Development of a Ship Performance Monitoring System and Data Analysis of Spliethoff Vessels

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By

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Performed at

SPLIETHOFF

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Abstract

Spliethoff is a ship-operating company with around 120 cargo vessels under management. The vessels of Spliethoff are generating a lot of operational data as they sail around the globe. To make better decisions based on this data, a system is required that takes operational data and translates it to useful information, accessible in the office and on the ship through online dashboards. Ultimately, better informed decision making should lead to cost minimisation in the areas of fuel consumption and maintenance. In this research a Ship Performance Monitoring System (SPM System) for operational data of Spliethoff's vessels was developed, after which data analysis was performed with the goal to minimise operational cost of the vessels.

The SPM System was developed using a *Rapid Prototyping* methodology. By conducting decision support analysis, data requirements analysis and user requirements analysis, Key Performance Indicators (KPIs) for the system were established and coupled to end-users. In general, one can state that when developing new information systems, end-user involvement is key. If end-users are not involved from the start, interest will be low, resulting in limited added value.

Using the SPM System, data analysis was performed targeting a number of key questions with regards to fuel efficiency, maintenance and ship operation.

Firstly, from the data analysis it can be concluded that for a Spliethoff S-Type vessel the most fuel efficient speed is 14 knots, both in laden and unladen condition. It is recommended to implement this speed for all voyages where the schedule allows it. Accurate implementation of this speed optimum could result in bunker cost savings of up to 10% over a voyage.

Regarding engine efficiency, the specific fuel consumption (SFC) of the main engines of all three vessels is worse than the specifications given by the engine manufacturer. This is according to expectation, given the fact that manufacturers specifications are attained at different conditions. The development of SFC over time showed that the main engine maintenance schedule currently employed is working effectively, so it is advised to continue in the same manner.

Hull and propeller fouling negatively influence fuel consumption and speed of a ship. In the data analysis different trends are found regarding fouling. Therefore is is recommended to prolong the measuring period to at least a year before drawing any conclusions. If after a year a fuel consumption increase in the region of 5% is measured, it is advised to increase hull cleaning frequency to once every year. Regardless of any measured fouling increase, it is recommended to inspect the hull of all vessels at least twice a year to increase knowledge of fouling.

A ship's crew is of large influence on the operational cost of a ship. Consequently, more intensive collaboration between office and ship on the vessel's operation is suggested, using data in a supporting role. Training crew for correct use of onboard decision support systems and giving feedback on performance will build awareness among crew and increase fuel efficiency.

The SPM System can be improved by installing thrust sensors on the vessels. Implementing a newer correction method for wave added resistance will also enhance the system significantly. Thirdly, it is recommended to reduce dependence on manually entered data to a minimum, due to the inherent inaccuracy of manual input. Finally, matching data quality of all different data sources will increase the precision of the system. In general, the biggest challenge for Spliethoff is to create a company culture where decision making is data-driven. This will yield the biggest benefits.

Acknowledgements

To begin with, I would like to thank my graduation committee. Without the continuous help and guidance of Eddy and Koos, my thesis would have been considerably harder to complete successfully. Trough their combined experience they were able to warn me in time for any potential pitfalls and they gave me a solid plan to follow.

Of course I would also like to express my gratitude towards Karel for giving me the opportunity to do the project at Spliethoff. For both of us it has been an interesting journey; building the system from the ground up, learning about data analytics and having new insights every day. Throughout the project, Karel was able to provide me with all necessities to successfully finish, whether it was knowledge, hardware, software, company contacts or something else. A special thanks goes out to Tijn, who freed up time for my project whenever possible and always had a fitting solution for any IT related problems.

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Roeland Grutterink
July 4, 2017, Amsterdam

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Chapter 1

Introduction

Spliethoff Group, a ship-operating company with 120 cargo vessels under management (September, 2016), has been a market leader in its industry for decades. The evolution of Spliethoff Group over the years can be found in Table 1.1. Spliethoff Group is divided into subsidiaries Spliethoff, Sevenstar Yacht Transport, BigLift Shipping, Transfennica, Wijnne Barends and Bore. As of May, 2016, Spliethoff (biggest subsidiary; active in the breakbulk sector), is ranked fourth in the world measured by deadweight tonnage (DWT) [Fields [2016]].

Year	**Remark**
1921	Establishment of Spliethoff's Bevrachtingkantoor B.V.
1946	Delivery of first new vessel M/V Keizersgracht; total DWT of fleet 1,360 tonnes
1965	20 general cargo vessels in fleet with a total DWT of 20,000 tonnes
1975	First order of series of vessels (six)
1999	Acquisition Sevenstar Yacht Transport B.V.
2001	Acquisition BigLift Shipping B.V.
2002	Acquisition Transfennica OY
2003	Acquisition Wijnne Barends B.V.
2009	Establishment of Transfennica Logistics B.V.
2016	Acquisition Bore Ltd
2016	120 vessels in Group's fleet with a total DWT of more than 1,200,000 tonnes

Table 1.1: Development of Spliethoff Group over 95 Years [Spliethoff [2016]]

To maintain this leadership position, the company must adapt to its constantly changing business environment and utilise new technologies to increase revenue or reduce costs. One opportunity lies in the operational data Spliethoff's vessels are generating whilst sailing around the world.

The recent acquisition of Finnish shipping company Bore Ltd by Spliethoff Group (July, 2016) has opened the door for Spliethoff to examine Bore's use of data and transfer some of that knowledge. Bore has already been using its vessels operational data to some extent since 2012, with positive results. Five of Spliethoff Group's vessels have a system installed similar to Bore's vessels, where data is sent to the head office, but the actual transition from raw data to usable information is still very much in the exploratory phase. Understanding this information and using it to actually improve performance of Spliethoff's vessels -and ultimately the company's performance- is the aim of this thesis.

Spliethoff's goal is to develop a Ship Performance Monitoring (SPM) System, enabling personnel from operations, commercial and technical departments to track vessels in the fleet and monitor Key Performance Indicators (KPIs). Presenting reports on the vessel's performance to affiliated departments and providing the ship's crew with accurate instructions will help them make solid, well-informed decisions and yield benefit from the SPM System.

Figure 1.1 shows a general SPM System layout. Various sensors on the ship collect data which is stored in a database on the ship. Via communication satellite or wireless internet the sensor data from the ship's database is sent to a shore-based database. In the office, users connect to the shore-based database, where data of all vessels in the fleet can be accessed for analysis and reporting on a dashboard.

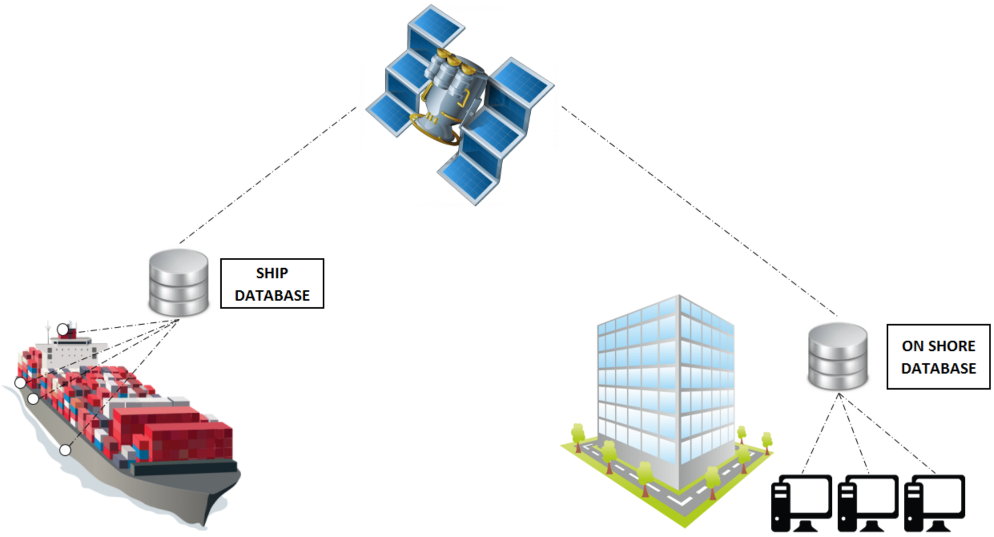


Figure 1.1: Ship Performance Monitoring System

1.1 Business Intelligence

In essence, the SPM System to be developed is a Business Intelligence (BI) System, designed specifically for a ship-operating company. Before diving into the possibilities of BI and applying them to the shipping industry, defining BI will be useful. It is a broad term that encompasses the field of Information Systems and can be described in different ways.[Rouibah and Ould-ali [2002]] define BI as a strategic approach for systematically targeting, tracking, communicating and transforming relevant weak signs into actionable information on which strategic decision-making is based. A more general definition by [Golfarelli et al. [2004]] states that BI is the process of turning data into information and then into knowledge to enable effective decision making.

Another viewpoint is given by [Chang et al. [2006]] saying BI means using your data assets to make better business decisions. It is about access, analysis, and uncovering new opportunities. [Adelman [2002]] makes a distinction between BI and Decision Support Systems (DSS) by stating that BI is the result of in-depth analysis of detailed business data including database and application technologies, as well as analysis practises. Sometimes used synonymous with "decision support", though BI is technically much broader, potentially encompassing knowledge management, enterprise resource planning, and data mining, among other practises.

Although the definitions in this section are all formulated differently, clearly BI is about using data to create information, after which well-informed decisions can be made based on that information.

1.1.1 Influence of Business Intelligence on Decision Making and Company Performance

Now that BI has been defined, seeing how it can positively influence company performance if used smartly is interesting. Especially for a company like Spliethoff, which is active in a very competitive market, the benefits of a BI System should be clear before committing to such a system.

There are numerous sources stating that company performance is positively affected in companies utilising BI and data-driven decision making. [Provost and Fawcett [2015]] define data-driven decision making as the practice of basing decisions on the analysis of data rather than purely on intuition. A recent study by [Brynjolfsson et al. [2011]] on data-driven decision making affecting firm performance had interesting results. They developed a measure of data-driven decision making that rates firms as to how strongly they use data to make decisions across the company. They showed statistically that the more data-driven a firm is, the more productive it is for a wide range of factors. Data-driven decision making also is correlated with higher return on assets, return on equity, asset utilisation, and market value, and the relationship seems to be causal [Provost and Fawcett [2015]].

In [Kiron et al. [2015]] it is stated that despite the issues a lot of companies have with accessing data, 67% of the respondents out of a survey say that using analytics has created at least a moderate competitive advantage for them. Another survey by a team at the MIT Center for Digital Business tested the hypothesis that data-driven companies would be better performers. After interviewing 330 public North-American companies, it was found that companies in the top third of their industry in the use of data-driven decision making were, on average, 5% more productive and 6% more profitable than their competitors [McAfee and Brynjolfsson [2012]].

[Barton and Court [2012]] propose a step-wise approach on how to capitalise on data, namely:

1. Choose the right data
    - Source data creatively
    - Get the necessary IT support
2. Build models that predict and optimize business outcomes
3. Transform your company's capabilities
    - Develop business-relevant analytics that can be put to use
    - Embed analytics into simple tools for the front lines
    - Develop capabilities to exploit big data

According to [Power [2002]], a Decision Support System will create a competitive advantage if three criteria are met:

1. Once the DSS is implemented it must become a major or significant strength or capability of the organisation
2. The DSS must be unique and proprietary to the organisation
3. The advantage provided by the DSS must be sustainable for at least 3 years

In a research by [Popovic et al. [2012]] it is established that the implementation of BI Systems can contribute to improved information quality in many ways, such as: faster access to information, easier querying and analysis, a higher level of interactivity, improved data consistency due to data integration processes and other related data management activities (e.g. data cleansing, unification of definitions of key business terms, master data management). A BI success model is proposed, which is displayed in Figure 1.2. It was found that an analytical decision-making culture directly and positively affects the use of information in business processes, as one can clearly extract from the model.

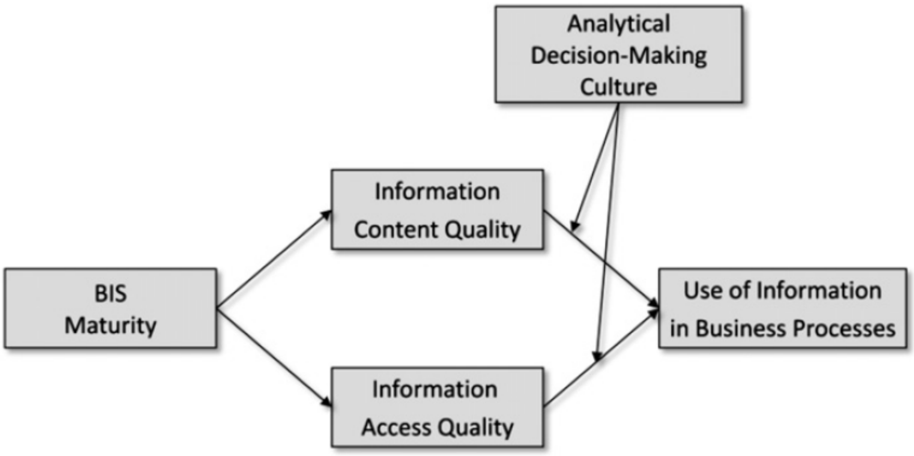


Figure 1.2: A BI Systems Success Model [Popovic et al. [2012]]

[Provost and Fawcett [2015]] add by saying methods and methodology for visualising data are vital. More importantly, they say that understanding the fundamental concepts, and having frameworks for organising data-analytic thinking, not only will allow one to interact competently, but will help to envision opportunities for improving data-driven decision making or to see data-oriented competitive threats.

In summary, literature agrees on the fact that companies employing BI are more successful in their markets, provided the company adopts an analytical decision-making culture.

1.1.2 Current State of Business Intelligence at Ship-Operating Companies

With the benefits of BI proven, the current state of BI at shipowners is explored. According to [Beulah et al. [2015]] the technology focuses on “informed decision making” as a core element for empowering mariners and marine managers. It leverages on BI in creating its technology framework to provide key deliverables to the shipping industry in the form of vessel and fleet monitoring.

In a presentation by [Ando [2011]], the performance monitoring and data collection of NYK Line’s fleet is highlighted. Here, NYK uses BI for weather routing in an effort to reduce fuel consumption. Also, the technical performance of the vessel can be evaluated (for instance a new propeller design). A weather routing system is again the main topic in a presentation from [Singh [2014]]; the number of users is not mentioned.

There are also less positive opinions on the adoption of BI in shipping however. [Keefe [2014]] says that convincing a conservative industry, one sometimes described as being in the Stone Age technologically, to leap forward more fully into the digital age can be a challenge. Investing in the tools needed to sift through all that data can also be difficult. According to Rob Bradenham, former General Manager of ESRG (vessel monitoring and data analytics leader in the marine industry), this is due to a number of reasons. Firstly, shipping is a very old industry that has been around for thousands of years, with shipping companies that have been around for hundreds of years, meaning they are sometimes slow to jump on the next big thing. Also, the marine industry in general has been burned by technology (investing big money in the latest technologies, but becoming obsolete quite quickly), hence the cautiousness. The required mindset to be able to leverage these new technologies is more forward looking than that of the average ship owner or operator [Keefe [2014]].

Another factor that might be of influence is cashflow related. When the main focus lies on creating a steady positive cashflow today, investing in new technologies which might benefit the company tomorrow has a lower priority. In other words, focus on cashflow and annual profits results in short-term vision, not aiding adoption of new technologies.

A reason why shipowner/ship operators so far have not all been able to implement SPM Systems successfully is because the industry often lacks the required expertise and becomes overwhelmed. The steps that have to be taken to successfully implement an SPM System are [Mantel [2016]]:

1. Specify the optimum solution;
2. Collect the data;
3. Aggregate data;
4. Manage the data securely;
5. Analyse the results;
6. Make recommendations;
7. Implement effective action.

At most shipowners, resources are simply missing to complete all aforementioned steps well, leading to no return on investment after acquisition of an SPM System.

The employment of BI at shipowners is currently primarily focused on two elements: heading off system failure (preventive maintenance) and cutting fuel costs and consumption [Keefe [2014]]. In [Fathom [2014]], current functions of SPM Systems are categorised and summarised as follows:

- Trim optimisation
- Speed and throttle optimisation
- Weather routing and route optimisation
- Condition-Based Maintenance (CBM) - hull and propeller (fouling); machinery
- Efficiency of hotel functions
- Fleet management

At the moment the market is being flooded with providers of SPM Systems. Eniram, Kyma Ship Performance, DNV GL, Kongsberg, Trelleborg, NAPA, Marorka, SkySails, TecnoVeritas, BMT SMART, Interschalt, Norcomms and We4Sea are some of the main companies offering SPM Systems.

In a survey by [Rojon and Smith [2014]], the reasons for monitoring fuel consumption and the tools used to do so have yielded some interesting results. The respondents were shipowners, shipowner-operators, charterers, management companies and shipping divisions of cargo companies operating in the LNG sector, the container sector, dry bulk sector and tanker sector. The first key finding is that the vast majority of respondents (92%) measure fuel consumption, but only 12% of the respondents are using automated continuous monitoring communicated to shore-based offices. This indicates a very weak adoption of BI in the shipping industry. Next to that, the external pressure from legislation, investors and other stakeholders does not seem to be a reason for ship owners and operators to adopt monitoring of fuel consumption (less than 20%).

Currently, some shipping companies using BI office solutions are for instance Bergese, Bore, Canada Steamship Lines, Chevron Shipping, CSCL, Dynacom Tankers, Exmar, Gearbulk, Golar LNG, Hyundai Merchant Marine, Kuwait Oil Tanker Co., Laurin Maritime, Maersk, MSC, Neste Shipping, Norden, Qatar Gas Corp., Samco, Stena, Thenamaris, Teekay Shipping, UASC and Wan Hai Lines [Kyma [2016]][NAPA [2013]][Marorka [2017]][Norcomms [2017]]. This list is obviously not complete, it does however show that a lot of big players in the market have adopted some type of BI, so there is evolution. In essence all the systems are designed to provide information that improves decision making.

Concluding, one can state that although SPM Systems are available, the industry is only slowly realising that it can use this technology to its benefit. In other cases an investment has been made in a system without yielding sufficient return on investment due to a lack of resources and expertise. A relatively small group of early adopters -the biggest companies or niche companies- is leading the way, but there are still big steps to be made. Especially with regards to BI, which covers a range of functions wider than only ship performance monitoring, there will be ample opportunity for shipping companies to gain efficiency. [Thier [2016]] denotes a statement of recently appointed Maersk board member Jim Hagemann Snabe. Hagemann Snabe says that the next step for Maersk is to make the company more IT savvy and increase their understanding of the possibilities in digital media. This indicates willingness of the shipping industry to change and adopt new technologies, so evidence of change exists.

1.2 Spliethoff Group

Spliethoff Group has a leading role within the shipping industry. The Group is diversified into several different sectors through its subsidiaries. The main subsidiary, Spliethoff, is a general cargo (or breakbulk) specialist operating across the globe. Its fleet consists of about 50 vessels with cargo cranes and removable tweendecks, and all vessels are 1A ice-classed [Spliethoff [2016]]. A stand-out feature of Spliethoff is the fact that they have large series of identical ships.

BigLift Shipping is a subsidiary active in the heavy-lift and project cargo segment. Employing a fleet of 15 vessels with heavier cranes than Spliethoff's vessels, it serves the mining, offshore and petrochemical industry among others and therefore operates in a segment above Spliethoff (bigger lifting capability) [BigLift [2016]].

As the name implies, Sevenstar Yacht Transport is active in the transportation of yachts and operates two semi-submersibles. They also often charter vessels from BigLift or Spliethoff for voyages.

In the short sea segment, Spliethoff Group is represented by Wijnne Barends. Using a modern fleet of about 35 vessels, Wijnne Barends navigation area is Scandinavia, the Baltic States, Western Europe and the Mediterranean [WijnneBarends [2016]].

Subsidiary Transfennica is a Container Roll-on/Roll-off (ConRo) liner service between the Baltic Sea and Western Europe with 12 ships in operation.

Finally, Bore Shipping was added to the Group in the summer of 2016 to strengthen Spliethoff Group's position in the RoRo market. Operating a fleet of eight RoRo vessels, Bore is known for its forward thinking mentality and innovative attitude. For example, Bore is the first shipowner in the world who installed rotor sails from Norsepower on one of their vessels to reduce fuel consumption. Bore's drive to constantly look for new technologies that may reduce fuel consumption has made them buy a complete eco-efficiency package from Finnish software company NAPA. This package -among other modules- contains a module for performance monitoring of vessels. As this thesis centres around the development of such a system, lessons could be learned from new subsidiary Bore. There is however a fundamental difference between Bore's approach to ship performance monitoring and Spliethoff's. As mentioned, Bore bought a ready-made software package from a company, whereas Spliethoff wants to develop the system in-house. Thereby Spliethoff remains in control of its data and gains as much knowledge as possible in the development process. In essence, when it comes to performance monitoring of vessels, Spliethoff aims at knowledge transfer from Bore.

In the first place the SPM System will be developed for Spliethoff, after which it could be implemented at other Spliethoff Group subsidiaries too (once benefits proven).

1.2.1 Operational Cost of a Vessel

To see how an SPM System can positively influence the reduction of operational cost at Spliethoff, a breakdown of all costs of a cargo vessel is useful. [Stopford [2009]] classifies costs into five categories, namely: operating costs, periodic maintenance costs, voyage costs, capital costs and cargo handling costs. Operating costs essentially are crew costs, stores and maintenance costs outside dry-dock. Periodic maintenance costs consist of the costs incurred when the ship is in dry-dock for major repairs (special survey). Bunker costs, port charges and canal dues all fall under voyage costs. Capital costs depend on the manner of finance; this could be dividends to equity or interest and capital payments on debt finance. Finally, cargo handling costs represent the expense of loading, stowing and discharging cargo.

In a study by [Gentle and Perkins [1982]], capital expenses account for roughly 27% of the *daily at-sea operating costs* for a container ship of 14000 DWT. Insurance costs, repair- and maintenance costs and victuals are 2-3%. Crewing costs and bunker costs are both about 25% of the expenses.

A more recent article by [HellenicShippingNews [2015]] states that bunker cost account for 70% of a vessel's voyage expenses. When comparing this number to the former number, one has to realise that voyage expenses only includes bunker costs, navigation, port, pilotage and canal charges and cargo handling costs. Besides, fluctuating fuel prices are obviously also of major influence.

A complete cost breakdown in percentages for an average ship in Spliethoff's fleet is given in Table 1.2. These values are for a 13 year old 16000 DWT Spliethoff general cargo vessel under Dutch flag at 2016 prices. These costs depend on many factors that change over time, nevertheless the table does give a good indication of relative ship costs.

In all sources, similar high percentages for voyage costs are given and it becomes clear that controlling this element can have a massive influence on the total expenses of a vessel. Especially with the new regulations of the International Maritime Organization (IMO) targeting a worldwide cap of sulphur content of marine fuel at 0.5% by 2020, bunker costs are likely to rise. Ship operators will have to switch to more expensive Marine Gas Oil (MGO) or invest in scrubbers [Zeng [2016]].

Cost Component	**Percentages**	
Operating Cost	30%	
Crewing		58%
Stores		7%
Maintenance		24%
Insurance		5%
Administration		6%
Periodic Maintenance Cost	3%	
Voyage Costs	44%	
Fuel oil		48%
Diesel oil		14%
Port and canal costs		38%
Capital Costs	10%	
Cargo Handling Costs	13%	

Table 1.2: Breakdown of Average Spliethoff Vessel Cost (2016)

1.3 Research Objectives

Spliethoff's primary objective is to maximise shareholder value, which can be translated to a maximisation of profit. One way to achieve maximum profit is by minimising cost (assuming a market with perfect competition). In this project the focus lies on minimisation of operational cost, through ship performance monitoring. The areas where cost savings are pursued using information from the SPM System are in bunker costs and maintenance costs.

To monitor ship performance, first a system has to be developed that can provide the required information. This system has to be able to translate operational data into valuable information, usable in the office and on the ship. Therefore the design objective is:

Develop a Ship Performance Monitoring System for operational performance data of Spliethoff's vessels and analyse this data, with the goal of minimising operational cost of the vessels.

This thesis is divided into two parts, namely development of the SPM System and analysis of the operational data from Spliethoff's vessel using the newly developed SPM System. Hence, the design objective can be split into multiple sub-objectives and questions that all contribute to achieving the design objective.

1. Develop Ship Performance Monitoring System
   (a) What development methodology is optimal for the SPM System?
   (b) Which decisions have to be supported by the SPM System?
   (c) What data is required to support selected decisions?
   (d) Who are the key stakeholders of the system and what are the user requirements?
2. Data Analysis and Results
   (a) Determine the most fuel efficient speed of a Spliethoff S-Type.
   (b) Determine the actual fuel consumption of a Spliethoff S-Type for a given speed.
   (c) Determine the effect of hull- and propeller fouling on fuel consumption and speed.
   (d) Determine the specific fuel consumption of the main engine to predict maintenance actions
   (e) Determine the influence of crew on ship's operation and on fuel consumption specifically.

Concluding, the added value of this thesis is twofold, namely a methodological research into the development of an SPM System and an empirical research into the data obtained with the SPM System.

1.4 Research Methods and Thesis Structure

In the first part, a literature study is performed to find the optimal system development methodology. Afterwards, design-research is done to find the decisions that need support, the KPIs and the data requirements of the system. A stakeholder analysis is executed to find the key stakeholders of the system. This serves as the foundation for setting the user requirements. This part concludes with a technical overview of the IT infrastructure and the various correction methods used in the system. The correction methods are found through literature study.

The SPM system is used to compare the data of three Spliethoff ships in the second part. Information can be created by filtering and visualising data. This information can then be used to answer the five goals of the second part. The dataset consists of data taken from three identical Spliethoff S-Type vessels (mv Singelgracht, mv Slotergracht and mv Schippersgracht) over a six month period (December, 2016 - May, 2017).

