5	8,8	68	211

Figure B.14: Fuel consumption of the Fairmaster on different power settings

Schedule Fuel / Speed per Vessel

		Jumbo Jubilee (2 engines)							Jumbo Jubilee (1 engine)				
Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag	Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag
100%	5,8	-30	40,5	16,7	101	401	100%	5,8	-30	20,9	11,7	74	281
	6,5	-30	40,5	16,3	104	391		6,5	-30	20,9	11,5	76	276
	7,5	-30	40,5	15,8	107	379		7,5	-30	20,9	11,3	77	271
	8,1	-60	40,5	14,8	114	355		8,1	-60	20,9	10,5	83	252
95%	5,8	-30	38,6	16,8	96	403	95%	5,8	-30	19,9	11,4	73	274
	6,5	-30	38,6	16,5	97	396		6,5	-30	19,9	11,1	75	266
	7,5	-30	38,6	16,2	99	389		7,5	-30	19,9	10,7	77	257
	8,1	-60	38,6	15,0	107	360		8,1	-60	19,9	10,2	81	245
90%	5,8	-30	36,7	16,5	93	396	90%	5,8	-30	19,0	11,1	71	266
	6,5	-30	36,7	16,2	94	389		6,5	-30	19,0	10,9	72	262
	7,5	-30	36,7	15,8	97	379		7,5	-30	19,0	10,7	74	257
	8,1	-60	36,7	14,8	103	355		8,1	-60	19,0	9,9	80	238
85%	5,8	-30	34,8	16,2	90	389	85%	5,8	-30	18,0	10,7	70	257
	6,5	-30	34,8	15,9	91	382		6,5	-30	18,0	10,4	72	250
	7,5	-30	34,8	15,6	93	374		7,5	-30	18,0	10,0	75	240
	8,1	-60	34,8	14,5	100	348		8,1	-60	18,0	9,5	79	228
80%	5,8	-30	32,8	16,0	85	384	80%			niet beschikbaar			
	6,5	-30	32,8	15,7	87	377				niet beschikbaar			
	7,5	-30	32,8	14,7	93	353				niet beschikbaar			
	8,1	-60	32,8	14,3	96	343				niet beschikbaar			
75%	5,8	-30	29,0	15,2	79	365	75%			niet beschikbaar			
	6,5	-30	29,0	14,9	81	358				niet beschikbaar			
	7,5	-30	29,0	14,2	85	341				niet beschikbaar			
	8,1	-60	29,0	14,0	86	336				niet beschikbaar			

Figure B.15: Fuel consumption of the Jumbo Jubilee on different power settings

Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag	Power Setting	Draft	Trim	Fuel	Speed	kg/nm
100%	5,8	-30	41,1	15,9	108	382	100%	5,8	-30	20,6	11,2	76
	6,5	-30	41,1	15,5	110	372		6,5	-30	20,6	11,0	78
	7,5	-30	41,1	15,0	114	360		7,5	-30	20,6	10,8	79
	8,1	-60	41,1	14,0	122	336		8,1	-60	20,6	9,8	87
95%	5,8	-30	39,2	16,0	102	384	95%	5,8	-30	19,6	10,9	75
	6,5	-30	39,2	15,7	104	377		6,5	-30	19,6	10,6	77
	7,5	-30	39,2	15,4	106	370		7,5	-30	19,6	10,3	79
	8,1	-60	39,2	14,2	115	341		8,1	-60	19,6	9,7	84
90%	5,8	-30	37,2	15,7	99	377	90%	5,8	-30	18,6	10,6	73
	6,5	-30	37,2	15,5	100	372		6,5	-30	18,6	10,4	75
	7,5	-30	37,2	15,0	103	360		7,5	-30	18,6	10,2	76
	8,1	-60	37,2	14,0	111	336		8,1	-60	18,6	9,2	84
85%	5,8	-30	35,3	15,4	96	370	85%	5,8	-30	17,7	10,2	72
	6,5	-30	35,3	15,1	97	362		6,5	-30	17,7	9,9	74
	7,5	-30	35,3	14,8	99	355		7,5	-30	17,7	9,6	77
	8,1	-60	35,3	13,7	107	329		8,1	-60	17,7	9,0	82
80%	5,8	-30	33,3	15,2	91	365	80%			niet beschikbaar		
	6,5	-30	33,3	14,9	93	358				niet beschikbaar		
	7,5	-30	33,3	13,9	100	334				niet beschikbaar		
	8,1	-60	33,3	13,5	103	324				niet beschikbaar		
75%	5,8	-30	29,4	14,4	85	346	75%			niet beschikbaar		
	6,5	-30	29,4	14,1	87	338				niet beschikbaar		
	7,5	-30	29,4	13,4	91	322				niet beschikbaar		
	8,1	-60	29,4	13,2	93	317				niet beschikbaar		

Figure B.16: Fuel consumption of the Fairplayer on different power settings

Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag	Power Setting	Draft	Trim	Fuel	Speed	kg/nm
100%	5,8	-30	41,1	16,1	106	386	100%	5,8	-30	21,2	11,1	79
	6,5	-30	41,1	15,8	108	379		6,5	-30	21,2	10,8	82
	7,5	-30	41,1	15,5	110	372		7,5	-30	21,2	10,6	83
	8,1	-60	41,1	14,3	120	343		8,1	-60	21,2	9,8	90
95%	5,8	-30	39,2	16,3	100	391	95%	5,8	-30	20,2	10,7	79
	6,5	-30	39,2	16,0	102	384		6,5	-30	20,2	10,4	81
	7,5	-30	39,2	15,6	105	374		7,5	-30	20,2	10,2	83
	8,1	-60	39,2	14,6	112	350		8,1	-60	20,2	9,7	87
90%	5,8	-30	37,2	16,0	97	384	90%	5,8	-30	19,2	10,5	76
	6,5	-30	37,2	15,7	99	377		6,5	-30	19,2	10,2	78
	7,5	-30	37,2	15,4	101	370		7,5	-30	19,2	10,0	80
	8,1	-60	37,2	14,3	108	343		8,1	-60	19,2	9,2	87
85%	5,8	-30	35,3	15,8	93	379	85%	5,8	-30	18,3	10,0	76
	6,5	-30	35,3	15,5	95	372		6,5	-30	18,3	9,7	78
	7,5	-30	35,3	14,5	101	348		7,5	-30	18,3	9,5	80
	8,1	-60	35,3	14,1	104	338		8,1	-60	18,3	9,0	84
80%	5,8	-30	33,3	15,0	93	360	80%			niet beschikbaar		
	6,5	-30	33,3	14,7	94	353				niet beschikbaar		
	7,5	-30	33,3	14,0	99	336				niet beschikbaar		
	8,1	-60	33,3	13,8	101	331				niet beschikbaar		
75%	5,8	-30	29,4	14,3	86	343	75%			niet beschikbaar		
	6,5	-30	29,4	14,0	88	336				niet beschikbaar		
	7,5	-30	29,4	13,3	92	319				niet beschikbaar		
	8,1	-60	29,4	13,0	94	312				niet beschikbaar		