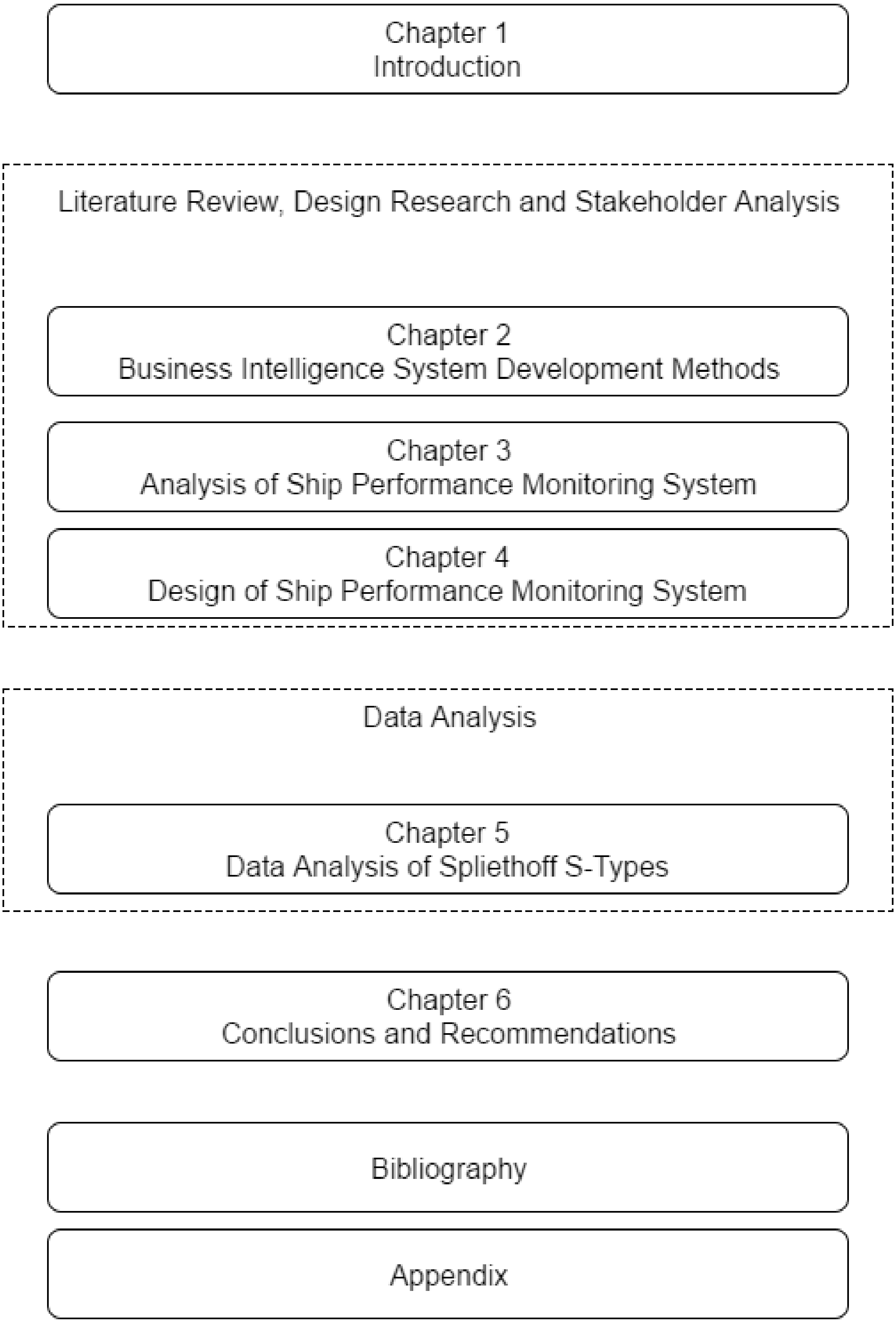


Figure 1.3: Report Structure and Methods

Part I

Development of Ship Performance Monitoring System

Chapter 2

Development Methods of Ship Performance Monitoring System

2.1 Introduction

To ensure that a correct method is chosen for development of the SPM System, a comparison between existing development methods is performed. As mentioned before, the SPM System essentially is a BI System, specifically developed for ship-operators. Therefore BI System development methods can be analysed in this chapter.

The three main methods available for developing BI Systems are covered. Other methods exist, such as ROMC Analysis (too descriptive), Evolutionary Development (hard to implement for more than one end-user), Parallel Development (very time consuming and needs a big development team) and Agile Development (integration problems). However these methods are not often used because of named issues [Veronica [2007]][Turban et al. [2005]].

The main phases a BI project goes through as proposed by [Gangadharan and Swami [2004]] are depicted in Figure 2.1. It is a life cycle also used by for instance [Frost et al. [2011]].

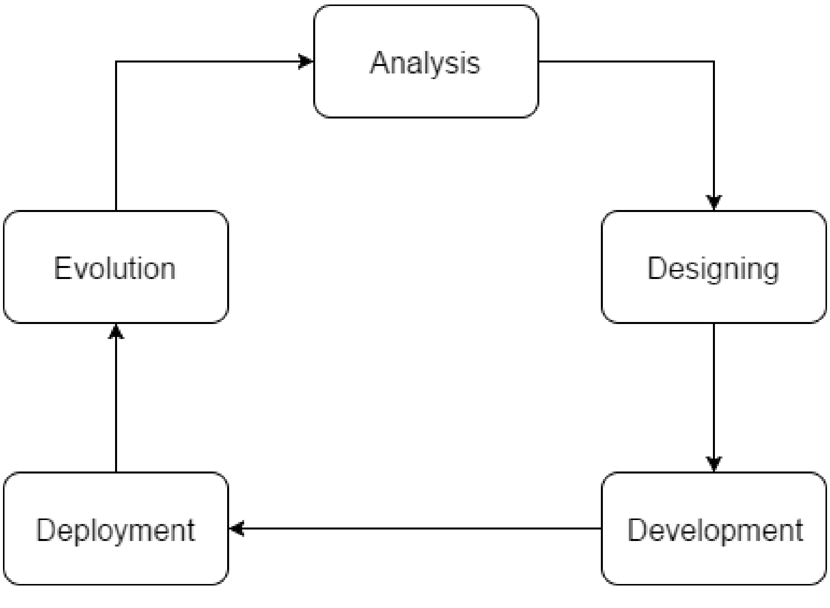


Figure 2.1: Life Cycle of BI System [Gangadharan and Swami [2004]]

A general hierarchy for the design and development of BI Systems (or DSS) can be found in Figure 2.2 as used by [Power [2002]]. At the bottom one can find the three primary development methodologies. A clear distinction between the three proposed methods is given, first focusing on the Systems Development Life Cycle. Subsequently, Rapid Prototyping and End-User Development methodologies are investigated, after which a conclusion is given including a motivated choice of method for this thesis project. Advantages and disadvantages of all methods are incorporated in the analysis.

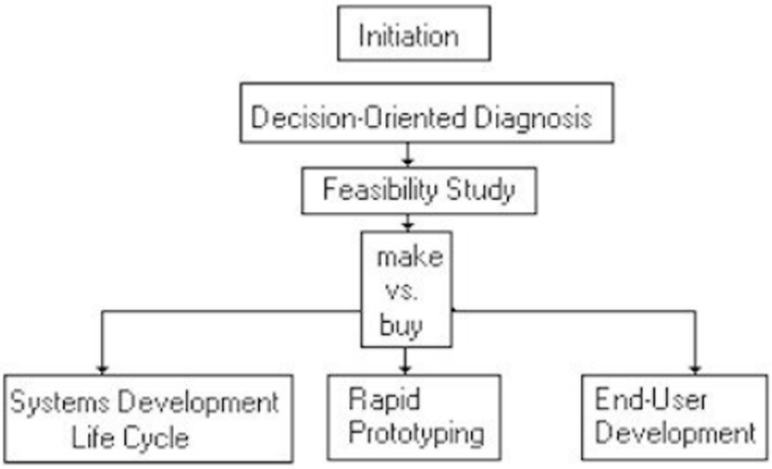


Figure 2.2: A BI System Design and Development Hierarchy [Power [2002]]

2.2 Systems Development Life Cycle

The Systems Development Life Cycle (SDLC) -sometimes referred to as the waterfall model [Veronica [2007]][Turban et al. [2005]]- consists of several well defined phases. It is therefore categorised as a phased methodology [Turban et al. [2005]]. The main steps of the model can be found in Figure 2.3. When looking at the model, the process starts out of business needs. In this phase a number of steps should be run through as described by [Veronica [2007]] of identification of problems, setting objectives for the BI System, identifying decisions supported by BI System, determining outputs of BI System, defining functional and non-functional requirements and performing feasibility studies.

Afterwards, in the analysis phase, the end-user and IT specialist work together to gather requirements for the new system. The design phase strives for a solution definition based on the requirements and constraints. The technical architecture is established and main components are designed. Implementation follows, here the system is distributed among the end-users [Veronica [2007]].

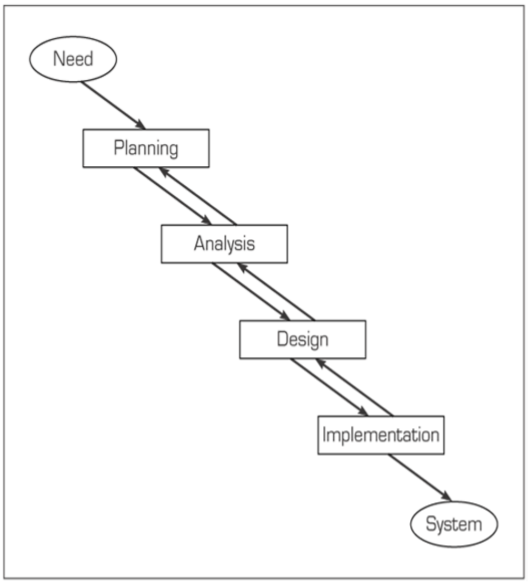


Figure 2.3: Systems Development Life Cycle [Turban et al. [2005]]

2.2.1 Advantages and Disadvantages

According to [Power [2002]], SDLC is mostly used for development of enterprise-wide DSS. Due to the strict phases and comprehensive approach, a large DSS can be developed successfully, although this process takes a considerable amount of time. There are quite a few issues with SDLC, for example [Power [2002]] says that in many situations a full-scale SDLC approach can be too rigid for building DSS, especially for those DSS that have rapidly changing requirements. Some other issues presented by [Turban et al. [2005]] and [Veronica [2007]] are that managers requirements are hard to specify in advance as they are prone to change, the documentation cost is large, it is hard to perform system updates and decision makers are not sufficiently involved in the process. Of these concerns, not involving decision makers is the number one problem, because lack of stakeholder involvement is the primary reason for implementation failure [Turban et al. [2005]].

Concluding, it seems that SDLC without any adaptations is not an optimal method for developing smaller BI Systems, although the method does offer a very strong development framework. If this method could be adapted, aimed more towards end-user involvement, an optimal combination could be found.

2.3 Rapid Prototyping

In Rapid Prototyping a small DSS is developed in a short amount of time [Veronica [2007]]. Figure 2.4 shows the process, clearly depicting an adaptation from SDLC with a feedback loop added for prototyping. [Power [2002]] uses the same process for Rapid Prototyping; starting with identification of user requirements. Then, a first iteration prototype is developed through the steps of analysis, design and implementation. Testing the first iteration prototype will uncover flaws, which will then be taken out in the second iteration prototype. This is an ongoing process until the DSS is satisfactory for all end-users. It is essentially incremental development with constant feedback from potential users.

According to [Power [2002]], the best prototype approach is to have the actual prototype evolve directly into the finished product. In this approach the prototype is attached to a database and features are added to it, but it remains written on the high-level originally used for prototype development. Also [Power [2002]] states that when comparing Rapid

Prototyping to the SDLC approach, prototyping appears to improve user-developer communication. It introduces deliberate flexibility and responsiveness into the development process. Finally [Power [2002]] concludes by saying that the system that is developed with Rapid Prototyping is more likely to meet user needs than in a system developed through SDLC.

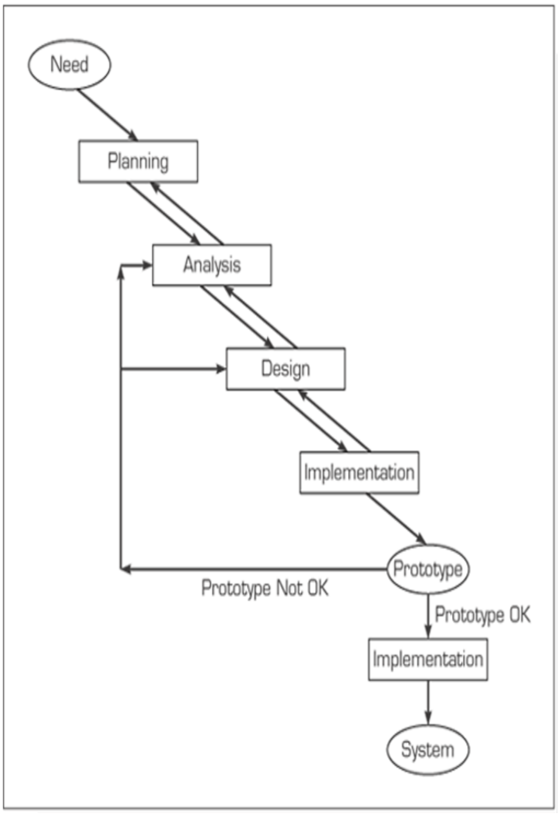


Figure 2.4: Prototyping Development Process [Turban et al. [2005]]

2.3.1 Advantages and Disadvantages

There are numerous advantages to the Rapid Prototyping methodology, the most important advantages being the short development time and end-user involvement. Also, the fact that the end-user can get a feel for the system at an early stage and “learn” the system as it develops is a big bonus. Again, in short time a core system can be developed, which can later be extended if necessary, thus reducing development risks and costs. As the user is involved from the beginning, unwanted elements can be identified and deleted. This takes away the need for detailed and exact user requirements that are 100% correct. [Turban et al. [2005]][Veronica [2007]]

Obviously, there are also disadvantages. The main one being that the problem may get lost as one moves from prototype to prototype. Also, the quality of the final iteration may differ from the intended quality level. Another disadvantage may be that the final prototype is poorly tested before implementation. Finally, dependencies, security and safety of the system may be ignored. [Turban et al. [2005]]

As one can see in Figure 2.4, Rapid Prototyping in essence is an adaptation of SDLC, with a loop added for prototyping. This loop poses great advantages with regards to end-user involvement; exactly the problem in SDLC. Therefore Rapid Prototyping looks like a good mixture between well-structured development and intensive user involvement.

2.4 End-User Development

With the End-User Development methodology, the responsibility for building and maintaining a DSS is put on the manager who is going to use it [Power [2002]]. This means that there is little or no help from IT specialists. This often implies the use of DSS tools and generators available on the market [Veronica [2007]]. The process includes prototyping, but there are no fixed phases as in the other two development methodologies. End-user DSS development of complex DSS is not desirable, since a manager usually has no experience building such complex systems [Power [2002]]. The skillset of a manager might not always be a good fit with the skills needed for development of complex DSS, so this could become a very costly and inefficient process.

2.4.1 Advantages and Disadvantages

The main advantages of end-user developed DSS are that the delivery time is short and the specification of user requirements can be eliminated. End-user involvement is no issue, since the end-users will be building the DSS themselves. This then also takes away any implementation problems. If executed well, End-User Development could be a low-cost solution. [Turban et al. [2005]][Veronica [2007]]

However, since end-users are often not fit for development of DSS, the concerns and disadvantages are numerous. The biggest problem of this development method has been mentioned before, namely that the developer doesn't have adequate expertise in information system development. This means that models may not be tested properly and contain errors, the quality of the final system may be low and security risks may increase. Furthermore, maybe an inappropriate software product has been selected as a development environment and databases are poorly constructed and difficult to maintain. Other problems are the lack of testing and lack of documentation. In the end it all comes down to the fact that end-users rarely follow a systematic development process and don't have the skills required for the job. [Turban et al. [2005]][Veronica [2007]][Power [2002]]

2.5 Conclusions

As the BI System to be implemented at Spliethoff will not be a large, enterprise-wide system, the SDLC methodology is probably too rigid and strict. More importantly, it has become quite clear that successful development of BI Systems is heavily dependent on end-user involvement; SDLC is lacking in this respect. Also, the SDLC process might not deliver a finished product of high quality in this project due to the relatively long development time.

End-User Development has numerous disadvantages, with the main issues all related to a lacking skillset of the system developer (the end-user). This can have an effect on quality, security, development time, database construction, testing and all-round success of the project.

Rapid Prototyping, like End-User Development, is a good method for attaining quick results, as development time is short. Moreover, Rapid Prototyping relies on intensive end-user involvement, increasing the chance of successful implementation and added value. In short time a core system can be developed, after which modules can be added at a later stage, reducing risks and costs. Finally, as the end-user is involved from an early stage, unwanted elements can be identified and deleted. In short, the main advantage of increased decision maker participation can also be attained in Rapid Prototyping, without the drawbacks of End-User Development. Rapid Prototyping uses the solid framework of SDLC and adds a prototyping loop, increasing the likeliness of success of the BI System. Rapid Prototyping will therefore be chosen as development methodology for the BI/SPM

System in this project. [Power [2002]] supports the argument for Rapid Prototyping by saying that two-thirds of the organisations in a survey had built their DSS using an evolutionary, prototyping approach and the remaining organisations had used more of an SDLC approach. A summary of the decision criteria for all three methods is presented in Table 2.1.

Criteria / Methods	SDLC	Rapid Prototyping	End-user development
End-user involvement	-	+	+
Development time	-	+	+
Structure	+	+/-	-
Proper testing	+	+	-
Flexibility	-	+	+

Table 2.1: BI System Development Methods with Decision Criteria

Chapter 3

Analysis of Ship Performance Monitoring System

3.1 Introduction

The first step in the Rapid Prototyping development process is analysis of the SPM System. The primary goal of the analysis is to determine user and system requirements.

Before determining the user requirements, it has to be decided which business decisions are going to be supported by the SPM System. An overview of relevant other systems which are already being used at Spliethoff can provide useful scope in this respect.

After establishing the decision areas needing support, the KPIs required to provide supporting information are determined. Finding out what data sources are available and what data is necessary to construct the KPIs is the next step.

When developing and implementing a new system at a company, learning whose interests should be considered and who are affected by the new system can contribute to the success of the project. A stakeholder analysis is performed to provide this information.

After the stakeholder analysis, user requirements are set. This phase focuses on providing end-users with the right KPIs. An explanation on why users need certain KPIs is included. A conclusion is given regarding the key stakeholders and the most important KPIs.

3.2 Decision Support Analysis

One of the primary goals of any information system is to support business decisions using information created from data. Business decisions are made on all levels in an organisation; Robert Anthony (1965) classified decisions in four categories associated with organisation levels. In Figure 3.1 the four levels are shown.
Strategic Planning decision processes are related to allocating resources, controlling organisational performance, establishing broad policies and evaluating investment or merger proposals.
Management Control decision processes are associated with acquisition and use of resource by operating units, buyer and supplier behaviour, introduction of new products and research and development expenditures.
Operational Control decisions relate to the effectiveness of organisational actions, monitoring product/service quality and assessing product/service needs. Finally, **Operational Performance** relate to day-to-day decisions made in functional units by managers to implement strategic decisions, functional tactics and operational activities [Power [2002]]. Classifying the business decisions to be supported is very important in this analysis, because it gives a first indication on who the intended users are going to be.

Figure 3.1: Categories of Organisational Decisions [Power [2002]]

Before going into the decisions to be supported, a clear explanation on how Spliethoff as a company achieves its main goal, maximising profit, is given. From a practical point of view, profit maximisation is attained by trying to find the maximum voyage result or Time Charter Equivalent (TCE). The TCE depends on a lot of factors such as freight-rates, bunker prices, voyage distance, duration of voyage and more. Not all of these factors can be influenced, but finding an optimum speed-consumption balance is key in attaining maximum TCE.

When a voyage is being planned, the flowchart displayed in 3.2 is used by operators, commercial representatives and the ship's captain to obtain the optimum speed-consumption setting. The voyage planning is initiated at the last port of loading. In the first phase, the captain uses a weather routing system on the ship to revert back to the office with recommended route and distance to next destination. The office then calculates TCE for this distance for three speeds (eco-, medium- and full speed). The speed with highest TCE is selected, checking whether the required ETA is met or not. If not, another speed is selected. In the following phase, the connection to the next voyage is checked and the captain is contacted again for approval. At this stage, it could happen that the captain does not approve the voyage plan due to adverse weather conditions or other factors. Otherwise the instructed speed will be followed.

Spliethoff currently aims at improving decision making in five areas through the SPM System, all corresponding with the research objectives set up in section 1.3.

1. Determine the most fuel efficient speed of a Spliethoff S-Type.
Referring to the paragraphs above, for every voyage the speed with highest TCE is determined. This can either be eco-speed, medium speed or full speed. Eco-speed is the term used at Spliethoff to indicate the most fuel efficient speed of the ship i.e. the speed with lowest fuel consumption in kg/nm. Full speed is the speed at maximum power and medium speed is somewhere in between (not defined specifically).

At the moment, a captain is sometimes instructed by an operator in the office to sail at eco-speed to the next destination, as the schedule allows for a low speed. However, often the captain and operator have only a vague idea of what this speed exactly is for that particular vessel. Of course this speed also differs from ship to ship. If the SPM System could provide information on the exact eco-speed of a vessel, this will simplify communication between commercial representative, operator and captain. Also, it will save fuel costs as the ship is now actually being sailed at the correct most fuel efficient speed.

2. Determine the actual fuel consumption of a Spliethoff S-Type for a given speed.
When planning a voyage, a pre-calculation is performed, giving a first estimate of a voyage

TCE. At the moment, simple tables and rule of thumb are used to estimate the bunker consumption of a vessel at a given speed and draught. Getting more accurate information from the SPM Sytem on the fuel consumption of an S-Type for a given speed and draught will make pre-calculations more precise and improve the decision making process. Again, this information can be used directly in the process of selecting speed with highest TCE of Figure 3.2 by commercial representatives and operators.

3. Determine the effect of hull- and propeller fouling on fuel consumption and speed.
Measuring hull and propeller fouling is also an area of interest. At the moment, hull cleaning is performed primarily based on feedback from the ship's crew or commercial representatives, ascertaining that the vessel is not able to make full-speed or runs slower than normal at a certain power setting. A more predictive method is not used right now. The hull and propeller are cleaned regardless of their condition when the vessel is in dry-dock twice every five years. Monitoring the effect of hull fouling on performance will increase Spliethoff's knowledge and could save significant cost when used effectively.

4. Determine the specific fuel consumption of the main engine to predict maintenance actions.
Engine performance monitoring is another terrain where the SPM System could add value. Analysing developments in specific fuel consumption (SFC) of a ship's main engine may help to better predict service actions, resulting in cost savings. Also, the business development department of Spliethoff constantly investigates new technologies that might result in fuel savings. For example, the effect of fuel additives can also be measured in SFC, so again the SPM System could add value here.

5. Determine the influence of crew on ship's operation and on fuel consumption specifically.
Monitoring the influence of crew on board the vessel on fuel consumption is a key objective. Before the start of this project, some preliminary fuel consumption monitoring has already shown that different chief engineers and captains have very different approaches to the operation of the ship, leading to differences in fuel consumption. Some captains show a lot of interest in fuel efficiency and are willing to adapt their methods of operation, whereas others are very reluctant to change and like to rely on their extensive seafaring experience. With the SPM System, data could be used as an argument to convince captains a certain new method is actually more effective/efficient than the one they are exercising now.

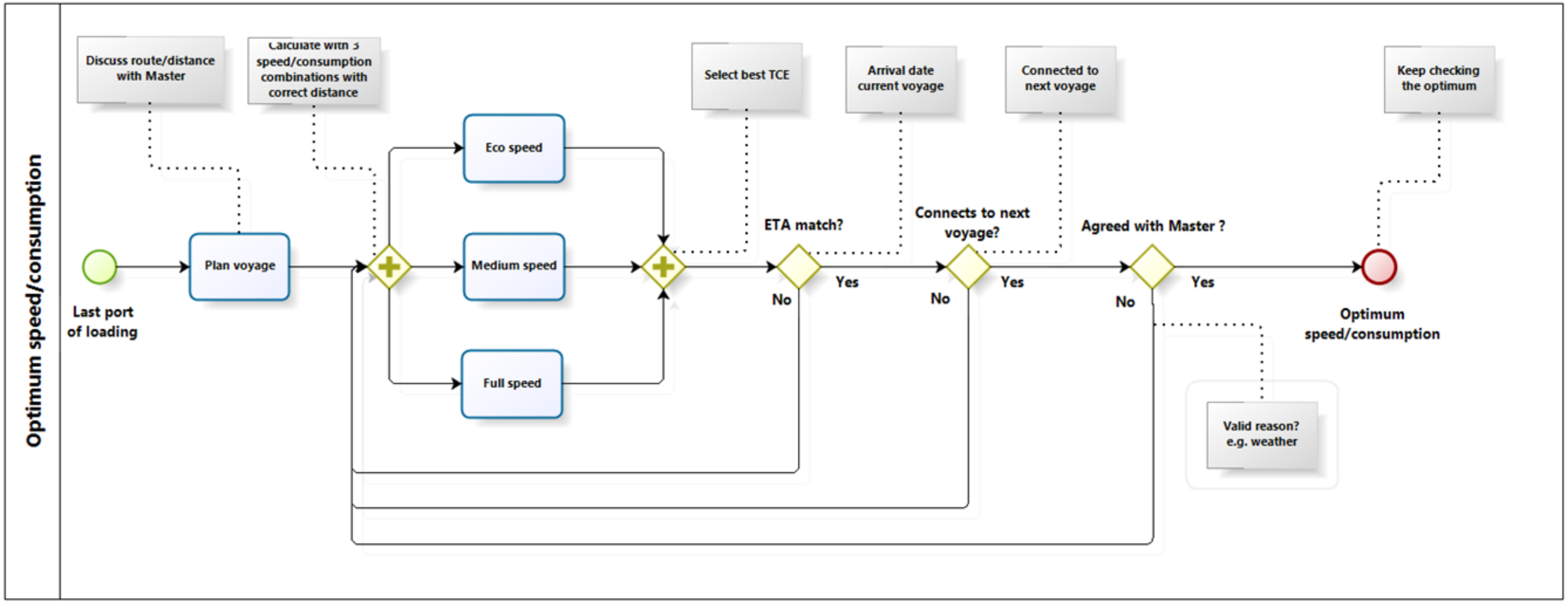


Figure 3.2: Optimum Speed/Consumption Flowchart Spliethoff

On a more general note, although decision areas for the SPM System can -and have to- be specified in advance, a lot of new insights will come once the data is there to be analysed. These new insights do not necessarily have to be in the same decision processes as selected beforehand. As [Chang et al. [2006]] says, business intelligence is also about uncovering opportunities, not just about decision support.

All five described business decision processes for the SPM System are of operational nature and fall into the Operational Performance class of organisational decisions. Consequently, one can conclude that upper management probably will not be using the system intensively. In the future more functions might be added to the SPM System, changing the intended users, however in this project the focus lies on operational performance.

Spliethoff uses some other systems to support decisions; the ones relevant for this project are mentioned next. The SPM System to be developed is not intended to replace any existing systems, rather complement them.

On the ships, SPOS Onboard of MeteoGroup is used for weather routing when planning a voyage. Conditions such as wind, waves, swell, current and other environmental elements are taken into account, providing the captain with optimal routing (in terms of safety and efficiency) according to weather forecasts [MeteoGroup [2016]].

On the vessels, the Propulsion Efficiency Monitor of VAF Instruments is also installed. This monitor shows the real-time value of ship speed, propeller shaft speed, shaft torque, shaft power, fuel consumption in kg/h, fuel consumption in kg/nm and other key parameters on the bridge and in the engine room. This monitor can now also be accessed in the office through a “remote-desktop” functionality, so some real-time ship monitoring is already taking place.

In the office, the main DSS currently used is the Voyage Management System (VMS) of Dataloy Systems AS. Before, an in-house developed application was used (Fleetcom). However, VMS better matched the requirements of Spliethoff’s account department and has a broader range of functions, so VMS was introduced in 2013. Other systems were evaluated, but none could offer the functionality of VMS. The system has a comprehensive list of features which include a cargo planner, vessel planner, Contracts of Affreightment, bunker hedge, budgeting, terminal suitability check, stowage planner, voyage estimation, time charter in/out, scheduling, bunkers, offhire, vessel reports, laytime calculation, accounts receivable/payable, hire payable, claims, time correction, area administration and air emissions [DataloySystems [2016]]. Ergo, this system will remain leading in the office among operators, commercial representatives and others when planning a voyage.

3.2.1 Key Performance Indicators

In this section KPIs are found that provide relevant information for the five decision areas as described in the Decision Support Analysis.

1. Determine the most fuel efficient speed of a Spliethoff S-Type.
As defined in the previous section, the most fuel efficient speed (“eco-speed” at Spliethoff) of a vessel is characterised by the speed with the lowest fuel consumption in kg/nm. Fuel consumption in kg/nm is a function of numerous parameters, the most important ones being vessel speed, main engine power, draught and hull fouling. Environmental factors also affect this measurement, such as extra resistance due to waves, wind load, water depth and currents. Finally, whether the shaft generator is switched on or not affects the main engine power needed to sail at a certain speed. On longer ocean passages however, the shaft generator is turned on by default, so only eco-speed with shaft generator switched on is the operational condition that will be investigated.

To find a useful KPI for eco-speed, one has to take into account all influencing factors on the fuel consumption in kg/nm. Especially with regards to waves, wind, water depth and current extra measures will have to be taken.

As three Spliethoff S-Type ships are going to be compared in the data analysis, making sure the data is comparable is very important. To have comparable data, the measured data will have to be corrected for the influence of the environment the ship is sailing in. For example, one moment ship A could be sailing at 17 knots with wind from astern, no current and following waves, giving a certain value for fuel consumption. Ship B could also be sailing at 17 knots, but now it is experiencing wind and waves head-on, with current from the front. The fuel consumption of ship A will be very different from the consumption of ship B, even though the ship is sailing at the same speed (and draught). In section 4.3 calculation methods are presented on how the effects of waves, wind, current and shallow water are corrected for in the SPM System.

Combining the main factors of influence on eco-speed, a performance indicator can be found. A graph displaying fuel consumption in kg/nm plotted separately against speed and power for different draughts, including a correction for wind, waves, water depth and current will give the required information. The bottom of the trend line will give eco-speed, the sought after parameter to be used by operators and captains. To make eco-speed more easy to find, a simple value of eco-speed per ship type could be given.

2. Determine the actual fuel consumption of a Spliethoff S-Type for a given speed.
At Spliethoff, MT/day is the preferred unit with which fuel consumption of a vessel is denoted. The fuel consumption of a ship is a function of many different factors. In essence, the same parameters apply here as with eco-speed. Speed, power, draught, hull fouling and the environment are the main influencing factors. Consequently, a correction for wind, waves, water depth and current is necessary once more.

As operators and commercial representatives will mostly be using this information, it should be easy to understand and self-evident. A graph could provide the required information by plotting corrected fuel consumption in MT/day against speed and power for a number of draughts. If required, the graph could be tabulated for ease of use.

3. Determine the effect of hull- and propeller fouling on fuel consumption and speed.
Hull- and propeller fouling can be measured with total ship resistance, but thrust is easier to calculate with the data available (see section 3.3), and this parameter practically provides the same information. Here as well, a correction for external factors will have to be made. Plotting the thrust against time will show variations in thrust, but only correctly if a speed and draught range is chosen. The speed and draught range will have to be chosen smartly and sufficiently narrow, preferably at values where the ship spends most of its operational time at (to increase size of the data set).

4. Determine the specific fuel consumption of the main engine to predict maintenance actions.
SFC is a function of a large amount of factors, the main ones being engine power, engine RPM, engine torque, calorific value of fuel, density of fuel and maintenance condition of the engine. By correcting for calorific value, this factor can be taken into account. To accurately measure SFC, a chart can be used, where SFC in g/kWh is plotted against power.

To monitor engine condition again a coefficient could be plotted over time. Using the coefficient $\frac{FOC}{P_B}$ over time, with brake power P_B and main engine fuel consumption FOC development of the engine condition can be followed.

5. Determine the influence of crew on ship's operation and on fuel consumption specifically.
It is harder to find KPIs for this goal, as not a single parameter is targeted. A map showing the vessel's position at a certain time with the option to display speed, power, shaft generator power, water depth, wave height, wave direction, wind speed, wind direction, current rate and current direction at that position can give a lot of information. For instance, checking whether the crew is handling weather developments effectively, could be valuable. Also one can check if the vessel is slowed down in shallow areas and whether the scrubber is turned off outside SECA areas (drop in shaft generator power). Fuel consumption in MT/trip (berth-berth) for the same voyage might give valuable information when evaluating a crew's performance over a number of the same voyages.

To compare the vessels on a different level, the eco-speed could be taken from the three S-Types and each ship could be compared against the ship type average. The KPI would have the form of this coefficient: $\frac{eco-speed}{eco-speed_{ave}}$. The same could be done for fuel consumption in MT/day and thrust. A list of all information to be generated by the SPM System is presented in Table 3.1.

Type	**Information**
Graph	(Corrected) fuel consumption in kg/nm plotted against speed per draught condition
Table	Eco-speed per ship type per draught condition
Graph	(Corrected) fuel consumption in MT/day plotted against speed per draught condition
Table	(Corrected) fuel consumption in MT/day per speed per draught condition
Graph	(Corrected) thrust plotted against time at speed and draught range
Graph	SFC plotted against engine power
Graph	SFC coefficient plotted against time at power range
Map	Ship's position at time x
Value	Fuel consumption in MT/trip (berth-berth) for the same voyage
Value	$\frac{eco-speed}{eco-speed_{ave}}$
Value	$\frac{FOC}{FOC_{ave}}$
Value	$\frac{Thrust}{Thrust_{ave}}$

Table 3.1: SPM System Information Output

3.3 Data Requirements Analysis

To create the information required for decision support, several data sources are available. The primary data source is the *sensors database* located on Spliethoff's main server (see chapter 4 for IT infrastructure). In this database, all data collected by sensors of Spliethoff's ships is stored. Currently, this is data from the vessels mv Plyca, mv Timca, mv Singelgracht, mv Slotergracht and mv Schippersgracht. For the S-Type vessels ship speed through water and over ground (respectively STW and SOG), heading (true), water depth below keel, latitude, longitude, fuel consumption (main engine, generators and boilers), fuel density, expansion factor, calorific value of fuel, fuel flowrate (main engine, generators and boilers), temperature of fuel flow (main engine, generators and boilers), propeller shaft power, propeller shaft torque, propeller shaft rpm and shaft generator power and fuel consumption in kg/nm is universally logged for named vessels. None of the vessels is equipped with a thrust sensor or propeller pitch sensor for cost or practical reasons. A complete list of all sensor types being logged in the sensors database per ship can be found in Appendix A. Due to the amount of sensors and the data logging frequency (once every five minutes), the size of the database is substantial (288 data points per sensor per day).

A second source of data is the ship *messages database*, where the departure, noon and arrival messages of ships are stored. In a departure message information is given about port of departure, unmooring time, use of pilots, departure draught, use of tugs, expected arrival draught and expected time of arrival (ETA) for pilot station and berth. Also distances are given for berth-pilot, pilot-pilot and pilot-berth. Finally, the amount of fuel onboard at the start of the voyage is given both for Heavy Fuel Oil (HFO), Marine Gas Oil (MGO) and luboil with an expected amount to be consumed over the next voyage.

In the noon messages, which are given every 24 hours when the ship is sailing, the date, position, updated ETA to pilot station, hours since last message, miles since last message, miles to pilot station, wind speed/direction, current rate/direction and wave height/direction are given.

The arrival messages show the port of arrival, arrival time at pilot station, time of mooring, distance pilot-pilot, use of tugs and the remaining amount of fuel left in the tanks.

It is important to note is that all the messages are subject to manual input. In other words, the messages are created by an officer on the bridge and are therefore prone to contain inaccurate or false information. The current rate/direction and wave height/direction for example is not measured, but estimated visually using experience and environmental knowledge.

As accurate data on wind, waves and current is important for the correction calculations that have to be performed, a different source is used. MeteoGroup provides accurate hindcast weather data, available after 24 hours. The hindcast weather files contain time, latitude, longitude, air pressure at sea level, wind speed/direction, precipitation, visibility, icing, significant wave height, average wave height, wave period, swell height/direction/period, current rate/direction, air temperature and sea temperature.

For ship-specific data, the complete documentation from the shipyard is available. This includes CAD drawings of the hull, the general arrangement, model test results, machinery drawings, detail drawings and more.

STW is measured using an acoustic correlation speed log and was found to be very unreliable. At times STW would measure three knots above SOG, without any significant current at that very moment. Hence, STW is derived from SOG using current data from MeteoGroup. The calculation method can be found in subsection 4.2.3.

The available data does not necessarily correspond with the data required to create useful information for decision support. To determine which data is necessary, a look at the KPIs is a good starting point, after which required data can be established.

When looking at the first KPI in Table 3.1, a graph is needed showing corrected fuel consumption in kg/nm plotted against speed and power for different draughts. To achieve this, ship speed, draught and fuel consumption in kg/nm are all available to create the required information in reports. For correction of environmental conditions, heading, water depth, wind speed/direction, significant wave height, swell direction and current rate/direction are all available. However, thrust also has to be available to deduct mentioned environmental factors from. Thrust sensors exist, but they are quite expensive so they are not installed on any of the ships. Sensors measuring pitch on the propellers are also not installed. Here, a different method will have to be found to acquire the required data (see subsection 4.2.3).

The second graph in Table 3.1 focuses on more accurate prediction of bunker usage when planning a voyage. Fuel consumption in kg/h, speed, power and draught are required and available from the ship. Just like the previous KPI, correcting for the environmental conditions is required, so the same data as in the former case is necessary. A method for calculation of thrust is also needed.

To measure hull fouling, a chart where thrust is plotted over time for a certain speed and draught range gives the desired result. Speed and draught data are both available. Thrust has to be calculated.

The fourth KPI should measure SFC. SFC can be calculated using fuel consumption and power output of the main engine. A correction for the calorific value of fuel is useful, as this value varies significantly depending on the bunker location. Main engine power is also needed for the chart. The SFC coefficient is also used here to monitor engine condition. For this coefficient again main engine power and fuel consumption are necessary. All of this data is available, so there should be no issues in attaining this KPI.

Measuring the influence of the ship's crew on vessel performance and fuel efficiency can be achieved through analysis of all previously described graphs. Some additional KPIs that could increase monitoring capabilities are a map showing the current position of the ship, fuel consumption in tonnes per voyage. The data requirements for current position is latitude and longitude of the ship, which is available. Ship speed data obviously is also available, which can be taken from the departure- and noon messages. From the departure- and arrival messages, fuel consumption in MT/trip can be calculated.

3.4 User Requirements Analysis

For the stakeholder analysis a methodology proposed by [Schmeer [1999]] will be followed, since it provides a generic step-wise approach, applicable to different sorts of projects. This methodology uses *focus groups* to identify stakeholders, their interests, influence and other attributes and categorises them. The main advantages of focus group stakeholder identification are that it is a rapid, cost-effective and adaptable method. Categorisation of stakeholders is performed using *interest-influence matrices*, which make power dynamics explicit [Reed et al. [2009]]. Some process steps of Schmeer have been adapted slightly to make the methodology a better fit for this project.

Other methodologies for stakeholder identification are *semi-structured interviews* and *snow-ball sampling* which are not used because both methods rely heavily on interviewing which is time-consuming, costly and results may be biased. For stakeholder categorisation other methods are also available such as the *Q methodology* and *stakeholder-led categorisation.* Q methodology is not chosen because it again involves interviewing and it does not identify all possible options. Stakeholder-led categorisation may have meaningless results due to reliance on biased stakeholder input.

3.4.1 Stakeholder Analysis

In this section the stakeholder analysis process steps as suggested by Schmeer are followed, including identification and categorisation of stakeholders.

To start with, the purpose of the stakeholder analysis has to be determined. In this project, the purpose is to provide a starting point from which the user requirements for the SPM System can be defined. In other words, the results from the stakeholder analysis will be used as context for the user requirements. Next step is to define a so-called policy. In the context of a stakeholder analysis, policy refers to the project or program the analysis focuses on. In this project the policy is *new SPM System development and implementation.* Further defining the policy; *New SPM System development and implementation: To be developed and implemented at Spliethoff for three S-Types in the first place, focusing on fuel consumption and reduction of operational cost.*

The most important step in the stakeholder analysis is identification of all stakeholders. Starting in the office, as was established in section 3.2, the SPM System will mainly be used on the operational side, not by management. Consequently, **operators**, **commercial representatives** and **the technical department** will be using the system. From the ship's side, the **captain** and **chief engineer** are going to be involved, as they are necessary for manual input into the system and will also be using certain KPIs. **Commercial management**, **technical management** and **financial management** are not primary users, but undoubtedly there is an interest from these parties in operational and financial benefits. Finally, the **business development department** is responsible for fuel saving technologies, so they are heavily involved.

Other stakeholders which are less evident, such as the environment, bunkering companies, government, ISO, oil companies and Spliethoff's customers are also affected to greater or lesser extent. At the moment they do not have the power to directly obstruct the project however. Therefore they are not counted as key stakeholders, although this might change in the future.

The final step is to map the stakeholders in a table according to interest and power. In Figure 3.3 one can see the categorisation of the stakeholder grid. The x-axis shows interest of the stakeholder in the project and the y-axis displays the influence/power of the stakeholder. In this case, power represents the power to obstruct, rather than hierarchical power. This definition of power was chosen, because it gives a better indication of which stakeholders are essential to the success of the project. Figure 3.4 shows the grid with key stakeholders at their respective positions.

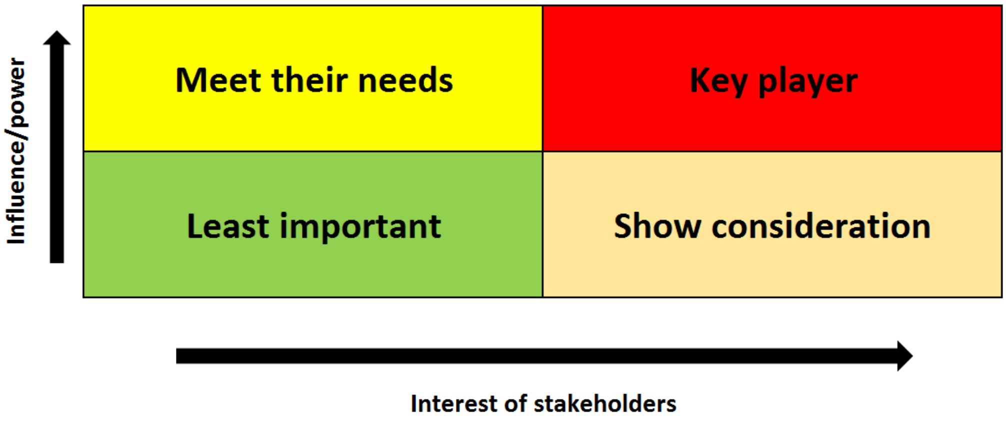


Figure 3.3: Interest versus Power Grid [Eden and Ackermann [1998]]

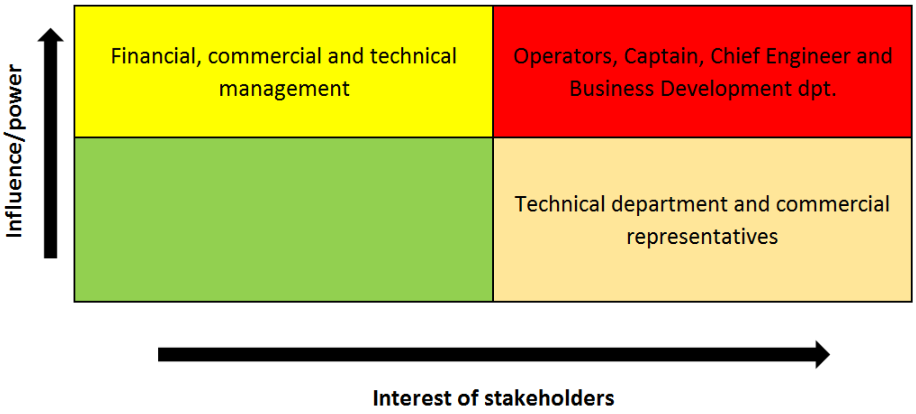


Figure 3.4: Interest versus Power Grid Completed

From the technical department interest is considerable as monitoring of engine performance and hull/propeller fouling actually both are in their field of expertise. However influence and obstruction power are not so big, therefore the technical department is placed in the lower right corner of the grid. The commercial representatives also have substantial interest in the project, since they can use the SPM System daily to make more accurate calculations, thereby aiding in the sales process. They however do not possess the obstruction power to be of major influence to the success of the project. Clearly, financial, commercial and technical management have a lot more power. They can stop the project if they want to, for example if the project does not show sufficient benefits. Interest of management is not very high, as they will not be working with the system on a day-to-day basis, placing them in the top left corner. The key players in this project are the operators, captains, chief engineers and the business development department. In the end, based on the dashboard, certain instructions will be given by the operators to the ship. If the captain or chief engineer decide not to follow instructions, the added value of the dashboard diminishes quickly, so in that sense these actors have a lot of power. Business development is in charge of the SPM System project, so they have a lot of interest and considerable power. The lower left corner of the interest-influence matrix is left blank.

3.4.2 Connecting Users to KPIs

The necessary KPIs for the SPM System now are known, as are the users. The next step is to connect the selected KPIs to users in a logical manner. Different users have different information needs, i.e. they want to look at different KPIs. The KPIs for the SPM System follow from the decision support analysis in section 3.2. Also input from the users established in section 3.4 was taken into account. Combining information from both sources, a list of users per KPI was established, which can be found in Table 3.2. Business development is in charge of the SPM System project, so they have access to all KPIs.

Fuel consumption in kg/nm plotted against speed and power for different draughts is an important KPI for business development, as eco-speed can be deducted from this graph. To simplify matters for users on the floor, a table showing eco-speed per ship is probably easiest. For normal day-to-day operation it would be too complicated and time-consuming for an operator to check the graph and find eco-speed himself. Operators can now find eco-speed in a table and give the captain accurate speed instructions. Captains and chief engineers on the other hand like to look at eco-speed too to understand why operators request a certain speed. As clear communication between the operator and commercial representative is of the utmost importance, the latter also needs access to this KPI.

Using the same principle as in the previous example, fuel consumption in MT/day plotted against speed for different draughts is interesting for business development. For operators, commercial reps and crew on the ship a table with speed and consumption is much more practical and easy to use. This KPI adds value because operators and commercial representatives use fuel consumption in MT/day in their calculations prior to a voyage, so this table enables commercial representatives to better predict bunker usage when planning a voyage. Captains also use the information when planning a leg.

All the fouling and engine condition related KPIs (thrust-time graph, $\frac{FOC}{P_B}$-time graph, SFC-power graph) are in principal for the technical department. Monitoring fouling and engine efficiency will help them plan hull cleaning intervals and maintenance actions. Business Development has an interest in whether main engines perform at manufacturer's specification, hence the interest in the engine condition KPIs. The chief engineer on the ship also wants information on the performance of the main engine, so he has access to SFC data too.

To monitor operation of the ship during a voyage, operators want to see a plot of the vessel's position with as much information as possible. Speed, draught, weather information, shaft generator power and main engine power are just some of parameters that can be plotted on the route of the vessel, giving a very large amount of information on which to evaluate crew performance.

Fuel consumption in MT/trip (berth-berth) for the same voyage is interesting as it gives operators, commercial representatives, commercial management and captains the opportunity to compare fuel consumption over a number of trips. If over a similar trip the fuel consumption shows large variations further investigation as to the exact reason why is desirable. Also, having more accurate information on bunker usage over a prior voyage will make pre-calculation more accurate for the next voyage.

3.5 Conclusions

The primary information output of the SPM System is: eco-speed per vessel, speed-consumption information per vessel, hull and propeller fouling state of vessel and main engine performance information. Nearly all of the necessary data to create this information is readily available from the data sources. The only data missing is ship thrust, which needs to be calculated. Also, the effect of wind, waves, shallow water and current on ship performance will have to be calculated.

With respect to the KPIs, the eco-speed table and speed-consumption table are probably the most important performance indicators, as most users will be employing these values on a daily basis. After that, the fouling and engine condition KPIs are probably most important, as there are substantial savings to be made in this area also.

After identification of the key stakeholders, it has become clear that the operator and captain are pivotal to the success of this project. If they somehow decide not to use the SPM System, the added value is reduced significantly. As the power of management in the organisational structure of Spliethoff is bigger than that of the key players, through this channel the policy could be enforced. To maintain a positive relationship between the office and the crew working on Spliethoff's ships this is probably not the best solution.

The preferred manner of ensuring key players are going to use the system is by involving them in the development process early on. This is exactly what Rapid Prototyping aims at (see section 2.3. In general, increasing interest among all actors, i.e. moving actors from left to right in the stakeholder grid, is always desirable.

KPI	**Users**
Graph with (corrected) fuel consumption in kg/nm plotted against speed and power for different draughts	Business Dev.
Table with eco-speed per ship	Operators Captains Chief Engineers Commercial reps Business Dev.
Graph with (corrected) fuel consumption in MT/day plotted against speed and power for different draughts	Business Dev.
Table with fuel consumption in MT/day per speed for different draughts	Operators Captains Chief Engineers Commercial reps Business Dev.
Graph with (corrected) thrust plotted against time for speed and draught range	Technical dpt Business Dev.
Graph with SFC plotted against main engine power	Technical dpt Business Dev. Chief Engineers
Graph with SFC coefficient plotted against time at draught range	Technical dpt Chief Engineers Business Dev.
Ship's position at time x	Operators Business Dev.
Fuel consumption in MT/trip (berth-berth) for the same voyage	Operators Captains Commercial reps Business Dev.
$\frac{eco-speed}{eco-speed_{ave}}$	Technical dpt Management Business Dev.
$\frac{FOC}{FOC_{ave}}$	Technical dpt Management Business Dev.
$\frac{Thrust}{Thrust_{ave}}$	Technical dpt Management Business Dev.

Table 3.2: KPIs and End-Users

Chapter 4

Design of Ship Performance Monitoring System

4.1 Introduction

Following the process steps of Rapid Prototyping as displayed in Figure 2.4, chapter 2, the design phase can start after a comprehensive analysis of the SPM System. In this phase, the technical and digital architecture is designed and system models are created.

A detailed explanation of the complete IT infrastructure supporting the SPM System is first given. All elements such as sensors, control boxes, databases and servers in the ship, datacenter and office will be dealt with. The processes where data is transformed, adapted and corrected is a critical part of the IT infrastructure and are described in subsection 4.2.3. Some of these processes are performed for correction of influence of wind, waves, current and shallow water, as mentioned earlier in chapter 3. The correction methods for these particular processes are presented in section 4.3.

A generic cost structure for the SPM System developed at Spliethoff is also given in this chapter, including a comparison with costs of a ready-made SPM System.

4.2 SPM System IT Infrastructure

The underlying infrastructure of the SPM System is a big and essential part of this project. As the flow size of data for this project is already substantial (288 data points per sensor per day) and is likely to increase, a robust IT infrastructure is required. Especially considering the fact that monitoring of ships will most likely become more critical in the future. For instance, emission related data (from the scrubber) and data from alarm systems will probably be added to the system in the coming years, thus only increasing the data flow even more. As it is very time-consuming and costly to rebuild an existing IT infrastructure, it has to be designed correctly from the start. The entire SPM System IT infrastructure can be split into ship, data warehouse and office.

Before diving into the various elements of the SPM System, a short explanation on general IT definitions is given. To start with, a *server* is a computer or program that provides services to other devices or clients. In this case, a server is a computer with large storing capacity where *databases* are stored. Databases are organised collections of data, in this instance organised using two-dimensional *datasets* (or tables), built up of *columns* and *rows*.

From top to bottom; a server stores databases, which in turn hold datasets containing columns and rows where data is stored.

4.2.1 Ship's Infrastructure

Starting with the set of sensors on the vessel, in Figure 4.1 one can for instance see the torque sensor connected to the VAF PEM4 module (propulsion efficiency monitor), sending data to the Wizzo datalogger via serial communication. Data from the anemometer, echo sounder and GPS are transferred to the Wizzo datalogger through a Moxa nPort. The Moxa nPort in essence transforms an NMEA signal to ethernet NMEA, removing the need to lay a separate cable for every sensor through the ship (very impractical). The Wizzo datalogger can be seen as a "black box" that collects sensor data on the ship and then sends it to a server.

In this case the sensor data is first sent to a Microsoft SQL (Structured Query Language) server onboard the vessel, where every five minutes a datapoint is stored from selected sensors. This onboard server is synchronised with Spliethoff's main Microsoft SQL server situated in Haarlem via VSAT (communication satellite) or 3G/4G wireless internet connection. Here it is stored for an undetermined period (read: infinitely) in the *sensors database*. The onboard server is cleared of data every three months, as there is no reason to store it any longer here and server capacity onboard the vessel is limited. It is possible to refill the onboard server with data from the main server in the cloud after clearing it, if so required. Summarising, data synchronisation can be executed from ship to shore and vice versa.