Figure B.17: Fuel consumption of the Jumbo Javelin on different power settings

Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag	Power Setting	Draft	Trim	Fuel	Speed	kg/nm	Nm/dag
100%	5,8	-30	41,1	16,3	105	391	100%	5,8	-30	21,2	11,3	78	271
	6,5	-30	41,1	16,0	107	384		6,5	-30	21,2	11,0	80	264
	7,5	-30	41,1	15,7	109	377		7,5	-30	21,2	10,8	82	259
	8,1	-60	41,1	14,5	118	348		8,1	-60	21,2	10,0	88	240
95%	5,8	-30	39,2	16,5	99	396	95%	5,8	-30	20,2	10,9	77	262
	6,5	-30	39,2	16,2	101	389		6,5	-30	20,2	10,6	79	254
	7,5	-30	39,2	15,8	103	379		7,5	-30	20,2	10,4	81	250
	8,1	-60	39,2	14,8	110	355		8,1	-60	20,2	9,9	85	238
90%	5,8	-30	37,2	16,2	96	389	90%	5,8	-30	19,2	10,7	75	257
	6,5	-30	37,2	15,9	97	382		6,5	-30	19,2	10,4	77	250
	7,5	-30	37,2	15,6	99	374		7,5	-30	19,2	10,2	78	245
	8,1	-60	37,2	14,5	107	348		8,1	-60	19,2	9,4	85	226
85%	5,8	-30	35,3	16,0	92	384	85%	5,8	-30	18,3	10,2	75	245
	6,5	-30	35,3	15,7	94	377		6,5	-30	18,3	9,9	77	238
	7,5	-30	35,3	14,7	100	353		7,5	-30	18,3	9,7	78	233
	8,1	-60	35,3	14,3	103	343		8,1	-60	18,3	9,2	83	221
80%	5,8	-30	33,3	15,2	91	365	80%			niet beschikbaar			
	6,5	-30	33,3	14,9	93	358				niet beschikbaar			
	7,5	-30	33,3	14,2	98	341				niet beschikbaar			
	8,1	-60	33,3	14,0	99	336				niet beschikbaar			
75%	5,8	-30	29,4	14,5	84	348	75%			niet beschikbaar			
	6,5	-30	29,4	14,2	86	341				niet beschikbaar			
	7,5	-30	29,4	13,5	91	324				niet beschikbaar			
	8,1	-60	29,4	13,2	93	317				niet beschikbaar			

Figure B.18: Fuel consumption of the Fairpartner on different power settings

Power Setting	Draft	Trim	Fuel	Speed	Nm/dag	kg/Nm
100%	5,7	-30	19,7	15,7	377	52,3
	6,6	-30	19,7	14,2	341	57,8
	7,7	-60	19,7	13,3	319	61,7
95%	5,7	-30	18,8	15,1	362	51,9
	6,6	-30	18,8	13,8	331	56,8
	7,7	-60	18,8	13,0	312	60,3
90%	5,7	-30	17,9	14,5	348	51,4
	6,6	-30	17,9	13,4	322	55,7
	7,7	-60	17,9	12,6	302	59,2
85%	5,7	-30	17,0	13,9	334	51,0
	6,6	-30	17,0	12,9	310	54,9
	7,7	-60	17,0	12,3	295	57,6
80%	5,7	-30	16,1	13,4	322	50,1
	6,6	-30	16,1	12,5	300	53,7
	7,7	-60	16,1	12,1	290	55,4
75%	5,7	-30	15,2	12,8	307	49,5
	6,6	-30	15,2	12,1	290	52,3
	7,7	-60	15,2	11,8	283	53,7
70%	5,7	-30	14,3	12,2	293	48,8
	6,6	-30	14,3	11,8	283	50,5
	7,7	-60	14,3	11,4	274	52,3
65%	5,7	-30	13,4	11,6	278	48,1
	6,6	-30	13,4	11,3	271	49,4
	7,7	-60	13,4	11,0	264	50,8
60%	5,7	-30	12,5	11,0	264	47,3
	6,6	-30	12,5	10,8	259	48,2
	7,7	-60	12,5	10,5	252	49,6