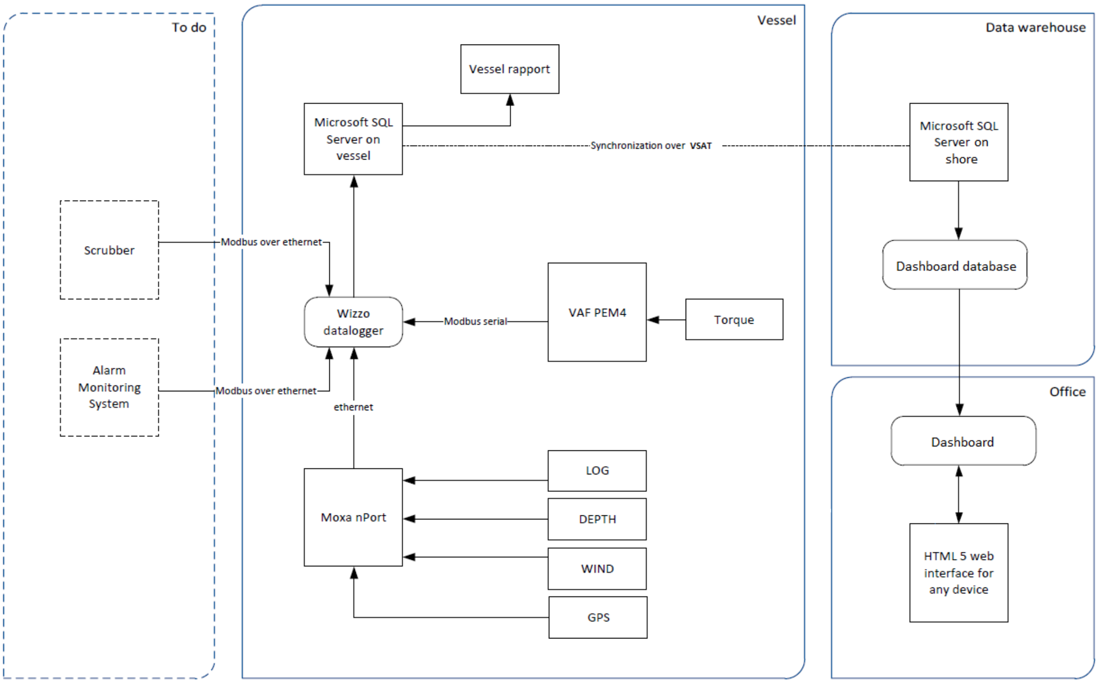


Figure 4.1: Complete Infrastructure including Vessel, Data Warehouse and Office

4.2.2 Data Warehouse

On the main server in Haarlem several Extract, Transform, Load (ETL) processes are performed which convert row-stored data to a new column oriented database called *dashboard database*. By pivoting from rows to columns, the data is now organised in a more logical manner providing easier access. The ETL processes also enable blending of data from different data sources. First, raw data is taken from *sensors database* or *messages database* on the main server (Extract), this data-table is then pivoted and other calculations are performed (Transform), after which the new table is loaded in the new dashboard database (Load). The sensors database, messages database and dashboard database are part of what is called the data warehouse.

The purpose of the ETL processes is to enable direct access to the required corrected data, so reports can be created in the dashboard straight from the new database. In other words, if the ETL process would not be there, one would have to load the raw data into a spreadsheet program (Excel), pivot the table, transform the pivoted raw data into corrected data and then load the new tables into the dashboard. These are all manual steps which can only partly be automated. The goal is to have an automated, continuously updating dashboard showing real-time KPIs, hence the introduction of ETLs. This structure can be found in Figure 4.2, which in fact simply is a more detailed, zoomed-in representation of the right-most part of Figure 4.1. The databases on the left represent the data sources containing *raw data*. Through the ETL processes this raw data is transformed to *good data* stored in dashboard database, after which the final conversion to *information* is made on the dashboard.

A comprehensive explanation on all ETL processes can be found in subsection 4.2.3.

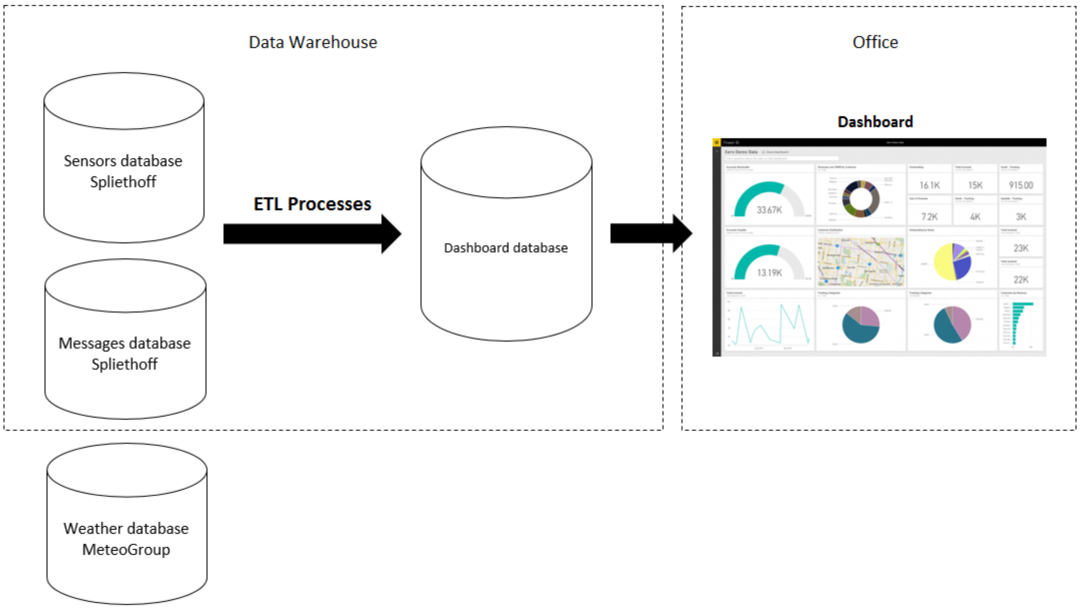


Figure 4.2: Data Warehouse and Dashboard Setup

The dashboard database shown in Figures 4.1 and 4.2 had to be designed specifically for this project. It is optimised for the required corrected data and for connectivity to the dashboard. Generally speaking, there are three types of databases: flat file, relational database (SQL) and NoSQL. The decision was made to use a relational database model for two main reasons. Firstly, a flat file (one big dataset containing all data) is very simple, but the major drawback lies in the fact that it is near impossible to group, filter and select data (query) in the database. Secondly, NoSQL is quite a new and advanced sort of database, not ideal for the structured sort of data of the SPM System. Hence, a relational database was constructed.

A relational databases stores data in two-dimensional tables; also information about the relationships between pieces of data is included [Harrington [2010]]. The main advantages of using a relational database are elimination of duplicate data, ease of access to information and the data being easy to update. Next to these advantages the ease of use and intuitiveness of relational databases are convenient characteristics.

The relational database model is based on the concept that every row in a dataset should be unique. This means that there must be a single column which uniquely identifies each and every row in the dataset. This column is referred to as the *primary key*. A *foreign key* is a column which is used to match values between separate datasets and is not the primary key of that dataset.[Browning et al. [1999]]

Now looking at Figure 4.3, in essence the structure of the data warehouse in Figure 4.2 is copied, only this time including a complete representation of the datasets contained in dashboard database and all relationships between the datasets. The datasets in dashboard database are Ship, Time, Weather, PrimeDim, NormDim, NoonDim, ShipType, Constants and Coefficients. The data sources described in the data requirements analysis of section 3.3 (sensors database, messages database and MeteoGroup weather) are shown here as Sensors database Spliethoff, Messages database Spliethoff and Weather database MeteoGroup.

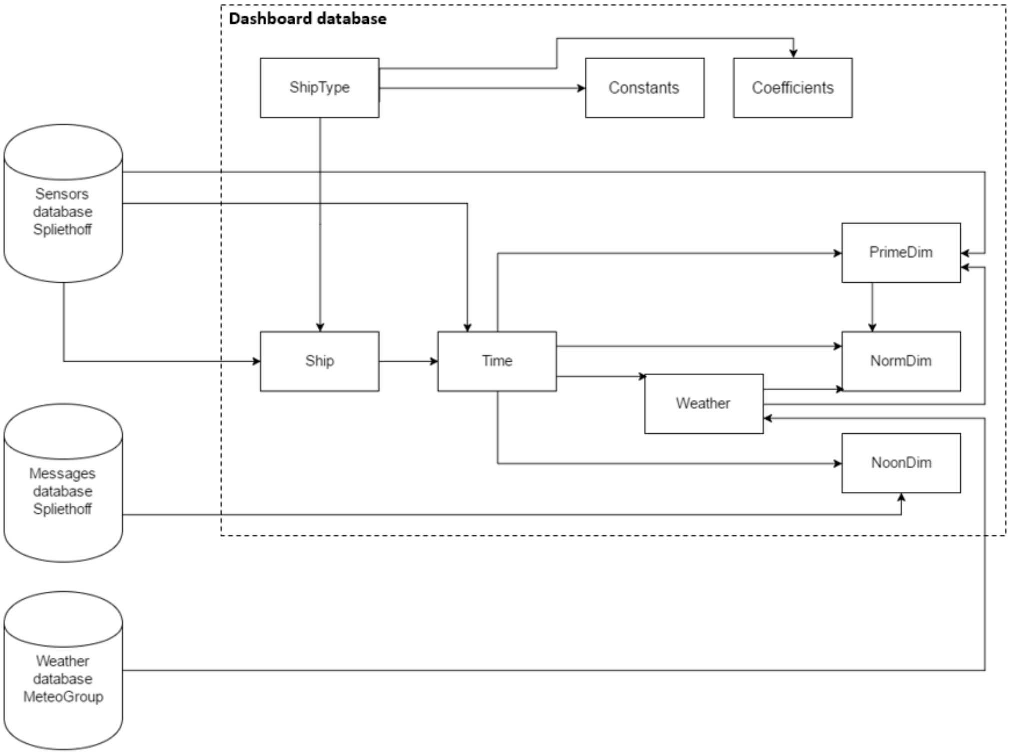


Figure 4.3: Dashboard Database Datasets and Data Sources

The entity/relationship diagram (ERD) of Dashboard database can be found in Figure 4.4 showing the datasets contained in the database, the relationships between respective datasets and the dataset columns. Starting with the left-most dataset, Ship, it is built up of three columns, ShipID, Shipname and IMONumber. The column ShipID contains unique identifiers for every single entry in column Shipname and IMONumber in the database and therefore is the primary key. This unique identifier is generated automatically by Microsoft SQL and is used so every row in the dataset has a unique ID. The third column IMONumber contains the IMO number of the vessel.

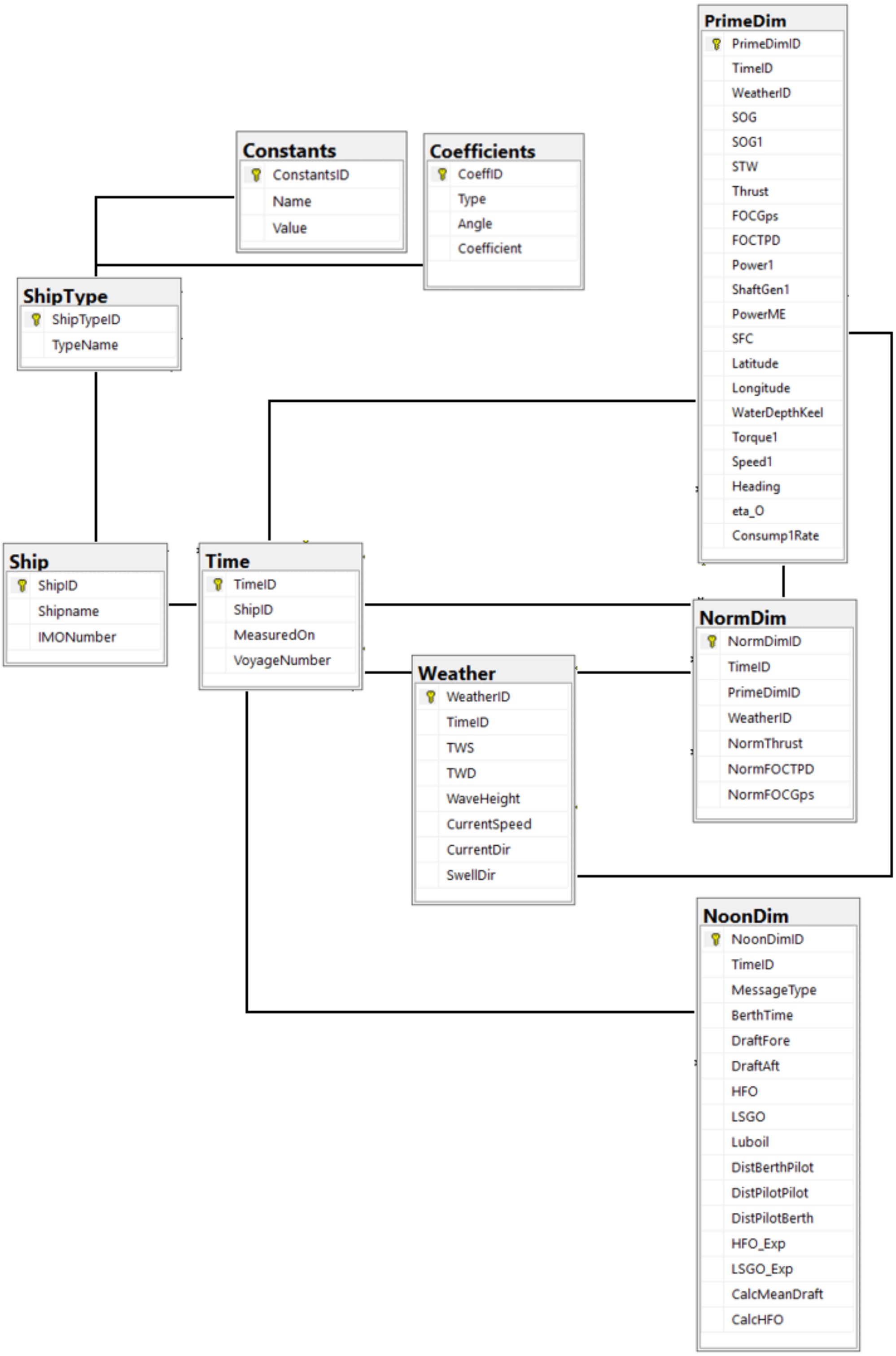


Figure 4.4: Entity/Relationship Diagram of Dashboard Database

Time, the second dataset from the left is connected to Ship by foreign key ShipID. The other columns are TimeID and MeasuredOn. Again, TimeID is filled with unique identifiers, making this the primary key. A TimeID is generated for every new entry in column MeasuredOn per ShipID. Column MeasuredOn contains the date and time of a single logged datapoint.

Weather holds selected weather data provided by MeteoGroup. The primary key is WeatherID and the foreign key is TimeID. In column TWS the true wind speed is stored.

Column TWD holds the true wind direction, column WaveHeight contains the significant wave height, column CurrentSpeed holds the current rate, CurrentDir stores the current direction and SwellDir contains the wave direction.

Constants table stores ship-specific values such as beam, block coefficient, length on waterline, etc. ConstantsID is the primary key, there is no foreign key. The Name column contains the name of a certain parameter e.g. "Beam" and the Value column holds the value of that certain parameter e.g. "25".

Coefficients table is used to store coefficients related to certain angles, like apparent wind angle. Column Type contains the type of angle, for instance Wind. Column Angle than holds the angle, with Coefficient column storing the coefficient related to that particular angle.

The table ShipType contains the different Spliethoff ship types such as D-Type, F-Type, S-Type, etc. This table is necessary to differentiate between the constants and coefficients of different ship types.

Datasets PrimeDim, NormDim and NoonDim contain the *dimensions* used in the dashboards. In data warehousing, a dimension is a collection of reference data about a measurable event [Rouse [2017]]. For instance, the calculated fuel consumption at a certain moment is called a dimension in BI.

Starting with PrimeDim, the primary dimensions are stored in this dataset. PrimeDimID is the primary key. TimeID and WeatherID in this case are both foreign keys, connecting PrimeDim respectively to the Time dataset and Weather dataset. Column SOG holds the speed over ground in knots, SOG1 is speed over ground in m/s and VTG52 is speed through water. Column thrust contains calculated thrust values. FOCGps is the fuel consumption in kg/nm. FOCTPD is the calculated fuel consumption in MT/day. Column ShaftGen1 stores the value for shaft generator output in kW. PowerME is the calculated power of the main engine. Column SFC contains values for the calculated specific fuel consumption in g/kWh. Columns Latitude and Longitude store position data of the ships. WaterDepthKeel contains water depth data from the depth sounder measured from the keel. Torque1 and Speed1 hold propeller shaft torque and rotational speed data. Heading stores true heading data and eta_O is the open water efficiency of the propeller. Finally, Consump1Rate is the fuel consumption of the main engine in kg/h.

Now, NormDim contains normalised dimensions for the influence of waves, wind, water depth and current. NormDimID is the primary key, TimeID, PrimeDimID and WeatherID are foreign keys connecting NormDim to respectively Time, PrimeDim and Weather. Column NormThrust holds calculated corrected thrust data. Column NormFOCTPD stores corrected fuel consumption in MT/day. Similarly, NormFOCGps stores corrected fuel consumption in kg/nm.

In the last dataset, NoonDim, dimensions are stored taken from the Messages database. NoonDimID is the primary key, with TimeID the foreign key connecting NoonDim to Time. Columns MessageTime and MessageType specify the input time of a message and whether its a departure, noon or arrival message. BerthTime actually registers the time a ship arrives to the berth, or departs from the berth (depending on whether its an arrival or departure message). DraftFore and DraftAft columns contain draught data from respectively the bow and stern of the ship and are used to calculate the mean draught of the vessel. Columns HFO, LSGO and Luboil hold data on the amount of Heavy Fuel Oil, Low-Sulphur Marine Gas Oil and Lube oil onboard. This bunker data can be used to calculate the amount of fuel used over a voyage. Columns DistBerthPilot, DistPilotPilot and DistPilotBerth all contain distance data. DistBerthPilot gives the distance from berth to pilot station in port of departure, DistPilotPilot gives distance from departure port pilot station to arrival port pilot station and DistPilotBerth holds the distance from arrival port pilot station to berth. HFO_Exp and LSGO_Exp contain the expected bunker consumption for a voyage, given in the departure message. CalcMeanDraft is the mean draught of the vessel calculated from DraftFore and DraftAft. CalcHFO is the calculated bunker consumption of a voyage.

When evaluating the quality of the data warehouse, a number of elements stand out. For instance, the previous main server in Haarlem occasionally had performance issues. Consequently, the decision was made to move all databases from this server to a much more stable cloud-based solution (Microsoft Azure) in the near future. The databases themselves are designed to be stable and should perform adequately, as long as they are run on a reliable server. The quality of the ETL processes described in the next section is completely dependent on the manner in which they have been programmed. As the ETL processes have been programmed under the supervision of a highly experienced IT-specialist, one can assume no principal mistakes have been made here.

4.2.3 Extract, Transform, Load Processes

The ETL processes executed in the data warehouse are explained next. As mentioned before, the ETL processes are necessary to enable automatic filling of dashboard database with data. To recapitulate, in the ETL processes raw data is extracted from either sensors database, messages database or MeteoGroup's weather database. This raw data then is transformed in a certain way, after which it is loaded into the dashboard database as good data. In short, in the ETL processes data preparation and data blending is performed. Four ETL processes had to be programmed to fill dashboard database, each process dedicated to filling a specific dataset.

The ETL processes have been programmed using a special ETL tool, Djuggler. Djuggler was designed specifically to connect to data sources (data warehouses, cloud applications, spreadsheets), prepare and blend data and write the output to a new location.

The calculations presented in the ETL processes are applied to instantaneous individually measured values.

ETL Process 1

In the first ETL process, the goal is to fill Weather dataset with weather data provided by MeteoGroup. MeteoGroup provides their weather data through an email service (API). The output of the API contains all necessary data (true wind speed, true wind direction, significant wave height, current rate, current direction and wave direction), but also contains a lot of superfluous data. In this ETL, the critical step is to select the necessary data and disregard other data. After selecting the right data, it is loaded directly in the Weather dataset of dashboard database.

This ETL is also used to fill the Time dataset. In the ETL the actual date and time a datapoint was measured on is converted to a time-unit that is uniform across the entire database (hence all datasets being connected to the Time dataset). This is necessary because although there is a uniform datalogging frequency (every five minutes), this does not mean the exact time a sensor is measured on is identical. Lets say one wants to compare main engine power to speed. It could be that main engine power is logged on 15:11:23, 15:16:23, 15:21:23, etc. and speed is logged 15:10:36, 15:15:36, 15:20:36, etc. Comparing these values datapoint for datapoint will then give problems.

To resolve this problem, a definition has been chosen which is uniformly applied over the entire database. In practice, the definition states that time will always be rounded down to the fifth minute. This means that for example 15:01, 15:02, 15:03 and 15:04 will all be transformed into 15:00. Likewise, 15:06, 15:07, 15:08 and 15:09 will be transformed into 15:05 and so on. Now, when someone wants to generate reports in the BI tool, all information is presented in the same "time-segments" with five minute intervals starting on the whole hour.

ETL Process 2
The goal of this ETL process is to fill PrimeDim dataset with data taken from Sensors database. Some values are taken from Sensors database and written directly to the PrimeDim dataset without any transformations (SOG in knots, shaft power, shaft generator power, water depth, shaft torque, shaft rotational speed, heading). The other values are calculated using combined data from Sensors database and/or the Weather dataset (STW, fuel consumption in kg/nm, thrust, fuel consumption in MT/day, main engine power, SFC, latitude, longitude, open water efficiency). Following next are the exact calculations of named values as programmed in the ETL process. In brackets the name of the corresponding dimension in dashboard database.

Speed over ground in m/s (SOG1)
Speed over ground (SOG) is measured at the ship in knots. For further calculations, a conversion from knots to m/s is necessary. To convert from knots to m/s a multiplication factor of 0.5144 is used.

$$SOG_{m/s} = SOG_{kn} * 0.5144 \tag{4.1}$$

Speed through water in m/s (STW)
In data samples, STW measurements from the speedlog were found to be very unreliable, at times showing more than three knots difference from SOG, at a position without any current. Captains have also indicated that sometimes speedlog measurements can show significant faults. Therefore the decision was made to use SOG as the base-value, from which STW would have to be derived.

If one looks at Figure 4.5, the vessel is moving forward at speed SOG. The direction of current relative to the bow is denoted by α (maximum 180 degrees). V_c is the current rate. Now, the vector component denoted by V_c^{eff} has to be found, as this component works in the opposite direction of the vessel's speed vector, thus affecting STW. As α and V_c are known, one can find V_c^{eff} with the following equation:

$$V_c^{eff} = cos(\alpha) * V_c \tag{4.2}$$

Important to note is that V_c^{eff} is negative for $\alpha > 90°$, as $cos(\alpha)$ is negative when $\alpha > 90°$. To find STW, the following formula has to be applied:

$$STW = SOG + V_c^{eff} \tag{4.3}$$

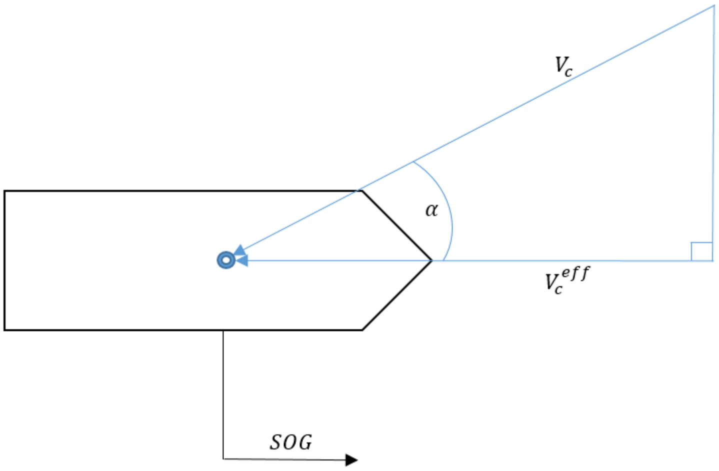


Figure 4.5: Vector Decomposition of Current Speed

Thrust (Thrust)
Thrust can not be measured on the ships (no sensor), so it is calculated. Power is measured on the aft part of the ship's shaft. This means that gearbox efficiency does not have to be taken into account when calculating thrust. Actually, one can assume that shaft power P_S is measured. From P_S it is two calculation steps to effective power P_E and thrust T. To find P_E, four efficiencies are required, namely hull efficiency η_H, open water efficiency η_O, shaft efficiency η_S and relative rotative efficiency η_R. Hull efficiency and relative rotative efficiency are taken from model tests (sea trial prediction) of an S-Type for the entire speed range (0-20 knots). However, as the vessels are equipped with a Controllable Pitch Propeller (CPP), open water efficiency varies depending on pitch. Unfortunately, a pitch sensor also is unavailable on the vessels, so open water efficiency is modelled by combining the open water diagram of a Wageningen B-4 60 controllable pitch propeller (four blades; disc area ratio 0.6) with the propulsion test results. The B-4 60 propeller was chosen because an S-Type propeller also has four blades and a disc area ratio of nearly 0.6. Shaft bearing losses are estimated at 0.5%, giving a shaft efficiency of 0.995 [Klein-Woud and Stapersma [2002]].

To find the open water efficiency, first torque coefficient KQ is calculated. To do this, torque τ, shaft rotational speed ω, seawater density ρ_{water} and propeller diameter D_p are needed. After calculation of KQ the corresponding η_O can be found in the propeller model. KQ is calculated with [Klein-Woud and Stapersma [2002]]:

$$KQ = \frac{\tau}{\rho_{water} * \omega^2 * D_p^5} \tag{4.4}$$

Depending on speed through water, η_H and η_R are selected. For η_S 0.995 is taken. The formula for effective power is [Klein-Woud and Stapersma [2002]]:

$$P_E = P_S * \eta_H * \eta_O * \eta_R * \eta_S \tag{4.5}$$

Thrust can then be found using [Klein-Woud and Stapersma [2002]]:

$$T = \frac{P_E}{V_s} * \frac{1}{1-t} \tag{4.6}$$

With speed through water V_s and thrust deduction factor t. The thrust deduction factor, like η_H and η_R is taken from model tests and is selected according to the ship's speed through water.

Fuel consumption in MT/day (FOCTPD)
On the ship, flowmeters measure fuel consumption in kg/h. There is no return duct, so the true consumption of the engine is measured. As fuel consumption in the office is usually referred to in MT/day, a conversion must take place to change the unit of individually measured values. Multiplying the measured value by 24 hours yields the fuel consumption in kg/day. Dividing this number by 1000 gives fuel consumption in the unit of MT/day.

$$FOC_{MT/day} = \frac{FOC_{kg/h} * 24}{1000} \tag{4.7}$$

Fuel consumption in kg/nm (FOCGps)
From SOG and fuel consumption of the main engine in kg/h, the fuel consumption in kg/nm can be calculated.

$$FOC_{kg/nm} = \frac{FOC_{kg/h}}{SOG_{kn}} \tag{4.8}$$

Main engine power (PowerME)
As described before, power is measured on the propeller shaft right before it goes out of the hull, giving shaft power P_S. So, some steps have to be taken to find the actual power output of the main engine. Figure 4.6 shows the lay-out of the engine room, indicating the torque sensor location (1), the main engine (2), gearbox (3) and shaft generator (4). Calculation of the main engine power output requires that gearbox efficiency and shaft generator output are taken into account. As the gearbox on a Spliethoff S-Types is a relatively simple one-step reduction gearbox in a medium speed diesel engine installation, gearbox efficiency may be assumed at 0.99 [Klein-Woud and Stapersma [2002]].

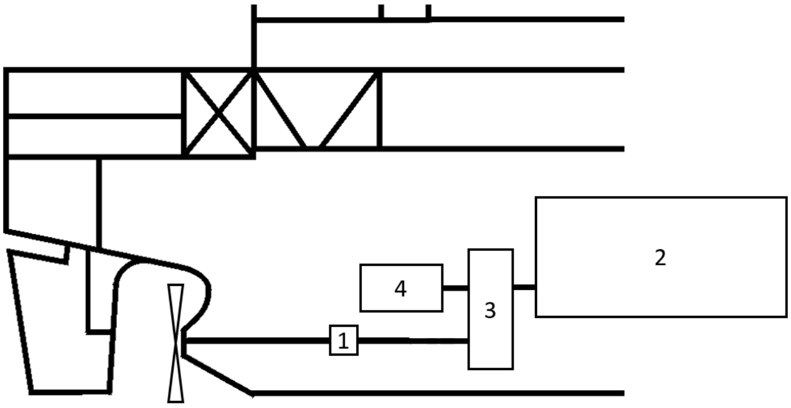


Figure 4.6: Engine Room Layout of Spliethoff S-Type

The shaft generator works from the Power Take-Off (PTO) of the main engine, in essence using a part of the main engine's power output to generate electrical power. Output of the shaft generator can be measured and has to be added to P_S to calculate main engine power P_B.

$$P_B = \frac{P_S}{\eta_{GB}} + P_{shaftgen} \tag{4.9}$$

Specific Fuel Consumption (SFC)
Specific Fuel Consumption of the main engine can be calculated using the power of the main engine and fuel consumption of the main engine in kg/h. There is however one more factor that needs to be taken into account, namely calorific value of the fuel. When the calorific value of the fuel changes this has a direct effect on SFC of the main engine, a higher calorific value yielding lower SFC and vice versa. By calculating to a calorific "base" value, this effect can be factored out.

$$SFC = \frac{Calorific_{measured}}{Calorific_{base}} * \frac{FOC_{kg/h} * 1000}{P_B} \tag{4.10}$$

ETL Process 3
The goal of the third ETL process is to fill the NormDim dataset with data. To fill NormDim with data, PrimeDim and Weather should already contain data, as NormDim requires data from both datasets for its columns. Three dimensions are taken from PrimeDim (thrust, fuel consumption in MT/day, fuel consumption in kg/nm) and corrected for the influence of wind, waves and shallow water. A complete description of the correction methods is given in section 4.3. The calculations as performed in the ETL process are explained next. Again, the name of the corresponding dimension in dashboard database is given in brackets.

Corrected thrust (NormThrust)
Thrust has to be corrected for shallow water, wind load and added resistance due to waves. First the correction for shallow water effects is made, using [Lackenby [1963]].

$$\frac{\delta V_s}{V_s} = 0.1242(\frac{A_m}{h^2} - 0.05) + 1 - \sqrt{(tanh(\frac{gh}{V_s^2}))} \tag{4.11}$$

With speed through water V_s, midship section area A_m, water depth h and gravitational constant g.

The ship's total thrust T is proportional to the cube of the ship's speed, so using the factor $\frac{\delta V_s}{V_s}$, a correction for shallow water can be made [Klein-Woud and Stapersma [2002]].

$$T_{factored} = \frac{T}{(\frac{\delta V_s}{V_s} + 1)^3} \tag{4.12}$$

The correction for wind load resistance increase R_{AA} is made using a method presented in [ITTC [2014]]. The formula is:

$$R_{AA} = \frac{1}{2} * \rho_{air} * V_{WR}^2 * C_X(\psi_{WR}) * A_{XV} \tag{4.13}$$

With air density ρ_{air}, relative wind speed V_{WR}, wind resistance coefficient C_X, relative wind direction ψ_{WR} and area of maximum transverse section exposed to wind A_{XV}. Relative wind speed is calculated using the following formula.

$$V_{WR} = \sqrt{V_{WT}^2 + V_s + 2 * V_{WT} * V_s * cos(TWA)} \tag{4.14}$$

With true wind speed V_{WT}, speed trough water V_s and true wind angle TWA. Wind resistance coefficient C_X is taken from the Figure 4.7, depending on the wind direction relative to the ship's bow (0 degrees representing wind straight on the bow).

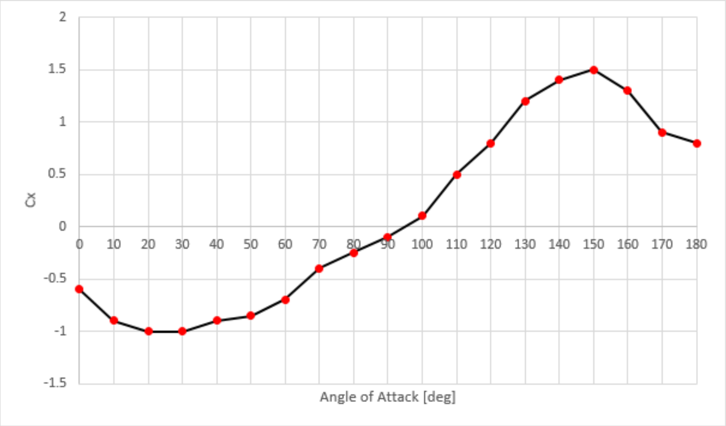


Figure 4.7: Wind Resistance Coefficients for a General Cargo Ship [ITTC [2014]]

Last, a correction has to be made for added resistance due to waves. One of the most recent methods developed at MARIN, STAwave-1 is used here for this correction [ITTC [2014]]. The STAwave-1 formula is presented next.

$$R_{AWL} = \frac{1}{16} * \rho_{water} * g * H^2_{w1/3} * B * \sqrt{\frac{B}{L_{BWL}}} \tag{4.15}$$

With seawater density rho_{water}, gravitational constant g, significant wave height $H_{W1/3}$, beam B and length of the bow on the water line to 95% of maximum beam L_{BWL}.

After the thrust is factored for shallow water effects, the wind load (R_{AA}) and added resistance due to waves (R_{AWL}) can be deducted, yielding corrected thrust.

$$T_{corr} = T_{factored} - R_{AA} - R_{AWL} \tag{4.16}$$

Corrected fuel consumption in MT/day (NormFOCTPD)

To find corrected fuel consumption in MT/day a coefficient can be used, derived from the thrust calculation. By dividing the corrected thrust with thrust uncorrected for wind, waves and shallow water a value between zero and one is found. This coefficient is denoted as C_{thrust} in the following formula.

$$C_{thrust} = \frac{T_{corr}}{T} \tag{4.17}$$

Corrected fuel consumption in MT/day now is calculated with the next formula.

$$FOC^{corr}_{MT/day} = C_{thrust} * FOC_{MT/day} \tag{4.18}$$

Corrected fuel consumption in kg/nm (NormFOCGps)

Fuel consumption in kg/h can be corrected in exactly the same manner.

$$FOC^{corr}_{kg/h} = C_{thrust} * FOC_{kg/h} \tag{4.19}$$

ETL Process 4

The purpose of the fourth ETL process is to fill the NoonDim dataset. In this ETL process the mean draught of the vessel and the bunker consumption of a voyage are calculated. Starting with mean draught:

$$T_{mean} = \frac{T_{fore} + T_{aft}}{2} \tag{4.20}$$

Voyage bunker consumption is calculated using bunker mass onboard at departure and at arrival (in metric tonnes).

$$m_{voyage} = m_{departure} - m_{arrival} \tag{4.21}$$

Besides these calculations, in this ETL process other information from the messages database is taken such as arrival/departure time berth, distance berth-pilot, distance pilot-pilot and expected bunker consumptions.

4.2.4 Dashboard

The final component of the SPM System IT infrastructure is the dashboard. In this project, *Tableau* is used as dashboard (or report tool) mainly because it has very advanced data analysis features and offers a cost efficient solution. Created reports can be shared with end-users via a web application, which can be accessed on any device (desktop, mobile phone, tablet).

Together with Qlik and Microsoft Power BI, Tableau is seen as a market leader in the field of BI tools [Parenteau et al. [2016]]. Their software has been developed specifically to visualise data and is used throughout industries. Connecting to a data source, filtering data and creating visualisations (KPIs) are all built-in features of Tableau.

In Appendix B, prototypes of the developed dashboards can be found.

4.3 Correction Methods

In this section calculation methods are given used in ETL process 3 to correct for the resistance increase due to environmental conditions. Correction methods are presented for added resistance due to waves, wind load and shallow water effects. The correction methodology used in the ETL is illustrated in Figure 4.8. The corrected value represents the theoretical "baseline" calm water performance of the vessel. By calculating to a baseline performance, vessels can be compared. In essence, the intended purpose of the correction model is to normalise all data to calm water performance data.

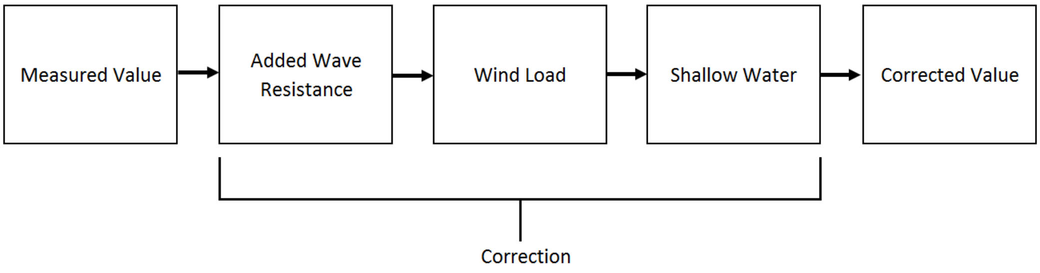


Figure 4.8: Calculation of Corrected Thrust

4.3.1 Wind Load

For the calculation of wind resistance a number of theoretical methods exist. The two most well known methods, [Isherwood [1973]] and [Blendermann [1996]] have been compared in [Nabergoj and Prpic-Orsic [2007]], showing large discrepancies between both methods.

Although [Arribas [2007]] and [Journee and Massie [2001]] also use [Isherwood [1973]], there are issues with this method. Mainly, since its development over 40 years ago, no new ship forms have been added to the database [Nabergoj and Prpic-Orsic [2007]].

A more recent method is proposed, presented in [ITTC [2014]]. This paper is the product of MARIN's Sea Trial Analysis - Joint Industry Project (STA-JIP). The main formula is:

$$R_{AA} = \frac{1}{2} * \rho_{air} * V_{WR}^2 * C_X(\psi_{WR}) * A_{XV} \tag{4.22}$$

With air density ρ_{air}, relative wind speed V_{WR}, wind resistance coefficient C_X, relative wind direction ψ_{WR} and area of maximum transverse section exposed to wind A_{XV}. Deck cargo is not accounted for in this formula, so a conservative approach is taken by using the maximum transverse area of the ship exposed to wind.

4.3.2 Wave Added Resistance

For the calculation of added resistance due to waves, a lot of prediction methods have been developed since the 1950's. An extensive explanation of all the methods will not be given, only the most prominent methods will be dealt with. One of the first methods is by [Havelock [1942]], who demonstrated that the additional resistance arises due to the phase difference between the ship motion for heaving and pitching and excitation of the waves [Zakaria and Baree [2007]]. This is a quite crude method that is not based on cross coupling of heave and pitch [Wilson [1985]], therefore Havelock considered his formulation only an approximation to the real problem [Arribas [2007]]. [Nabergoj and Prpic-Orsic [2007]] also consider Havelock a first-order approximation that is not accurate enough.

The first "modern" approach was introduced by [Maruo [1957]] (potential flow solution) and further elaborated in the years after by [Maruo [1960]], [Maruo [1963]] and [Joosen [1966]] (strip method). After Maruo, the next widely tested method is by [Gerritsma and Beukelman [1972]](radiated energy method), following a similar approach to Maruo, now simplified [Liu et al. [2011]][Zakaria and Baree [2007]].

From the research of [Zakaria and Baree [2007]] it follows that Maruo and Gerritsma-Beukelman yield reasonable results, especially in the range of wave length to ship length ratio from 0.8 - 1.5 approximately for fine and medium ship shapes. For a wave length to ship length ratio greater than 1.25, Joosen actually gives better results. For small wavelengths all three methods fail to predict added resistance accurately. A different viewpoint is given by [Arribas [2007]], saying that Gerritsma-Beukelman actually provides the best results since it predicts short-wave added resistance better. [Nabergoj and Prpic-Orsic [2007]] add to this that from Havelock, Maruo and Gerritsma-Beukelman, the latter provides a prediction technique equally accurate for all ship forms, except cruiser-stern ships with low block coefficients. [Boese [1970]] (integrated pressure method) also developed a theory, expanding on Havelock, however [Arribas [2007]] found that Boese sometimes overestimates the resistance peak value especially for high Froude numbers. This overestimation is also found by [Strom-Tejsen et al. [1973]] for Gerritsma-Beukelman compared to experimental results. It is summarised best by [Matulja et al. [2011]] who say that Havelock, Maruo, Joosen, Boese and Gerritsma-Beukelman have all been evaluated and none seem to predict the added resistance accurately over a wide range of ships forms and speeds.

Two methods that have been developed for all ship types at any speed and any heading are by [Faltinsen et al. [1980]] and [Salvesen [1978]]. Both methods are based on [Salvesen et al. [1970]] linear strip theory [Matulja et al. [2011]]. Faltinsen is a direct pressure integration method and Salvesen is a potential flow solution. [Matulja et al. [2011]] make a comparison of these two methods and conclude by saying that Faltinsen seems to agree better with the known experimental results and that the Salvesen method is unreliable for smaller wave lengths. [Seo et al. [2012]] and [Liu et al. [2011]] concur with this statement. However, a problem with Faltinsen is again the fact that it is very labour intensive and time consuming to implement this method, since a lot of variables have to be adapted regarding draught and weather conditions. Consequently, again a newer method is proposed by [ITTC [2014]], also developed in STA-JIP at MARIN, namely STAwave-1. The formula for STAwave-1 is:

$$R_{AWL} = \frac{1}{16} * \rho_{water} * g * H_{w1/3}^2 * B * \sqrt{\frac{B}{L_{BWL}}} \tag{4.23}$$

With seawater density rho_{water}, gravitational constant g, significant wave height $H_{W1/3}$, beam B and length of the bow on the water line to 95% of maximum beam L_{BWL}. This method however also has its restrictions, as STAwave-1 has only been validated for limited conditions. According to [ITTC [2014]], STAwave-1 yields accurate results when:

1. Wave direction relative to the bow is less than 45 degrees;
2. Significant wave height is smaller than $2.25\sqrt{L_{pp}/100}$ (2.85 metre for a Spliethoff S-Type);
3. Vertical accelerations are smaller than 0.05g.

A more recently developed method by MARIN, SPAWAVE, yields results for all relative wave directions, but is not openly available. [Grin [2015]] compared STAwave and SPAWAVE methods and concluded that both methods performed similarly for head waves. The added value of SPAWAVE therefore does not lie in higher accuracy, but in providing results for all wave directions.

4.3.3 Shallow Water Effects

In literature, a number of methods for the estimation of speed loss due to shallow water conditions were found. One of the first methods is by [Schlichting [1940]]. This method however is quite dated now, since it was developed on the basis of only three warship hull forms for slight shallow water effects [Rotteveel [2015]]. An adaptation on Schlichting by [Lackenby [1963]] is probably the most widely used method, but Lackenby only adapted the method on theoretical basis, meaning the method is still based on the old hull shapes. Consequently, results at MARIN pointed out that Lackenby's method gives a relatively high correction for the total resistance estimate [Rotteveel [2015]].

Another method by [Barrass [2004]] is more recent, but restricted since it only gives an estimate of speed loss reduction in depths up to $H/T = 3$, where H is the water depth and T is draught of the ship [Hasan [2013]].

The most recent method by [Raven [2016]] is an adaptation to Lackenby and shows results in better agreement with the measured shallow-water effects. However, this method has not been accepted by ITTC yet and has not been subjected to extensive testing and validation.

Therefore, for this project Lackenby will be used as it is also used in [ITTC [2014]]. The formula for speed loss in shallow water compared to the speed in deep water is:

$$\frac{\delta V_s}{V_s} = 0.1242(\frac{A_m}{h^2} - 0.05) + 1 - \sqrt{(tanh(\frac{gh}{V_s^2}))} \tag{4.24}$$

With V_s speed through water, A_m midship section area, h water depth and g gravitational constant.

4.4 Cost Structure

The cost structure of an SPM System is often an unknown for ship owners. Certain investments have to be made for the acquisition of hardware. However, the exact cost can be quite hard to specify in advance, especially since requirements are likely to change over the duration of the project. In this section an overview is given of the cost structure for the SPM System developed in-house at Spliethoff. A cost comparison is made with a typical off-the-shelf SPM System.

Manufacturer	**Component**	**Initial Cost**	**Annual Cost**
VAF	T-Sense Shaft Power Torque Meter + Propulsion Efficiency Monitor	€14,550.00	approx. €300
VAF	Flowmeter main engine	€1,550.00	approx. €30
VAF	Flowmeter generators	€1,550.00	approx. €30
VAF	Flowmeter boilers	€1,550.00	approx. €30
Wizzo	Datalogger	€4,260.00	approx. €40
Wizzo	Software package	€340.00	
	Server on ship	€6,000.00	
	VSAT synchronisation		€1,000.00
	Server on shore		€10.00
Tableau	Dashboard		€70.00
MeteoGroup	Weatherdata API		€200.00
		€29,800.00	**€1,710.00**

Table 4.1: Cost Structure of SPM System for one Vessel (2016)

In Table 4.1, the initial and annual costs are given of the SPM System for a single vessel (excluding installation costs). The costs are calculated assuming that the entire fleet of Spliethoff is equipped (50 vessels). The components listed in the table are all essential to the SPM System, so this represents the absolute minimum on required hardware. Electrical energy costs have not been included in the cost table, since no useful data on this part is available and estimations are therefore likely to be very inaccurate.

Clearly, a substantial initial investment of nearly €30,000.00 is required. After the first investment annual cost is relatively low at around €1,700.00. Nearly half of the initial investment is the torque sensor (propulsion efficiency monitor included); this component is highly critical to the system as accurate shaft torque and shaft speed measurements are essential. Flowmeters are installed to measure fuel consumption of various consumers. Synchronisation over VSAT is the main annual cost component. VSAT cost is dependent on the amount of data sent (€0.20 per MB), so the given number is approximated using historic information.

For the sensors the annual costs represent estimated maintenance costs. For the torque meter and the flowmeters, maintenance cost is assumed to be 2% of the initial cost as these sensors have some minor moving parts. For the Wizzo datalogger a lower percentage of 1% was taken as this component has no moving parts.[Idhammar [2017]]

Assuming a very conservative annual bunker consumption reduction of 1% thanks to the SPM System, an indication of the payback period can be calculated. Annual bunker costs of an S-Type amount to roughly €1,300,000.00 at 2016 prices. One percent of this number gives €13,000.00, indicating the annual savings thanks to the SPM System. $T_{payback} = \frac{29800}{13000} = 2.3$, so in this quick estimation, the SPM System has a payback period of just under two and a half years.

An off-the-shelf SPM software package usually costs in the region of €500.00 per ship per month. This amounts to total annual costs of €6,000.00 per ship. One has to understand that this doesn't include the hardware that needs to be installed on the ship, so the initial investment of about €30,000.00 still has to be made. In other words, in-house development of the SPM System at Spliethoff results in annual costs well over three times lower compared to buying an off-the-shelf system. Whether the third-party system yields better results (more fuel savings) cannot be determined beforehand.

4.5 Conclusions

Design of the IT infrastructure of the SPM System is an essential phase of the project, as considerations already have to be made for future developments. Re-designing the infrastructure can be very time-consuming and costly, so the right decisions have to be made at the start.

An architecture is used where all sensor data from the vessel is collected and logged via the Wizzo datalogger onboard the ship. This data is then stored in a server on the vessel, from which it is synchronised to the *Sensors database* located on Spliethoff's main database location. This database location also contains the *Messages database* and the new *Dashboard database.* The main database location including all databases is called the data warehouse. The weather database is located on an external location at MeteoGroup and is not part of the data warehouse.

To fill Dashboard database with data, four ETL processes are introduced, each filling a specific dataset in Dashboard database (datasets Weather, PrimeDim, NormDim and NoonDim). Some of these ETL processes are very simple (speed in knots converted to speed in m/s), other corrections are quite elaborate and use the correction formulae presented in section 4.3. Thanks to the ETLs, data preparation and data blending has been managed for the dashboard, so the dashboard can now directly connect to the Dashboard database. The calculation of thrust in ETL process 2 relies on a propeller model that simulates pitch settings. This part of the system could definitely be improved by installing thrust sensors on the vessels.

Correction methods for the extra resistance due to wind, waves and shallow water have all been taken from the most recent ITTC guidelines, as published in [ITTC [2014]]. The main limitation in these correction methods is the STAwave-1 method used for the correction of added resistance due to waves. STAwave-1 was only validated for waves in the bow sector (+/- 45 degrees), with a maximum wave height. Consequently, when waves are coming from other relative directions or when waves are above the maximum wave height a correction can not be made. For shallow water effects a correction is made using [Lackenby [1963]], despite being known to frequently overestimate somewhat. Although newer methods exist, none have been tested and validated as extensively as Lackenby's. The correction method for wind load does not take deck cargo into account, so a conservative approach is taken by always using the maximum transverse area exposed to wind.

The cost structure of the SPM System developed at Spliethoff has been investigated, giving a rough estimate for payback period of under two and a half years. Compared to an off-the-shelf SPM System the in-house developed system has over three times lower annual costs.

Part II

Data Analysis and Results

Chapter 5

Data Analysis of Spliethoff S-Types

5.1 Introduction

In this chapter operational data is analysed using the SPM System developed over the previous chapters. The main focus of the data analysis is to answer the research objectives of section 1.3. Recapitulating, the objectives are:

1. Determine the most fuel efficient speed of a Spliethoff S-Type.
2. Determine the actual fuel consumption of a Spliethoff S-Type for a given speed.
3. Determine the specific fuel consumption of the main engine to predict maintenance actions.
4. Determine the effect of hull- and propeller fouling on fuel consumption and speed.
5. Determine the influence of crew on ship's operation and on fuel consumption specifically.

The first two objectives aim at results for the S-Type vessel class, so to answer these goals data of all three vessels is combined in the analysis. The other three objectives are ship specific, so here the data of individual vessels is analysed and compared. In essence there are two approaches to ship performance data analysis, either data is corrected for the influence of waves, wind, shallow water and current, or one filters data for the variations caused by named environmental factors. In this data analysis both methods are used to answer the first and second objective. Hence, both filtered results and corrected results are presented. The corrected results have been attained using the correction model described in section 4.3. In short, in the correction model thrust is calculated after which the added resistance due to waves, wind and shallow water is deducted, giving the corrected thrust which represents the theoretical calm water "baseline" performance of the vessel.

The data analysis focuses on data of three Spliethoff S-Types mv Slotergracht, mv Singelgracht and mv Schippersgracht. All three vessels were built according to identical specification at the same yard, making them ideal subjects for performance comparison. The main particulars of the vessels can be found in Table 5.1; the general arrangement of mv Schippersgracht is included in Appendix C. S-Types have scrubbers installed, so they run on HFO all the time. In general, HFO 380 is used, which has a density of around 0.991 kg/m^3, kinematic viscosity of 380 mm^2/s and calorific value of about 40 MJ/kg.

Length (o.a.)	168.14 m
Length (p.p.)	159.14 m
Breadth (mld)	25.20 m
Depth (mld)	14.60 m
Draft (mld) (design)	10.00 m
Draft (mld) (summer)	10.71 m
Deadweight (at design draft)	18,946 MT
Deadweight (at summer draft)	21,402 MT
Gross Tonnage (international)	16,641 MT
Main Engine	Wärtsilä 6L64 MR 12,060 kW at 333 rpm

Table 5.1: Principal Particulars Spliethoff S-Type [MHI [2014]]

In the analyses of this chapter some specific trends are targeted. Starting with the first goal, the most fuel efficient speed ("eco-speed") of an S-Type must be found. It is assumed that when analysing fuel consumption of a ship, there is an optimal speed at which consumption in kg/nm is lowest. This assumption can be checked by taking a vessel's speed-consumption data and calculating the fuel consumption in kg/nm. In Table 5.2 the speed consumption data for a 6500 Car Equivalent Unit RoRo vessel is shown [Bialystocki and Konovessis [2016]]. The last column contains the fuel consumption in kg/nm, calculated with the formula:

$$FOC_{kg/nm} = \frac{FOC_{MT/day} * \frac{1000}{24}}{STW_{kn}}$$

The most fuel efficient speed for this vessel is 12.5 knots. For the S-Type vessels a similar analysis will be performed.

To illustrate when this speed could be implemented a real-world example is taken. Normally when a vessel is loaded, it has a certain ETA for the next port of destination to deliver the cargo, meaning a certain average speed has to be sailed at. From historical data of S-Types it is known that this speed often is 16-18 knots. However, in some cases the ETA gives sufficient leeway to implement a lower speed. It is at this point that "eco-speed" should be applied, as this will give the lowest bunker consumption for that voyage, pushing voyage result (TCE) up. For instance, this scenario can occur when the vessel has no new cargo yet.

Speed [kts]	FOC [MT/day]	FOC [kg/nm]
10	20	83
12.5	24	**80**
15	35	97
17.5	45	107
20	64	133

Table 5.2: 6500 Car Equivalent Unit RoRo Vessel Consumption Data

The second objective asks for speed-consumption information as shown in Table 5.2. To find this information, trend lines of a speed-consumption plot are analysed. An exponential trend should be visible here, as ship resistance increases exponentially with speed, with that also increasing power demand and fuel consumption exponentially [Klein-Woud and Stapersma [2002]][Dallinga et al. [2008]].

In the third objective, measuring the main engine's SFC is the primary goal. Three elements can be investigated; first of all, comparing current main engine performance against manufacturer specification can give insight into the condition of the main engine. From Wärstilä's specification it is known that for increasing power outputs, SFC shows a linear decreasing trend up to 85% engine load [Wärtsilä [1997]]. Secondly, plotting SFC over time may show a loss of efficiency due to deterioration of parts or engine wear. Here, again a trend line should give the answer. Finally, measuring the effect of fuel saving measures such as fuel additives can confirm or refute statements made by the manufacturer on fuel saving percentages.

For the fourth objective, hull- and propeller fouling is measured. As the ship is in operation, slime, weeds and barnacles grow on the vessel's hull and propeller, increasing ship resistance, therefore increasing the ship's power and thrust needed to sail at a certain speed. This resistance increase should become visible in a graph through an inclining trend line, if plotted over a long-enough period at a speed and draught range. The severity of fouling increase is dependent on a number of factors. Primarily the state of anti-fouling paint, the operational profile (vessel stationary or not) and seawater temperature are of big influence [Townsin et al. [1981]].