Figure B.19: Fuel consumption of the Jumbo Vision on different power settings

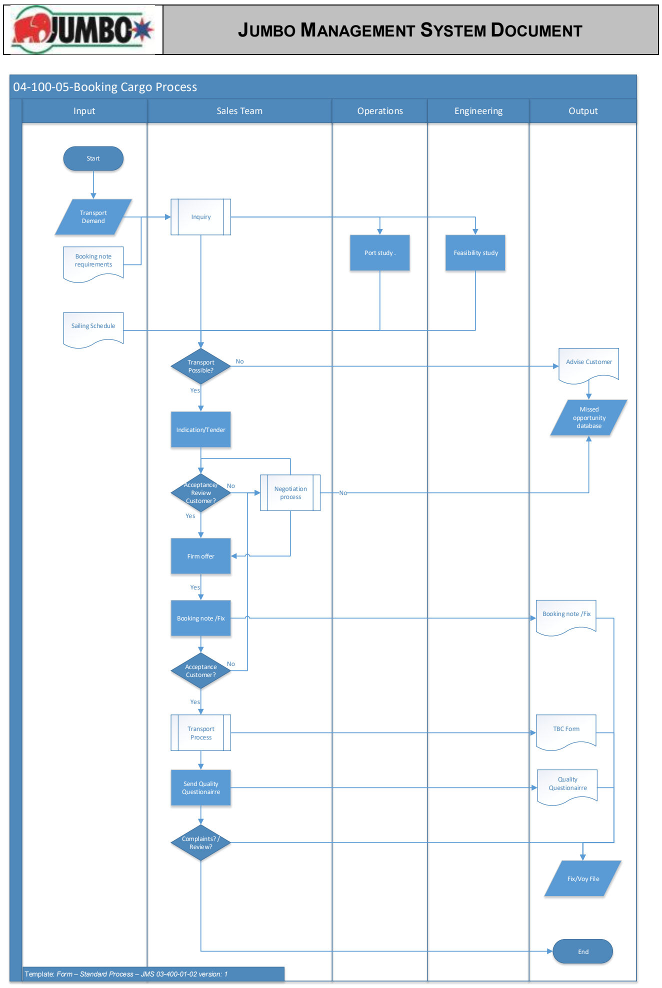
Power Setting	Draft	Trim	Fuel	Speed	Nm/dag	kg/Nm
100%	5,7	-30	19,7	15,7	377	52,3
	6,6	-30	19,7	14,2	341	57,8
	7,7	-60	19,7	13,3	319	61,7
95%	5,7	-30	18,8	15,1	362	51,9
	6,6	-30	18,8	13,8	331	56,8
	7,7	-60	18,8	13,0	312	60,3
90%	5,7	-30	17,9	14,5	348	51,4
	6,6	-30	17,9	13,4	322	55,7
	7,7	-60	17,9	12,6	302	59,2
85%	5,7	-30	17,0	13,9	334	51,0
	6,6	-30	17,0	12,9	310	54,9
	7,7	-60	17,0	12,3	295	57,6
80%	5,7	-30	16,1	13,4	322	50,1
	6,6	-30	16,1	12,5	300	53,7
	7,7	-60	16,1	12,1	290	55,4
75%	5,7	-30	15,2	12,8	307	49,5
	6,6	-30	15,2	12,1	290	52,3
	7,7	-60	15,2	11,8	283	53,7
70%	5,7	-30	14,3	12,2	293	48,8
	6,6	-30	14,3	11,8	283	50,5
	7,7	-60	14,3	11,4	274	52,3
65%	5,7	-30	13,4	11,6	278	48,1
	6,6	-30	13,4	11,3	271	49,4
	7,7	-60	13,4	11,0	264	50,8
60%	5,7	-30	12,5	11,0	264	47,3
	6,6	-30	12,5	10,8	259	48,2
	7,7	-60	12,5	10,5	252	49,6

Figure B.20: Fuel consumption of the Fairlane on different power settings

C

Booking

C.1. Jumbo Booking Cargo Procedure [14]



D

Sensitivity analysis

				20% renewable					
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	53	66.738.767	24.960.000	4.788.000	15.593.775	5.000.000	16.396.992
J	1	199	5	6.682.321	11.093.333	696.500	2.268.393	5.000.000	- 12.375.905
J-900	0	0	0	-	-	-	-	-	-
J-800	1	1246	55	37.623.275	16.222.222	3.364.200	6.961.402	5.000.000	6.075.451
J-700	0	0	0	-	-	-	-	-	-
J-600	7	9550	421	252.561.863	98.000.000	25.785.000	53.355.850	35.000.000	40.421.013
	10	12363	534	363.606.226	150.275.556	34.633.700	78.179.420	50.000.000	50.517.551