From data analysis, [Krapp [2011]] found 11 % per year power increase due to fouling for a reference speed. [Townsin et al. [1981]] on the other hand conducted data analysis with a measured power increase of 2-4% over 12 months for a reference speed. In [Hydrex [2010]] a power increase of 5% for a reference speed is mentioned. Combining these results, one can state that a 5% increase in power demands is more likely than 10% per year. Again, this strongly depends on the vessel's operational profile and state of anti-fouling paint.

On a typical Baltic to USA voyage of an S-Type, roughly 450 MT of HFO is consumed giving $135,000.00 voyage bunker costs ($300 per MT HFO 19-5-2017) [Bunker [2017]]. A fuel consumption increase of 5% per year will mean bunker costs have risen by around $6,750.00 for the same voyage a year later. According to Spliethoff's technical department, the costs for hull and propeller cleaning by divers (so not in dry-dock) are roughly $10,000.00 for an average size Spliethoff vessel. If a ship resistance increase of this magnitude would be measured, one can conclude that cleaning the hull more frequently than just at the special survey (twice every five years in dry-dock) would save significant costs, given an S-Type makes about 10 of these voyages in a year. In less than two voyages the hull cleaning costs would have been payed back already.

In the following sections, first the combined results are presented (both filtered and corrected). Here, the two first objectives are investigated. The last three objectives are ship specific, so individual ship results will be discussed of mv Slotergracht, mv Schippersgracht and mv Singelgracht in that order.

The data analysis is performed using Tableau Desktop, a business intelligence software tool. Tableau is used because it has quite advanced features with regards to scatter plots, line plots and trend lines, primary elements in the analysis (see chapter 4).

5.2 Combined Results

As described in the introduction, in this section the focus is on finding the most fuel efficient speed of the S-Type vessels and finding speed-consumption information. Both laden condition and unladen condition will be investigated. Unladen condition is defined as mean draught below 7.50 metre and laden condition is defined as mean draught above 9.5 metre. A 10 minute moving average (average of two consecutive instantaneous data points) is maintained in the combined results plots to reduce scatter. Also, as the weather data is provided in five minute average data points, this solution blends data of similar quality. Otherwise, instantaneously measured data points of the vessel would be combined with average weather data, introducing inconsistencies (instant versus average).

5.2.1 Filtered Results

To find the most fuel efficient speed, first the fuel consumption in MT/day over the entire speed range has to be established. Afterwards, the calculation method explained in the introduction (section 5.1) can be used to find the most fuel efficient speed. In the following graphs, filters have been applied so that only data up to a moderate sea state (wind speed 15 knots and wave height 2 metre) is displayed [WOCE [2002]]. This also reduces scatter and gives a representation closer to calm water conditions, without diminishing the dataset size too much.

As mentioned in the introduction, ship resistance increases exponentially with speed, hereby exponentially increasing power demand. This trend is displayed in Figure 5.1, where propeller shaft power is plotted against speed through water (STW). STW is calculated from speed over ground (SOG) using current data (see subsection 4.2.3 for calculation method) and shaft power is measured. Orange indicates the unladen condition and blue the laden condition. The red and green line respectively represent the laden model test curve and the unladen model test curve (model tests only provide data for the small speed range displayed).

As one can see, there is a split between the laden and unladen trend lines, meaning power demand to sail at a certain speed is higher in laden condition than in unladen condition. This is correct as in laden condition the vessel's displacement is much higher. For speeds below 10 knots the power difference between laden and unladen condition is marginal. A possible explanation is the strong decrease in hull and propeller efficiency in unladen condition. When sailing in unladen condition, the bulbous bow is no longer submerged, decreasing hull efficiency. The vessel is also trimmed quite strongly aft to submerge the propeller (forward draught 5,80 m; aft draught 7,40 m). This aft trim puts the propeller under an angle and changes inflow (oblique inflow to propeller) introducing negative effects such as increased cavitation and thrust fluctuations [Stapersma et al. [2000]]. Another possible explanation is the relatively small reduction in wet surface area when reducing draught from 10 metre (laden) to around 7 metre (unladen). According to [Holtrop and Mennen [1982]], viscous resistance reduces by only 10 % from laden to unladen condition for an S-Type sailing eight knots.

Compared to the model test curves, the trend lines lie at a higher level. This can be explained by the fact that the model test curves are measured in true calm water conditions and the measured data is not.

In Figure 5.2 fuel consumption in MT/day is plotted against STW (see subsection 4.2.3 for calculation method of fuel consumption). Again, the same filters have been applied for sea state, blue is laden data, orange is unladen data and red and green are the model test curves for laden and unladen condition. The exponential trend of the last graph is repeated here. With exponentially increasing ship resistance, power demand increases exponentially and fuel consumption increases exponentially. Now the fuel consumption data can be tabulated, after which the most fuel efficient speed can be calculated. Table 5.3 shows the fuel consumption in MT/day for laden and unladen condition and the calculated fuel consumption in kg/nm using the formula presented in the introduction. According to this data, the most fuel efficient speed lies between 12 and 14 knots for laden and unladen condition with respectively minimum consumption of 86 kg/nm and 82 kg/nm. This means that a Spliethoff S-Type covers the biggest distance per ton of fuel consumed at 12-14 knots, irrespective of draught condition. One could argue that in practice it is more beneficial for Spliethoff as a business to sail at 14 knots than 12 knots with respect to opportunity costs. Missing new cargo because the vessel is sailing at 12 knots instead of 14 knots clearly is an undesirable scenario. Maybe for that exact voyage, sailing 12 knots will yield a higher TCE than 14 knots. However, the cost of missing a shipment will outweigh the savings in bunker costs.

Another influencing element is the fact that engine cylinders and the turbo foul quicker at a lower engine load percentage, due to sub-optimal combustion [Tufte [2014]]. Consequently, at 12 knots the engine will foul more than at 14 knots. At the moment, company policy dictates that the vessel should sail at full-speed one hour for every 24 hours at eco-speed, to clean the engine.

Finally, the engine emits less heat at lower engine loads. This heat is normally used to pre-heat the bunkers and for hotel facilities. If the main engine does not create sufficient heat, external boilers are switched on which also need fuel to run. This diminishes the fuel savings of sailing at lower engine load somewhat. It is another argument for taking eco-speed at 14 knots instead of 12 knots.

When applying the found eco-speed to a typical S-Type voyage the economical benefits of implementation may become clear. From experience it is known that a vessel will get instructions to sail at "eco-speed" mostly for unladen voyages eastbound from the USA e.g. Jacksonville to Husum, Sweden (4910 nm). Up to now a captain would then simply reduce speed to for instance 16 knots. At 16 knots an S-Type consumes 85 kg/nm, meaning a total of $85 * 4910 = 417,350$ kg bunkers are consumed over the voyage. At eco-speed this would drop to $82 * 4910 = 402,620$ kg bunkers, a difference of 14,730 kg or 14.73 MT. This amounts to a bunker cost saving of $4,419.00 over a single voyage ($300 per MT HFO 19-5-2017) or 4% [Bunker [2017]]. This seems a marginal saving, however (depending on the market) in a year an S-Type can have up to five of these voyages, saving over $22,000.00 in bunker expenses.

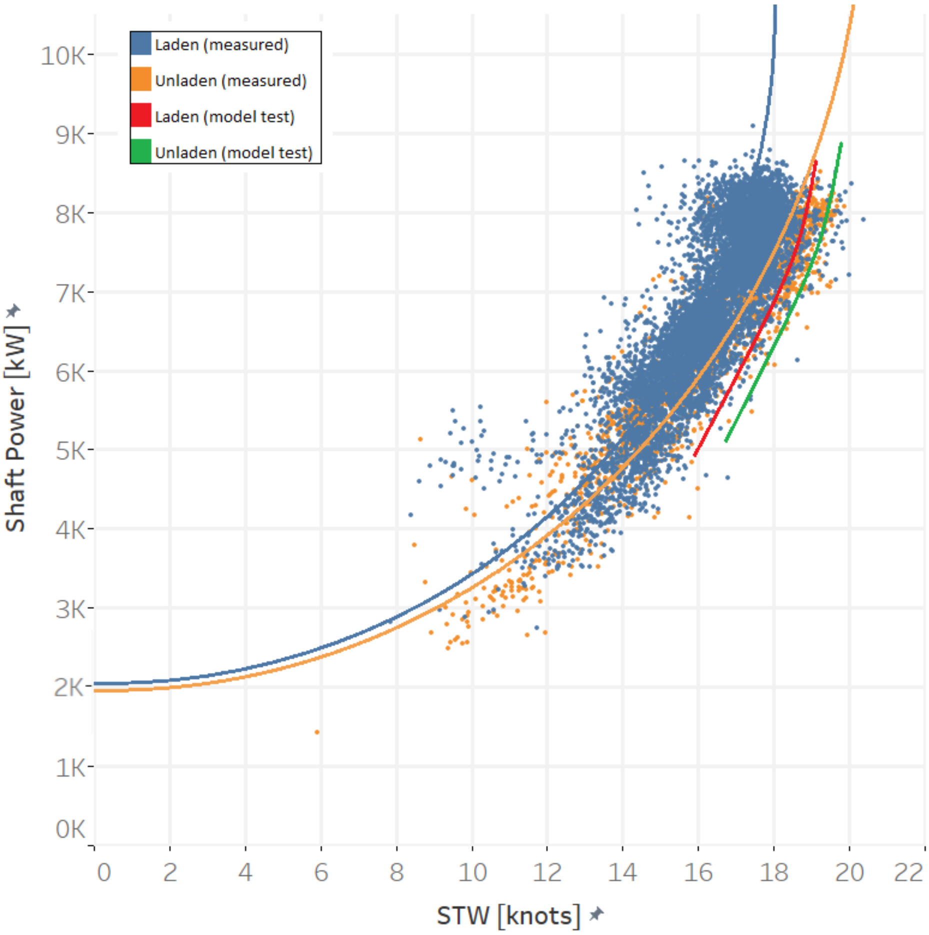


Figure 5.1: Speed - Power Plot (All Vessels)

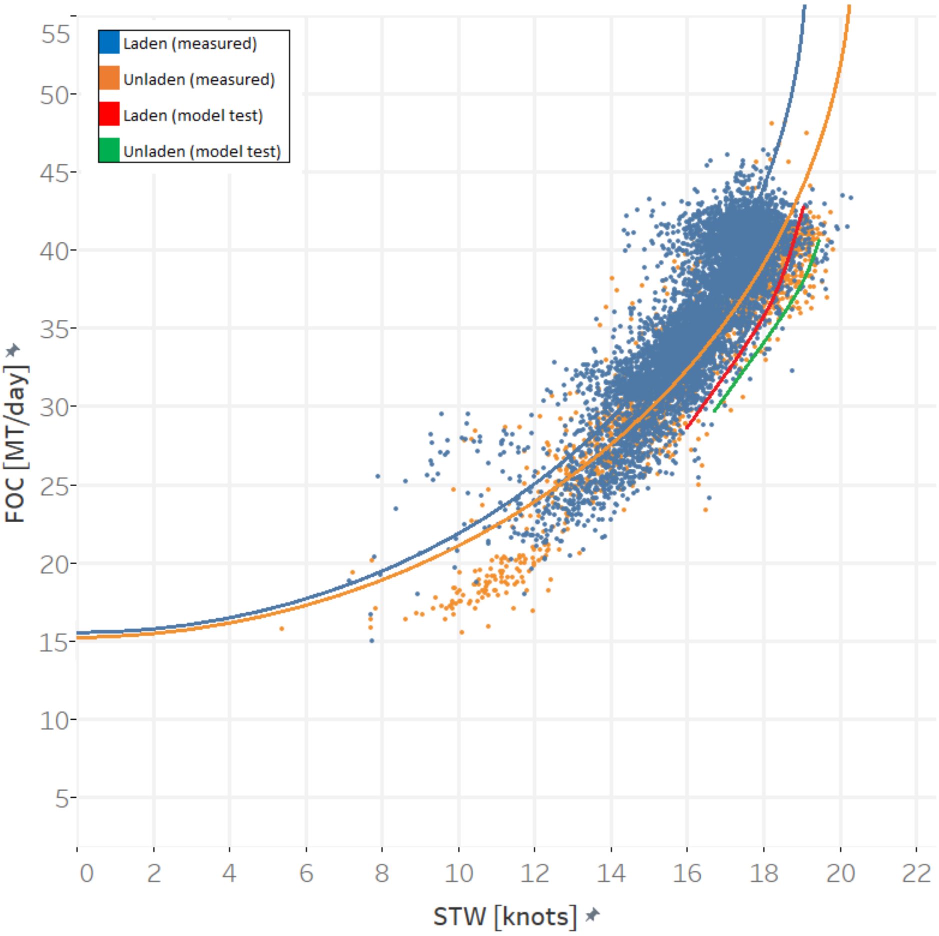


Figure 5.2: Speed - Consumption Plot (All Vessels)

Speed [kts]	FOC [MT/day] Laden	FOC [MT/day] Unladen	FOC [kg/nm] Laden	FOC [kg/nm] Unladen
2	15.5	15	323	313
4	16	15.5	167	161
6	17.5	16.5	122	115
8	19.5	18	102	94
10	22	21	92	88
12	25	24	**87**	**83**
14	29	27.5	**86**	**82**
16	35	32.5	91	85
18	44	39	102	90

Table 5.3: Speed - Consumption (All Vessels)

5.2.2 Corrected Results

To check the results for consumption in MT/day and kg/nm the corrected data can be used. In theory, the corrected results should show the baseline performance of the vessel in calm water conditions, thus taking away the need to filter for sea state as in the previous section. However, there are some limitations in the correction model. Most notably, the added wave resistance correction method (STAwave-1, see chapter 4) has only been validated for waves up to 2.85 metre and bow sector waves. This means that filtering still is necessary for these constraints. Because of this filtering and dependencies in the correction model, the corrected dataset is significantly smaller than the filtered dataset (filtered dataset: 9200 data points, corrected dataset: 4400 data points).

In Figure 5.3 corrected consumption over speed is plotted showing a similar trend compared to the filtered plot (Figure 5.2). If one tabulates this plot again, the most fuel efficient speed can again be found for laden and unladen condition (see Table 5.4). With the corrected data, different results are attained. This time, a different eco-speed range is found, namely from 8 to 10 knots for laden condition and 10 to 12 knots for unladen condition. This is probably due to the reduction in dataset size, meaning the corrected results are less reliable than the filtered results. In general, the differences in fuel consumption in kg/nm over the 8 to 12 knot range are very small. It is therefore hard to define eco-speed with accuracy.

Another reason for difference in results between filtered data and corrected data is the fact that the filtered data has been filtered back to moderate sea state (wave height 2 metre; wind speed 15 knots), whereas the corrected data represents calm water conditions. A positive aspect is the fact that the trend lines in the corrected plot are almost on the level of the model test curves. This indicates that the corrected results are closer to the calm water performance then the filtered results, as intended.

At this stage, it seems like the dataset of the corrected results is less reliable than the uncorrected dataset due to the reduction in dataset size. Consequently, it is advised to use the fuel consumption data of Table 5.3 until a bigger corrected dataset is available. This means that the most fuel efficient speed lies at 14 knots. Although the corrected dataset is relatively small, the results are promising as the trend lines have moved closer to the model test curves.

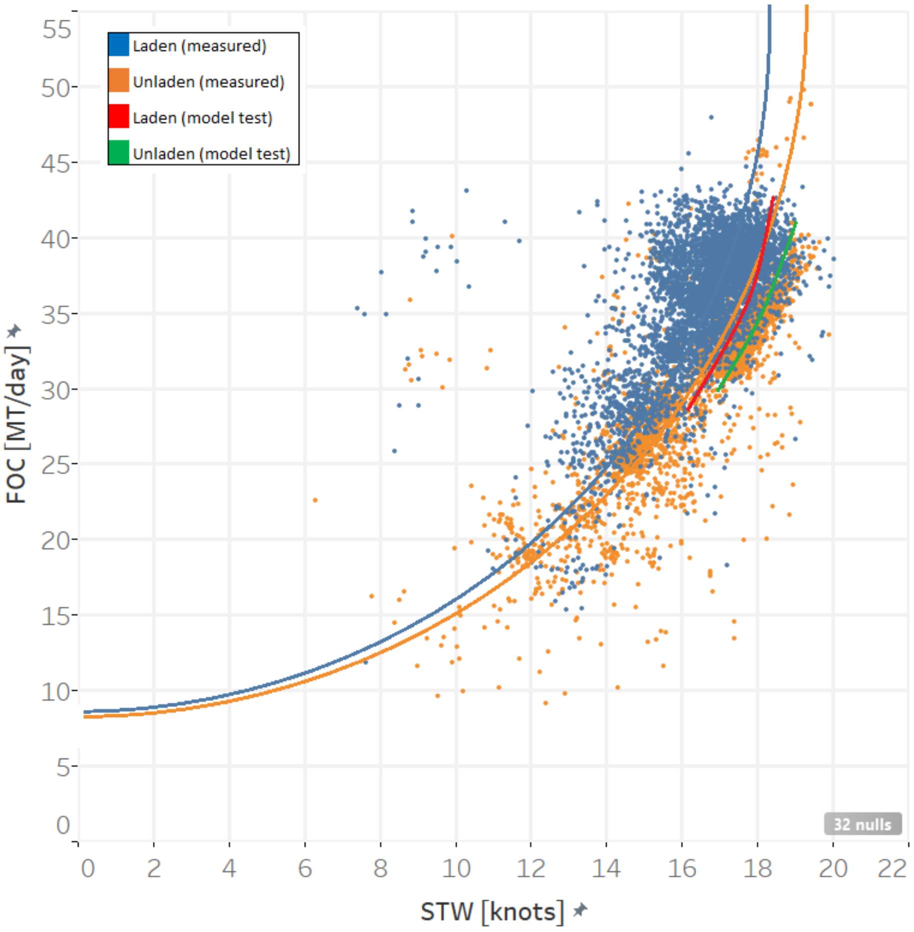


Figure 5.3: Corrected Speed - Consumption Plot (All Vessels)

Speed [kts]	**FOC [MT/day] Laden**	**FOC [MT/day] Unladen**	**FOC [kg/nm] Laden**	**FOC [kg/nm] Unladen**
2	9	8.5	188	177
4	10	9.5	104	99
6	11.5	11	80	76
8	13	12.5	**68**	65
10	16	15	**67**	**63**
12	20	18	70	**63**
14	25	22.5	74	67
16	32	28	83	73
18	42	37	97	86

Table 5.4: Corrected Speed - Consumption (All Vessels)

5.3 Individual Vessel Results

In the individual vessel results analysis the objective is to measure SFC, hull- and propeller fouling and the influence of crew on vessel operation. With regards to SFC a comparison between measured SFC and manufacturer's specification will be conducted, giving an indication on the relative health of the main engine. If large discrepancies are found between specification and the actual engine efficiency, extra investigation into the causes should follow. A secondary goal with regards to SFC is to measure developments in engine efficiency over time. This may give insight in the effectiveness of maintenance actions or engine overhauls. When analysing fouling a similar goal is pursued, i.e. measuring the effect of fouling on the performance of the vessel and checking whether cleaning of the hull has a measurable effect.

5.3.1 mv Slotergracht

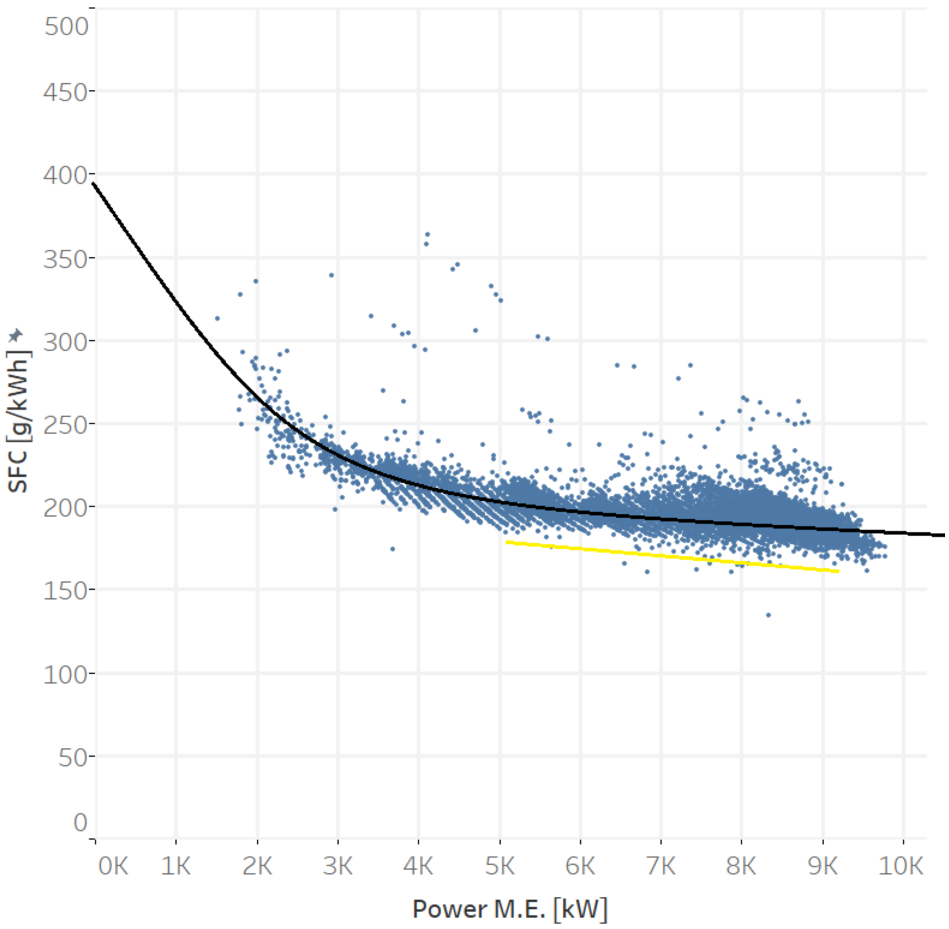


Figure 5.4: Power - SFC Plot (Slotergracht)

To monitor main engine efficiency, SFC is plotted against main engine power, shown in Figure 5.4 (see subsection 4.2.3 for calculation method SFC and main engine power). The measured data has been corrected for variations in calorific value of fuel (calculated to 42.7 MJ/kg). From manufacturer specifications it is known that lower power yields higher SFC. What becomes clear in this plot is that it is not a linear relation. In fact, for very low power outputs SFC becomes disproportionately high. The yellow line indicates SFC according to Wärtsilä for this engine type (fuel calorific value 42.7 MJ/kg, no engine driven pumps) [Wärtsilä [1997]]. The measured SFC is slightly higher than specification, which has two explanations. Firstly, the test conditions of Wärtsilä indicate “no engine driven pumps”, whereas on the S-Types under normal operation a lube oil pump and two cooling water pumps are driven by the main engine, raising SFC. Also, manufacturers specifications are usually attained under near laboratory conditions (optimal air temperature, fuel type, etc), giving different results.

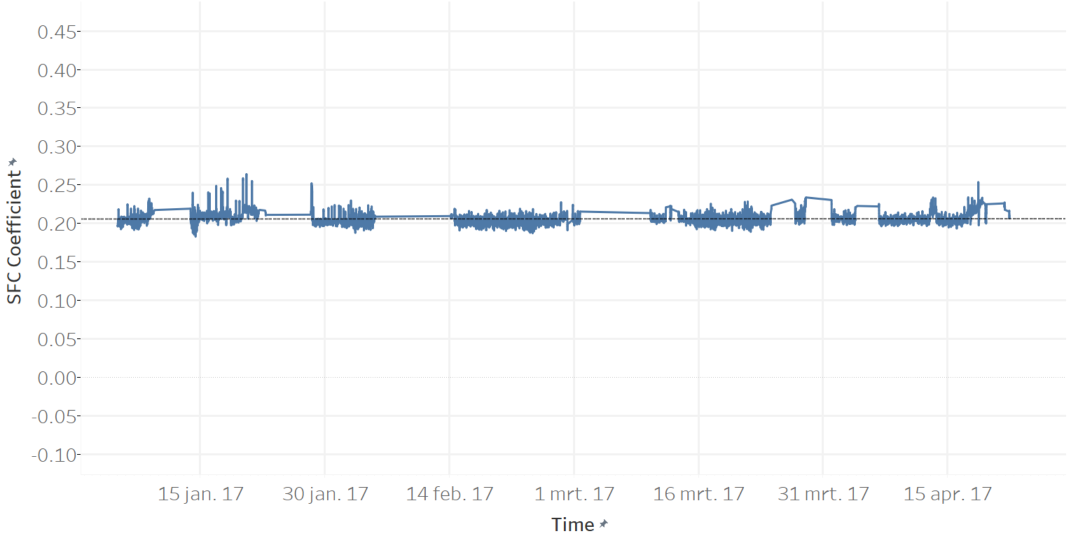


Figure 5.5: Time - SFC Coefficient Plot (Slotergracht)

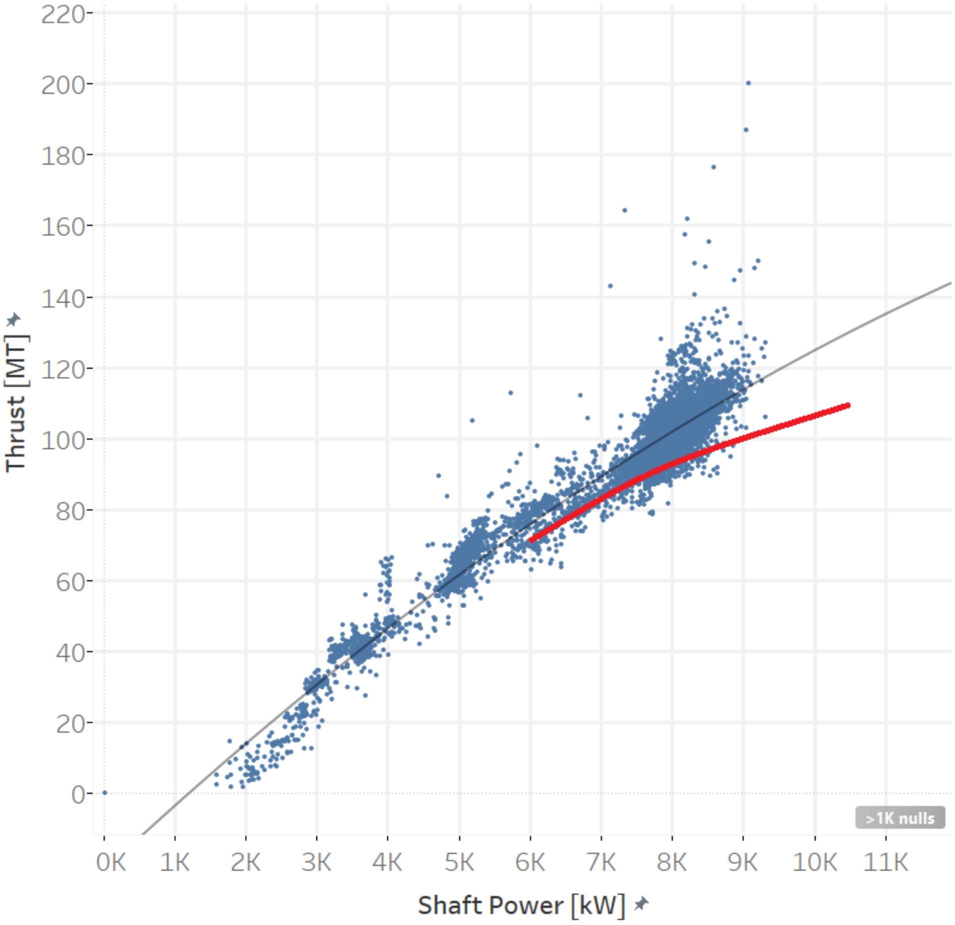


Figure 5.6: Power - Thrust Plot (Slotergracht)

Figure 5.5 shows the SFC coefficient ($\frac{FOC}{P_B}$) plotted over time, in an effort to follow developments in SFC. From the first SFC graph a near linear trend was observed above 4000 kW. The SFC coefficient should give comparable values above 4000 kW, so this filter was applied in the graph. Monitoring this chart will give insight into the development of engine efficiency over time. Ideally, a flat trend is observed, meaning there is no loss in efficiency. If the chart does show a sudden drop or rise, action should be taken. In this case, the graph's trend line is horizontal, so the engine has no measured loss of efficiency.

To measure hull and propeller fouling, thrust has to be calculated from power (see Formula 4.6). In Figure 5.6, the relation between power and thrust is displayed with filters for moderate sea state, including the model test curve taken from model tests (in red). A polynomial trend can be observed, with data points starting at 2000 kW. The trend follows from the open water efficiency of the propeller, which is a determining factor in the calculation from shaft power to thrust (see subsection 4.2.3 for the calculation method).

In Figure 5.7, thrust is plotted over time, with the aim to measure fouling. This resistance increase should become visible in the graph through an inclining trend line, if plotted over a long-enough period at a speed and draught range. In this case, thrust is plotted over a period of less than four months. For this plot, a filter was applied displaying speed through water between 17 and 18 knots in laden condition. The trend line shows a marginally declining trend line. This would indicate that hull fouling is becoming less, instead of worsening. However, one must note that thrust data is plotted over a speed range of a knot to have a useful amount of data. This could also introduce irregularities. To draw more decisive conclusions a longer measuring period is necessary.

A dashboard element which can be used to monitor crew's performance is the map view. Here the route of the vessel can be plotted, along with all kinds of other dimensions. In this case, wave height is displayed in colour (the darker the colour, the bigger wave height) over a voyage from Uddevalla, Sweden to Baltimore, USA. As one can see, the vessel has encountered the biggest waves on the North-Atlantic (significant wave height up to 4.9 metres). The office could use this feature to collaborate with crew on how to deal with adverse weather conditions by adapting sailing speed or routing. Ships are equipped with a weather routing system (SPOS; see chapter 3) and the crew is trained to use the system. This does not mean the system is always used optimally. In this respect, active communication between vessel and office is desired to achieve the best results.

To illustrate the effect of sub-optimal routing, a real-world example of a vessel sailing from Hong Kong, China to Puerto Vallarta, Mexico (7300 nm) is used. In [Singh [2014]] a captain ignores the route recommended by the weather routing system and sails rhumb line (straight line on map) to the next destination. The recommended route had the same ETA at a slightly lower average speed. After analysis it turned out that implementing this route could have saved approximately 160 MT of fuel which is 8% of total fuel consumption. At $300 per MT HFO (19-5-2017) this amounts to a saving of $48,000.00 over a single voyage [Bunker [2017]].

Other dimensions that could for instance be visualised on this map are speed, fuel consumption, heading, shaft power, SFC, shaft generator power, water depth, current rate, wind speed and draught.

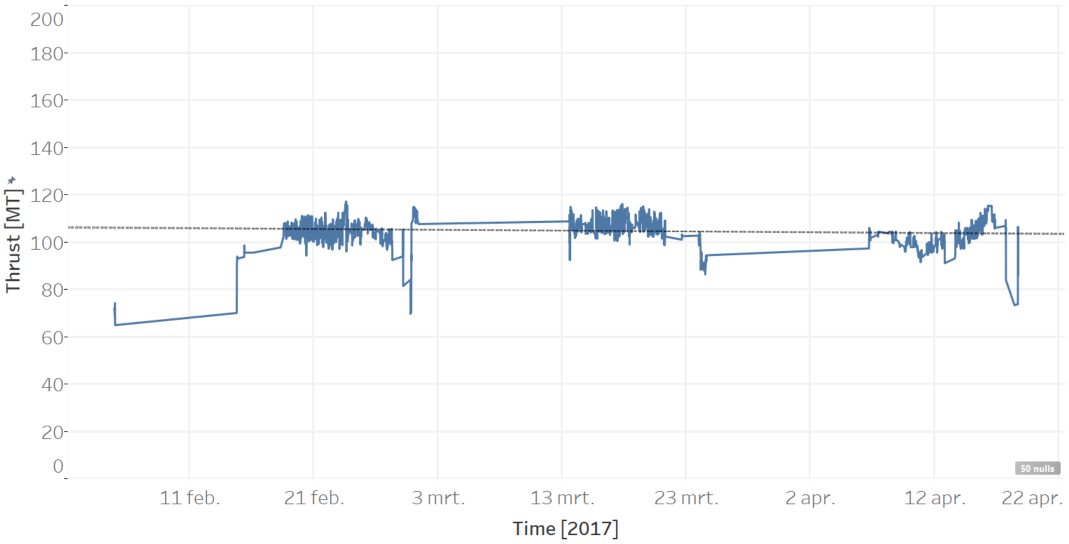


Figure 5.7: Time - Thrust Plot (Slotergracht)

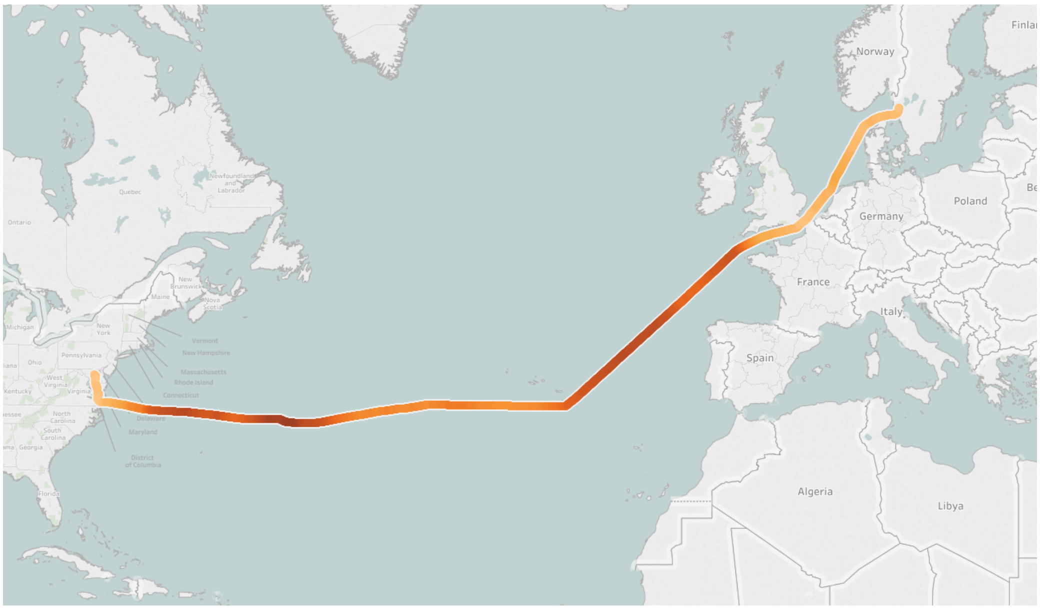


Figure 5.8: Map with Route and Wave Height (Slotergracht)

5.3.2 mv Singelgracht

Figure 5.9 displays SFC plotted against main engine power. Again, the calorific value of bunkers has been taken into account. A trend is found where SFC decreases linearly from 4000 kW. For main engine power lower than 4000 kW a strong increase in SFC is measured. A difference between the SFC data from Slotergracht and Singelgracht is that all data points for Slotergracht lie between 170 and 350 g/kWh, but for Singelgracht this range is bigger (170 - 450 g/kWh). Another difference is that below 2000 kW Slotergracht has very few data points; Singelgracht has a substantial part of the dataset between 1000 and 2000 kW. This could mean that the main engine of Singelgracht can run at lower power outputs than Slotergracht's main engine. Also, as with the Slotergracht, Wärtsilä's specification shows slightly lower values for SFC, which is as expected as Wärtsilä's test conditions are different to the measured conditions.

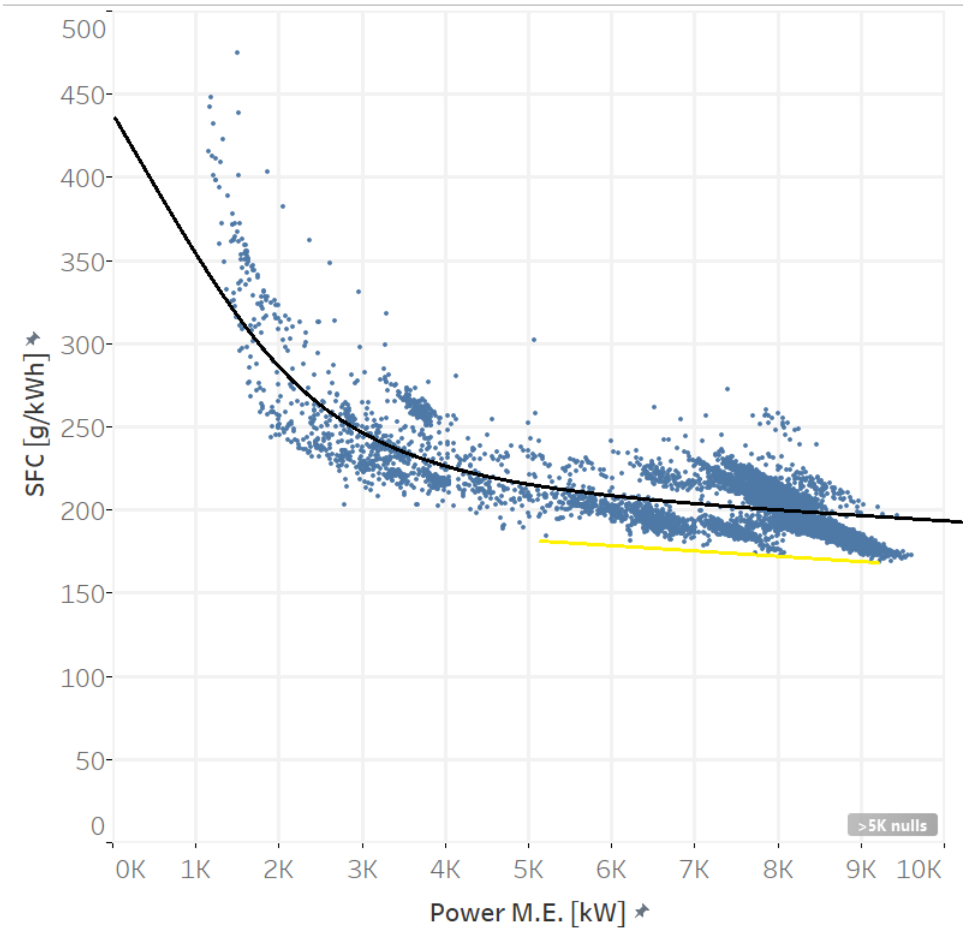


Figure 5.9: Power - SFC Plot (Singelgracht)

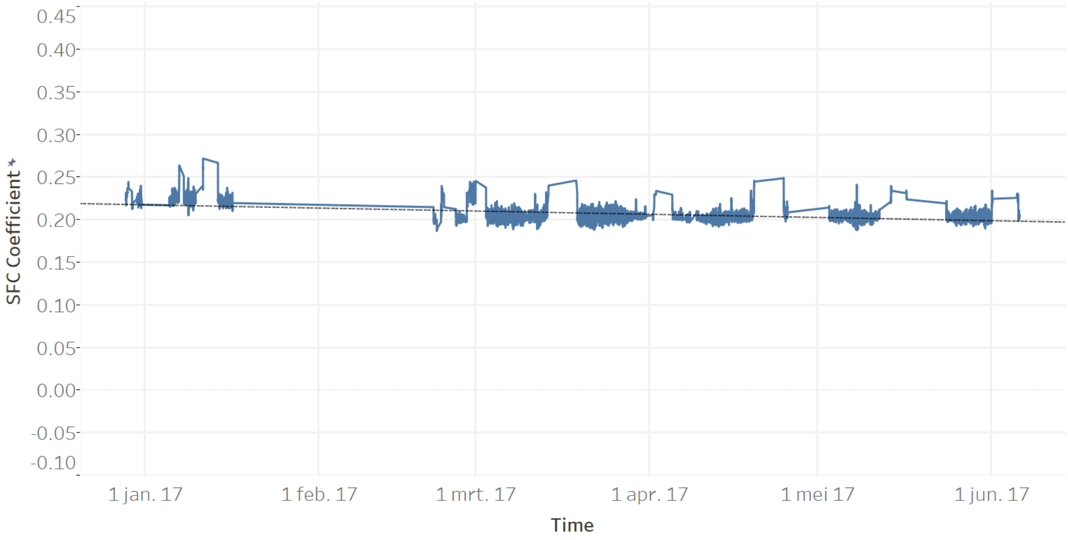


Figure 5.10: Time - SFC Coefficient Plot (Singelgracht)

In Figure 5.10 the SFC coefficient ($\frac{FOC}{P_B}$) is plotted over time. Following from the previous graph it has become apparent that this relation is linear from 4000 kW upwards. Therefore again a filter is applied, only plotting SFC coefficient for 4000 kW and higher. Contrary to Slotergracht, which showed a completely flat trend, in this case there is a declining trend line which means that the engine has actually become more efficient over the measuring period. This could be thanks to a number of maintenance actions executed over the measuring period. To verify this assumption, the chief engineer of the vessel was contacted. Extensive maintenance was executed between February and April 2017 with the most significant changes being the complete overhaul of two cylinders and the replacement of a fuel pump.

Thrust is plotted against power in Figure 5.11, showing a very similar polynomial trend as Slotergracht's results. The model test curve is added in red. Thrust is used to measure developments in fouling. The polynomial trend again is dictated by the open water efficiency of the propeller. Compared to Slotergracht, one can see that the dataset for Singelgracht is substantially smaller. This is because some sensor data required for the calculation of thrust became available later in the project.

In Figure 5.12 thrust is plotted over time on a speed range of 17-18 knots in laden condition. As one can see on the time-axis, this plot consists of data points plotted over less than two months. Therefore the inclining trend line -indicating a hull fouling increase- is not very reliable. That said, thrust lies on a level very similar to Slotergracht (100 MT) for the given conditions, so in that respect the results are in line with expectations.

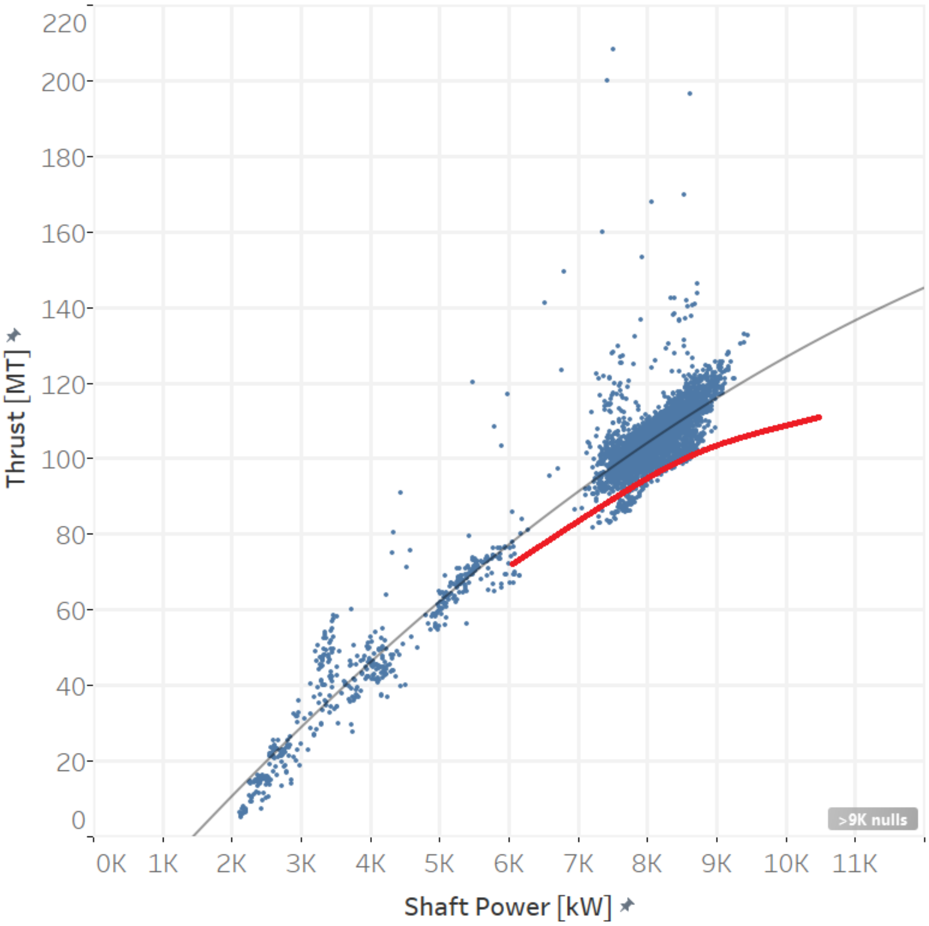


Figure 5.11: Power - Thrust Plot (Singelgracht)

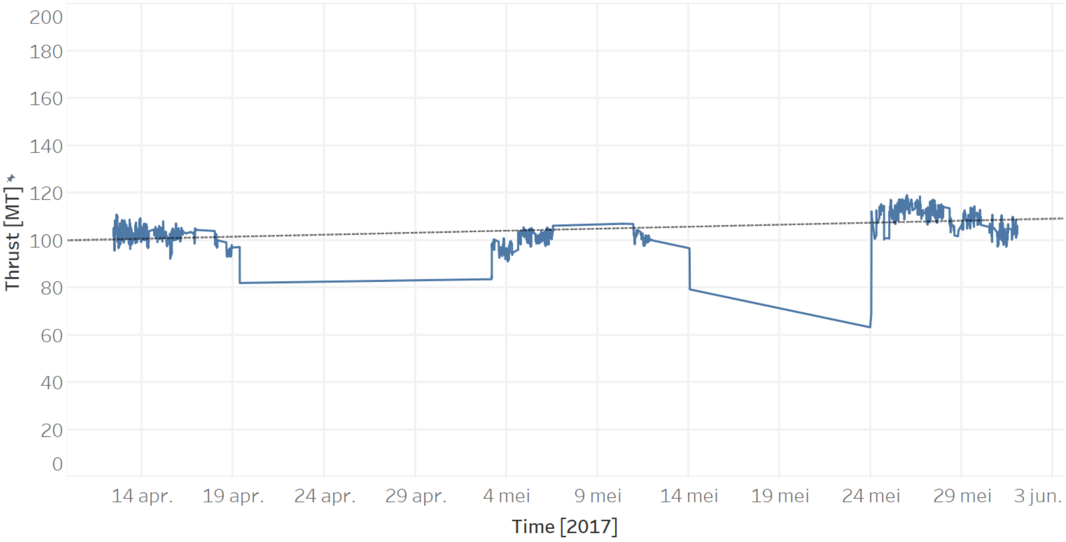


Figure 5.12: Time - Thrust Plot (Singelgracht)

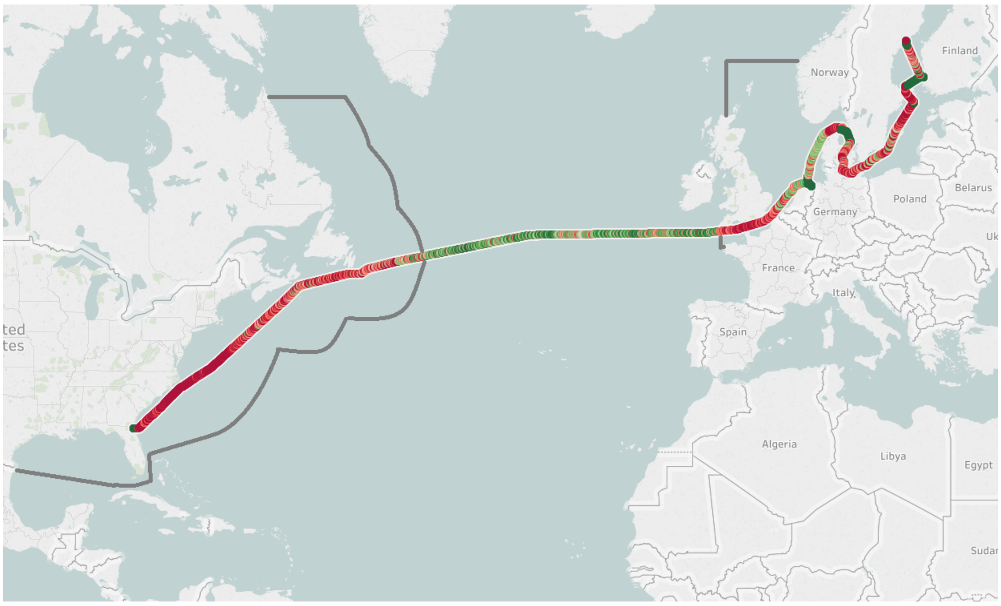


Figure 5.13: Map with Route and Shaft Generator Power (Singelgracht)

In Figure 5.13 again a map is displayed, this time showing the route of Singelgracht on one of her crossings (Husum, Sweden to Jacksonville, USA) along with shaft generator power visualised in colour (green = low power, red = high power). The grey lines indicate the Sulphur Emission Control Areas (SECA). As one can see, within SECA the shaft generator power generally is higher than outside SECA. One way to explain this difference is the fact that within SECA the scrubber has to be switched on, adding roughly 150 kW (±40%) to the electrical power needed. This amounts to nearly 1 MT/day extra consumption or $300 per day (HFO price 19-5-2017) [Bunker [2017]]. Using this visualisation, the office can check whether a scrubber is switched on and off timely by the crew. By communicating and collaborating with the ship from the office, cost savings could possibly be made in this area. Providing data feedback and voyage analyses to the crew, awareness on the subject of fuel efficiency is increased among the crew, leading to cost savings.

At the moment the system is primarily designed for data analysis after a voyage. In the near future a more "real-time" functionality is planned for development, so that warnings/alarms can be sent to the ship if aforementioned situation occurs.

5.3.3 mv Schippersgracht

Figure 5.14 displays SFC plotted against main engine power (correction for calorific value is applied once more). The declining trend familiar from Slotergracht and Singelgracht again is apparent here, with a couple of key findings. First of all, the trend line displays a stronger decline than those of Slotergracht and Singelgracht, indicating bigger SFC variations over the power range. For a more reliable trend line, between 8000 and 9000 kW more data points are necessary. Compared to Wärtsilä's specification, the gradient of the trend line is quite a lot steeper and SFC is higher.

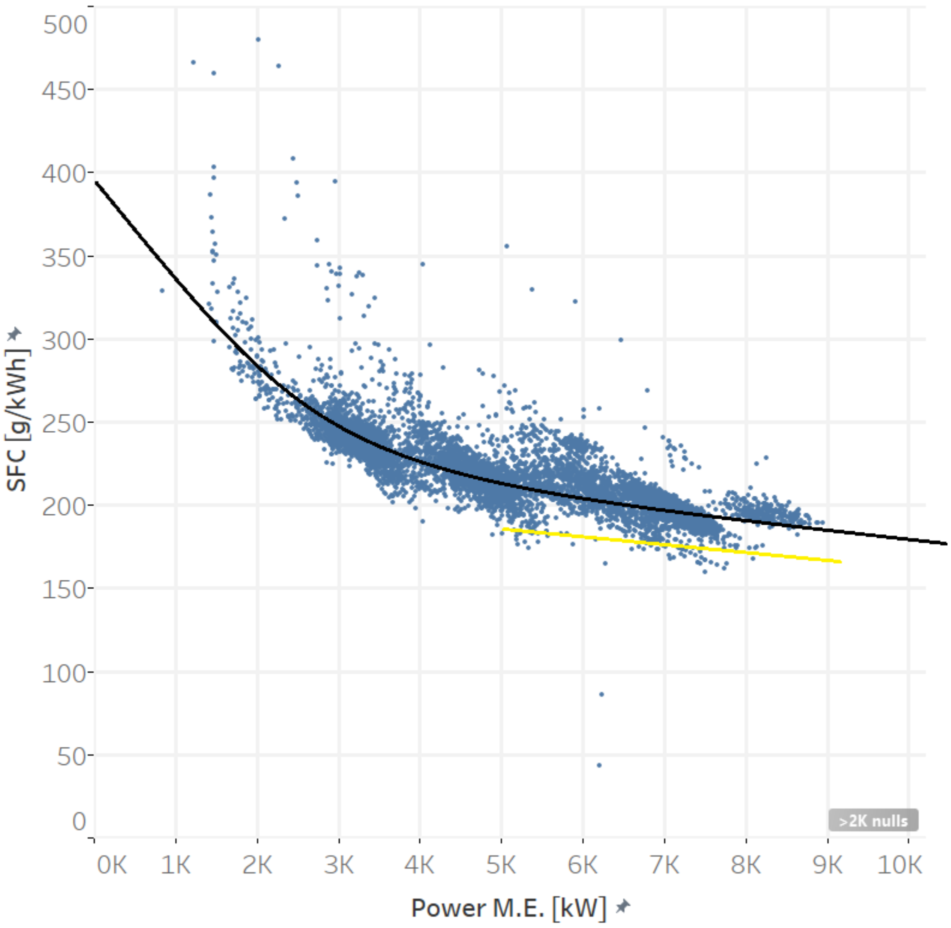


Figure 5.14: Power - SFC Plot (Schippersgracht)

To monitor engine condition, in Figure 5.15 the SFC coefficient is plotted over time. Just like the Slotergracht, a flat trend is observed. Over the measuring period there are no changes in efficiency. Again, this is the desired trend, as large variations in this chart could indicate a deteriorating engine condition.