Table D.1: Increasing demand due to rise in renewable energy of 20%

				50% renewable					
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	53	66.738.767	24.960.000	4.788.000	15.593.775	5.000.000	16.396.992
J	1	199	5	6.682.321	11.093.333	696.500	2.268.393	5.000.000	- 12.375.905
J-900	0	0	0	-	-	-	-	-	-
J-800	1	1354	57	38.791.380	16.222.222	3.655.800	7.564.798	5.000.000	6.348.560
J-700	0	0	0	-	-	-	-	-	-
J-600	7	9508	419	253.071.846	98.000.000	25.671.600	53.121.196	35.000.000	41.279.050
	10	12429	534	365.284.314	150.275.556	34.811.900	78.548.162	50.000.000	51.648.697

Table D.2: Increasing demand due to rise in renewable energy of 50%

				70% renewable					
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	47	67.313.706	24.960.000	4.788.000	15.593.775	5.000.000	16.971.931
J	1	199	11	6.104.382	11.093.333	696.500	2.268.393	5.000.000	- 12.953.844
J-900	0	0	0	-	-	-	-	-	-
J-800	1	1359	57	45.732.169	16.222.222	3.669.300	7.592.733	5.000.000	13.247.914
J-700	0	0	0	-	-	-	-	-	-
J-600	7	9547	419	247.249.783	98.000.000	25.776.900	53.339.089	35.000.000	35.133.794
	10	12473	534	366.400.040	150.275.556	34.930.700	78.793.990	50.000.000	52.399.795

Table D.3: Increasing demand due to rise in renewable energy of 70%

				8% oil					
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	61	38.426.417	24.960.000	4.788.000	15.593.775	5.000.000	- 11.915.358
J	1	988	31	61.453.446	11.093.333	3.458.000	11.262.171	5.000.000	30.639.942
J-900	0	0	0	-	-	-	-	-	-
J-800	0	0	0	-	-	-	-	-	-
J-700	1	1368	54	31.365.231	15.111.111	3.693.600	7.643.016	5.000.000	- 82.496
J-600	7	9581	388	260.301.406	98.000.000	25.868.700	53.529.047	35.000.000	47.903.659
	10	13305	534	391.546.500	149.164.444	37.808.300	88.028.009	50.000.000	66.545.747

Table D.4: Increasing demand due to rise in oil price of 8%

10% oil									
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	57	39.168.839	24.960.000	4.788.000	15.593.775	5.000.000	- 11.172.936
J	1	1315	48	69.993.524	11.093.333	4.602.500	14.989.630	5.000.000	34.308.060
J-900	0	0	0	-	-	-	-	-	-
J-800	0	0	0	-	-	-	-	-	-
J-700	0	0	0	-	-	-	-	-	-
J-600	8	10868	429	289.648.887	112.000.000	29.343.600	60.719.516	40.000.000	47.585.771
	10	13551	534	398.811.250	148.053.333	38.734.100	91.302.921	50.000.000	70.720.895

Table D.5: Increasing demand due to rise in oil price of 10%

6% oil, 35% ren									
vesselclass	vessels	vesseldays	number of fixes	Revenue [$]	CapCosts [$]	Wages[$]	Bunker[$]	Maintenance[$]	Profit [$]
K	1	1368	51	40.953.660	24.960.000	4.788.000	15.593.775	5.000.000	- 9.388.115
J	1	937	34	57.678.473	11.093.333	3.279.500	10.680.824	5.000.000	27.624.816
J-900	0	0	0	-	-	-	-	-	-
J-800	0	0	0	-	-	-	-	-	-
J-700	1	1290	28	37.049.750	15.111.111	3.483.000	7.207.230	5.000.000	6.248.409
J-600	7	9540	422	250.557.637	98.000.000	25.758.000	53.299.980	35.000.000	38.499.657
	10	13135	535	386.239.520	149.164.444	37.308.500	86.781.809	50.000.000	62.984.767

Table D.6: Increasing demand due to rise in oil price of 6% combined with an increasing renewable energy market of 35%