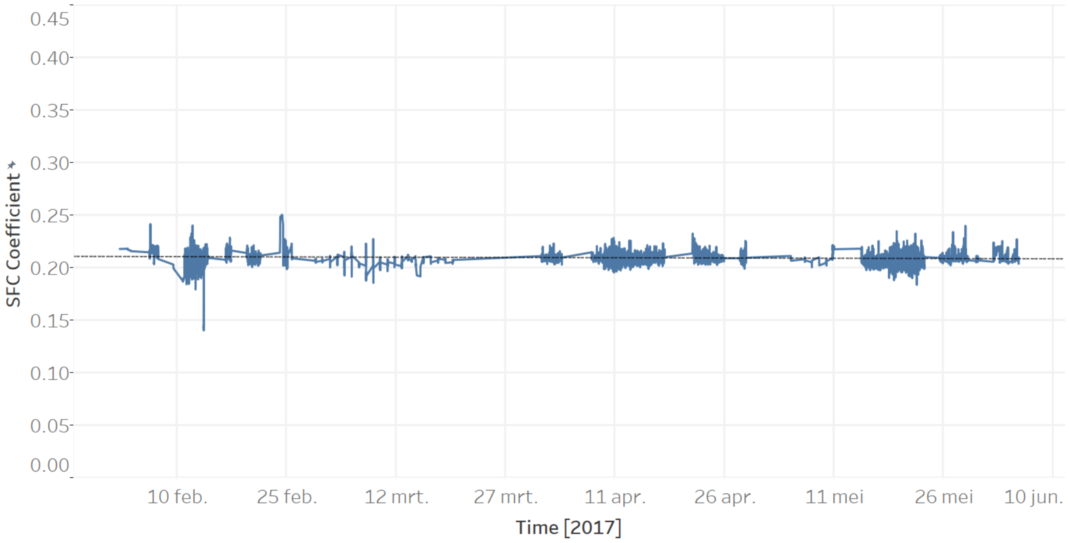


Figure 5.15: Time - SFC Coefficient Plot (Schippersgracht)

Thrust is plotted against power in Figure 5.16 for moderate sea state. The polynomial trend observed at Slotergracht and Singelgracht is also observed here, with the model test curve included (red line). The calculated thrust actually lies very close to the model test curve thrust, meaning thrust is calculated reliably. When comparing this data with that of the other S-Types it can be noted that at 8000 kW Schippersgracht produces the same 100 MT thrust as the other two S-Types.

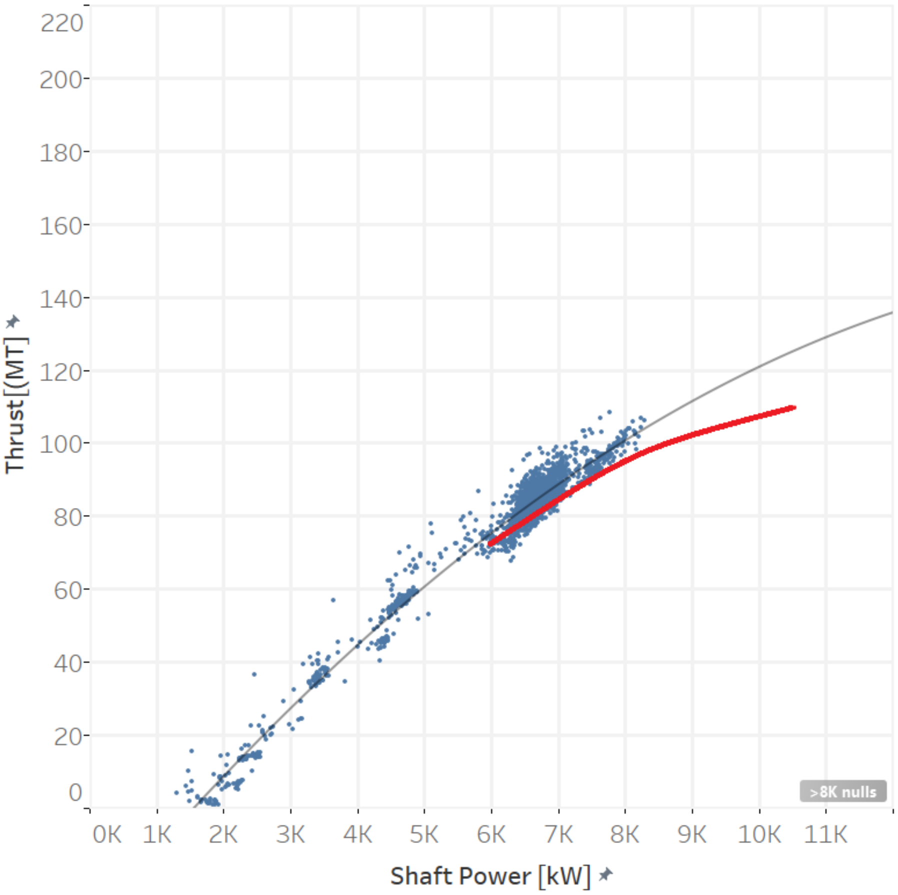


Figure 5.16: Power - Thrust Plot (Schippersgracht)

In Figure 5.17 thrust is plotted over time at a speed and draught range in an effort to measure fouling. In laden condition with a speed range taken between 17 and 18 knots, the resulting data gives a horizontal trend line. This indicates no change in hull fouling. However, due to certain sensor data being available late in the project, the dataset is quite small (two months). Therefore the trend is not very reliable and a bigger dataset is necessary to provide more certainty.

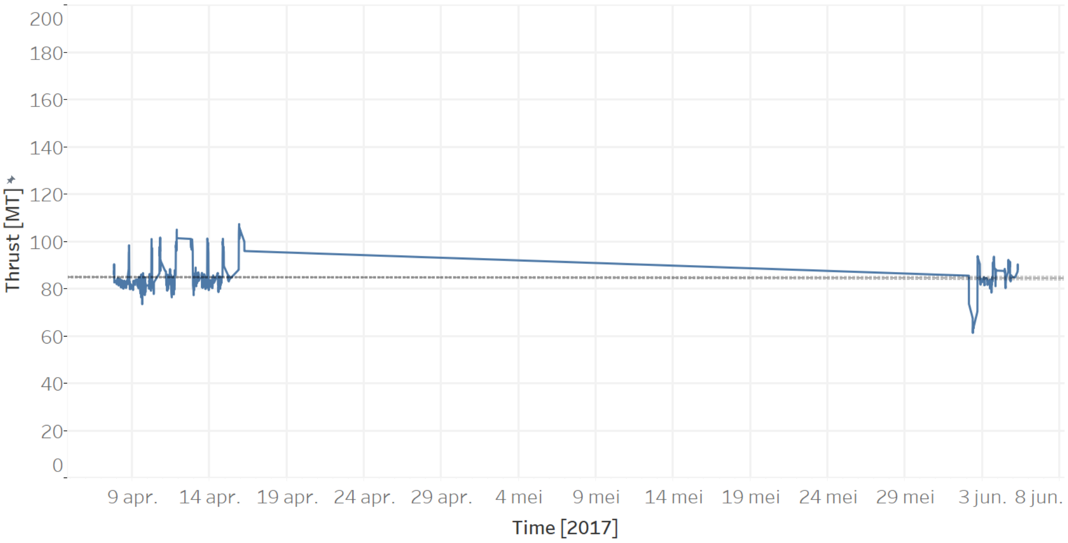


Figure 5.17: Time - Thrust Plot (Schippersgracht)

In Figure 5.18, the route of Schippersgracht is plotted as it travels from Gothenburg, Sweden to Baltimore, USA via Eemshaven, The Netherlands. In colour the rate of the current is shown, green indicating little current and red indicating strong currents. The strongest current measured over this leg was 2.6 knots in the Channel south of England. It is known from experience that in the North-Sea and the English Channel currents are strong. Visualised on a map like this, the office can monitor whether the captain is using currents to his benefit, or is ignoring them. Also, speed reduction when current is against the vessel or vice versa could be checked in the office using current direction data. Starting a dialogue between office and ship and working closely together to effectively act on environmental influences such as current and waves should benefit both parties. Training crew in correctly using the weather routing system (SPOS; see chapter 3) is key here.

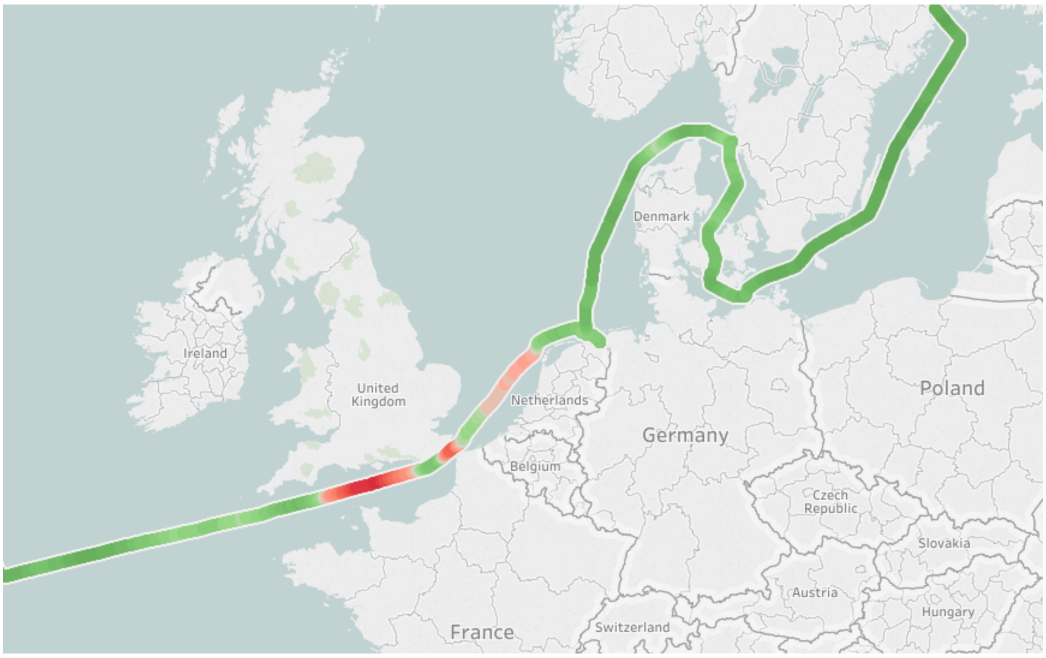


Figure 5.18: Map with Route and Current Rate (Schippersgracht)

5.4 Conclusions

When performing analysis on performance data of ships there are two approaches; filtering data for weather influences or correcting data for weather influences. In this chapter both methods have been applied to the data of all vessels combined, yielding different results. Due to the relatively complex correction model, the corrected dataset is 50% smaller than the filtered dataset. This influences the reliability of the corrected results strongly, meaning that at the moment the filtered results are used to base conclusions on. The corrected dataset size could be increased two ways; extending the measuring period or using another wave added resistance method with less restrictions, the latter probably being more effective. Such a method has been developed (SPAWAVE), but it is not openly available.

From the filtered results a number of conclusions can be drawn. First of all, the most fuel efficient speed for a Spliethoff S-Type is 14 knots, both in laden and unladen condition. Opportunity cost and fouling of the engine due to low load operation have been taken into account when determining this speed. A significant cost saving of at least 10% can be achieved with eco-speed compared to full speed over a voyage. It is recommended to implement eco-speed in all voyages where there is no set ETA for the next port or the ETA allows for slower speeds.

With regards to speed-consumption information of the S-Types, an interesting finding is the small difference in fuel consumption at speeds below 10 knots between laden and unladen condition. At eight knots STW, in laden condition fuel consumption is 20 MT/day and in unladen condition 18 MT/day. An explanation for this small difference could be the strong decline in hull and propeller efficiency when sailing in unladen condition. Also, the relatively small reduction in viscous resistance when reducing draught from 10 metre (laden) to around 7 metre (unladen) is of influence. At higher speeds the consumption difference between laden and unladen condition grows. When comparing full-speed fuel consumption with eco-speed fuel consumption, the absolute difference in MT/day is 30%.

The measured fuel consumption lies at a slightly higher level than the consumption according to the model test curves. This is as expected, as the model test curve consumption is based on calm water conditions and the measured data is filtered to moderate sea state.

From the individual vessel results, first SFC related conclusions are discussed. For all vessels the measured SFC lies on a higher level than engine manufacturer specification. This is according to expectation, as Wärtsilä's testing conditions differ from the operational conditions on the ship. The manufacturers specification in that respect can be used as a guideline which is nearly unattainable under normal operation of the ship. Between the vessels only minor differences in SFC are measured.

With regards to the developments of SFC over time, for Slotergracht and Schippersgracht flat trends have been observed. This indicates that engine efficiency over the measuring period (less than six months) has not changed. For Singelgracht, a declining trend was measured, indicating an improvement in engine efficiency thanks to some very extensive maintenance including the complete overhaul of two cylinders and a replaced fuel pump.

Literature states that fouling could result in fuel consumption increase of 5% per year, depending on factors such as the operational profile of the vessel and state of anti-fouling paint. However, the data showed mixed results. For Slotergracht -over a measuring period of less than four months- contrary to expectation, a decrease in fouling was measured. For Singelgracht and Schippersgracht the measuring period was two months or less, so the trends are very unreliable. It is therefore advised to monitor this KPI for a much longer period (at least a year), before making any statements. If an increase of 5% is measured, it is recommended to increase the hull cleaning frequency to once every year for all vessels. In this scenario the fuel savings far outweigh the hull cleaning costs.

In the different examples, it has become clear that monitoring crew's performance can be very valuable. Checking if weather routing systems are used effectively and if the scrubber is switched on or off in time can significantly reduce bunker costs. However, when monitoring crew performance related subjects, one has to take into account the “human factor”. Ideally, collaborating between office and ship and properly educating crew on new systems will give the best results from an economical and social point of view. In other words, a healthy relationship between office and ship is paramount when implementing changes in the ship's operation.

Chapter 6

Conclusions and Recommendations

This thesis project was born out of the necessity to investigate how operational data of Spliethoff's vessels could be used to benefit both economical and environmental performance of the company. The goal to develop a Ship Performance Monitoring System (SPM System) was set, starting with analysis of three identical sister ships, mv Slotergracht, mv Singelgracht and mv Schippersgracht. By taking three identical vessels, data could be combined and compared relatively easily. The information provided by the SPM System would be used to make better informed decisions, minimising cost in the areas of fuel consumption and maintenance.

The added value of this thesis is twofold, namely a methodological research into the development of an SPM System and an empirical research into the data obtained with the system. Therefore conclusions and recommendations are made in this chapter regarding development of the SPM System and the data analysis.

6.1 Conclusions

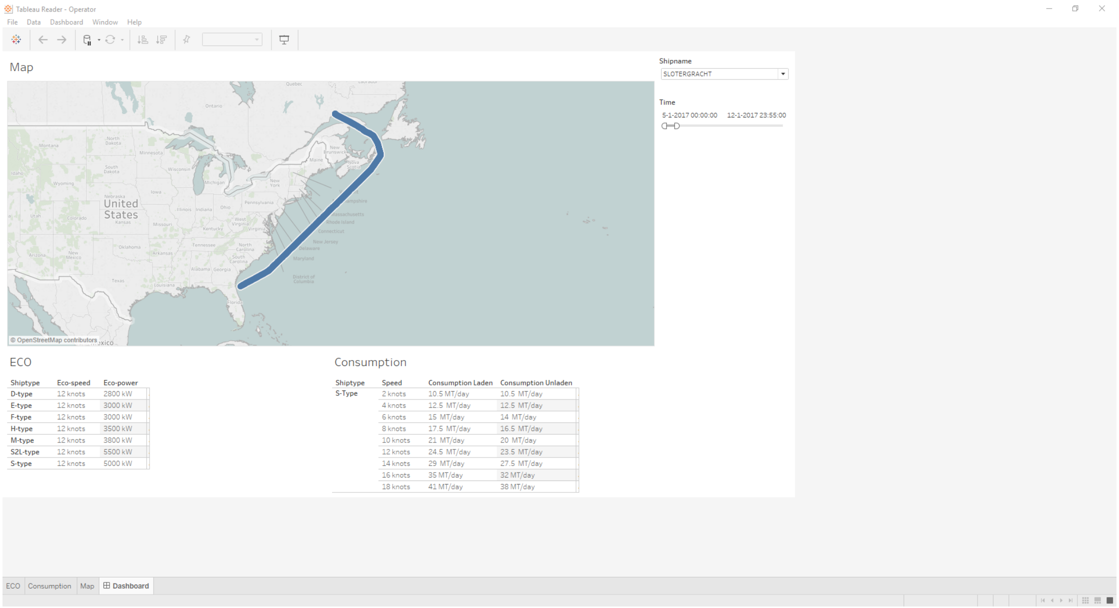
The SPM System was developed using a *Rapid Prototyping* methodology, focusing on intensive end-user involvement. Dashboards were designed to provide end-users with specific information. An example dashboard is shown in Figure 6.1. All dashboards of the SPM System can be found in Appendix B.

The cost structure of the SPM System developed at Spliethoff has been analysed, with a first conservative estimate for payback period of under two and a half years. Annual costs of this system are over three times lower than annual costs from a comparable off-the-shelf system.

From the data analysis, it can be stated that the most fuel efficient speed of a Spliethoff S-Type is 14 knots both in laden and unladen condition. Per voyage this could result in a bunker cost saving of up to 10% compared to full-speed operation.

A key finding in the speed-consumption analysis of the S-Types is the small difference between consumption in laden and unladen condition for speeds below 10 knots. Possible explanations are the strong decrease in hull and propeller efficiency when sailing in unladen condition and only a small reduction in viscous resistance compared to laden condition. In general, the measured fuel consumption of all vessels lies at a slightly higher level than the model test curve consumption. This is according to expectation as model test curve data is measured in calm water conditions and the measured data is retrieved up to a moderate sea state.

With regards to the correction model, a couple of statements can be made. The correction model is rather complex with a lot of dependencies. This limits the size of the



Shipname: SLOTERGRACHT

Time: 5-1-2017 00:00:00 12-1-2017 23:55:00

ECO

Shiptype	Eco-speed	Eco-power
D-type	12 knots	2800 kW
E-type	12 knots	3000 kW
F-type	12 knots	3000 kW
H-type	12 knots	3500 kW
M-type	12 knots	3800 kW
S2L-type	12 knots	5500 kW
S-type	12 knots	5000 kW

Consumption

Shiptype	Speed	Consumption Laden	Consumption Unladen
S-Type	2 knots	10.5 MT/day	10.5 MT/day
	4 knots	12.5 MT/day	12.5 MT/day
	6 knots	15 MT/day	14 MT/day
	8 knots	17.5 MT/day	16.5 MT/day
	10 knots	21 MT/day	20 MT/day
	12 knots	24.5 MT/day	23.5 MT/day
	14 knots	29 MT/day	27.5 MT/day
	16 knots	35 MT/day	32 MT/day
	18 knots	41 MT/day	38 MT/day

Figure 6.1: Operator's Dashboard

corrected dataset significantly. Consequently, the corrected trend lines are less reliable than the trend lines from the filtered dataset. The correction model as a whole is working as intended, because the corrected data trend lines are a lot closer to the model test curves than the filtered data trend lines.

Regarding engine efficiency, the specific fuel consumption (SFC) of the main engines of all three vessels is worse than the specification given by Wärtsilä. However, this is as expected, given the fact that Wärtsilä's testing conditions differ from normal operating conditions of the engine. In that respect, the manufacturer specification can be seen as a guideline, nearly unattainable under normal operation. Between the vessels only minor SFC differences are observed. For Slotergracht and Schippersgracht, over the measuring period no increase or decrease in engine efficiency was measured. On the contrary, Singelgracht actually displayed an improvement of engine efficiency thanks to a partial overhaul of the main engine. This gives an indication on the effectiveness of extensive main engine maintenance.

When looking at fouling, all vessels show different trends. Consequently, it is recommended to prolong the measuring period to at least a year before drawing any conclusions. In literature a fuel consumption increase of about 5% per year due to fouling was found, depending on operational profile and state of anti-fouling paint. If a percentage of similar magnitude is measured at Spliethoff's vessels after a year, increasing the hull cleaning frequency to once every year is recommended, as the bunker cost savings far outweigh the hull cleaning costs in this scenario.

Monitoring crew performance can be very valuable for Spliethoff. Especially checking whether a captain uses weather routing software correctly can uncover great operational cost savings potential. Depending on the voyage and weather conditions, correct weather routing can save up to 10% bunker costs over a single voyage. The aim for Spliethoff should be to have the office play a supporting role, collaborating with the ship to achieve maximum economic benefits without negatively affecting the relationship between office and ship.

To generalise, one can state that end-user involvement is key in development of information systems. From the data analysis it can be concluded that there is a definite speed optimum for ships with regard to fuel efficiency. Decreasing a ship's speed does not always lead to greater fuel efficiency over a voyage. Also, it can be stated that the difference in fuel consumption between laden and unladen condition for general cargo ships is marginal for relatively low speeds (below 10 knots). With regards to fouling, numerous sources state that the impact on fuel consumption is significant, offering big cost savings potential. Finally, the influence of crew on ship performance and fuel consumption is huge, meaning support from the office to the ship in this area could lead to substantial reduction in operational cost.

6.2 Recommendations

To improve the SPM System a number of measures can be taken. Firstly, installing a thrust sensor on the vessels should give more reliable results. Thrust is now calculated based on a propeller model, meaning it will never be as accurate as measured values. Also, the datasets will grow more quickly when thrust is measured instead of calculated, since the thrust calculation has a number of restricting dependencies.

Secondly, introducing a new added wave resistance method with less restrictions than STAwave-1 will improve the system dramatically. At the moment only bow sector waves up to a certain wave height can be used in the correction model. SPAWAVE, a more recent method also developed at MARIN does not have any of the restrictions of STAwave-1 and will therefore also increase the dataset significantly. SPAWAVE is only available against substantial cost, the main barrier for implementation.

As a third measure, the data in the messages database could be improved. Currently all this information is entered manually by the crew on board of the vessel, with the result that it is not very consistent or accurate. Communicating the importance of this data to the crew and training them, or even logging this automatically (if possible) would improve the value of this database markedly.

A fourth improvement for the SPM system is to match the data quality between all sources. At the moment some data is automatically logged instantaneously every five minutes and other data is logged automatically taking a minute average. This creates a data quality mismatch between data that is combined later on in the system.

Economically, a first recommendation is to instruct S-Type vessels to sail at 14 knots for voyages without time pressure, provided that the estimated time of arrival is met at this speed. With regards to the main engines, it seems like the maintenance schedule is effective, so this should be continued in the same manner. For fouling, if an increase in ship resistance of 5% is measured after a year, the hull cleaning intervals should be shortened to a year to begin with. Introducing a schedule where each ship's hull is inspected at least twice a year by divers is already a big step and will increase the knowledge of fouling greatly.

Finally, more intensive collaboration between office and ship on operation of the vessel is suggested, as this is a decisive factor in the vessel's performance and poses great cost savings opportunities. Stronger cooperation in voyage planning is where gains can be made; especially with regards to routing and speed.

On a general note, creating a company culture at Spliethoff where data-driven decision making is the norm is the biggest challenge, but will also yield the greatest benefits.

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Appendix A

Sensorlist Single Vessel

DeviceVendor	DeviceName	DeviceType	TagAlias	TagDescription	TagUnit
VAF	PEM4	Logger	CaloricValue1	Caloric Value of Fuel Type 1	MJ/kg
VAF	PEM4	Logger	CaloricValue2	Caloric Value of Fuel Type 2	MJ/kg
VAF	PEM4	Logger	CaloricValue3	Caloric Value of Fuel Type 3	MJ/kg
VAF	PEM4	Logger	CaloricValue4	Caloric Value of Fuel Type 4	MJ/kg
VAF	PEM4	Logger	Consump1Rate	Fuel consumption of consumer 1	kg/h
VAF	PEM4	Logger	Consump2Rate	Fuel consumption of consumer 2	kg/h
VAF	PEM4	Logger	Consump3Rate	Fuel consumption of consumer 3	kg/h
VAF	PEM4	Logger	Density	Density	kg/m3
VAF	PEM4	Logger	Eng1Acc1Mass	Point Accumulated fuel 1 mass of consumer 1	kg
VAF	PEM4	Logger	ExpansionFactor	Expansion Factor	
VAF	PEM4	Logger	Flow1Rate	Flowrate of flowmeter 1	l/min
VAF	PEM4	Logger	Flow1Temp	Temperature of flowmeter 1	degC
VAF	PEM4	Logger	Flow2Rate	Flowrate of flowmeter 2	l/min
VAF	PEM4	Logger	Flow2Temp	Temperature of flowmeter 2	degC
VAF	PEM4	Logger	Flow3Rate	Flowrate of flowmeter 3	l/min
VAF	PEM4	Logger	Flow3Temp	Temperature of flowmeter 3	degC
VAF	PEM4	Logger	Flow4Rate	Flowrate of flowmeter 4	l/min
VAF	PEM4	Logger	Flow4Temp	Temperature of flowmeter 4	degC
VAF	PEM4	Logger	FOCGps	Fuel consumption from speed over ground	kg/nm
VAF	PEM4	Logger	FOCSpeedlog	Fuel consumption from speed through water	kg/nm
FURUNO	GP150	GPS	GGA1	Global positioning system fix data UTC of position	
FURUNO	GP150	GPS	GGA10	Global positioning system fix data Geoidal separation m	
FURUNO	GP150	GPS	GGA11	Global positioning system fix data Age of differential GPS	
FURUNO	GP150	GPS	GGA2	Global positioning system fix data Latitude	
FURUNO	GP150	GPS	GGA3	Global positioning system fix data N/S	
FURUNO	GP150	GPS	GGA4	Global positioning system fix data Longitude	
FURUNO	GP150	GPS	GGA5	Global positioning system fix data E/W	
FURUNO	GP150	GPS	GGA6	Global positioning system fix data GPS quality indicator	
FURUNO	GP150	GPS	GGA7	Global positioning system fix data Number of satllites in use	
FURUNO	GP150	GPS	GGA8	Global positioning system fix data Horizontal dilution of precision	
FURUNO	GP150	GPS	GGA9	Global positioning system fix data Antenna altitude m	
FURUNO	GP150	GPS	GLL1	Geographic position Latitude	
FURUNO	GP150	GPS	GLL2	Geographic position NS	
FURUNO	GP150	GPS	GLL3	Geographic position Longitude	
FURUNO	GP150	GPS	GLL4	Geographic position E/W	
FURUNO	GP150	GPS	GLL5	Geographic position UTC of position	
FURUNO	GP150	GPS	GLL6	Geographic position Status	
GYRO	GYRO	Gyrometer	Heading	Heading, true	deg
OBSERMET	OMC138	Windmeter	TWD	Wind direction, true	deg
OBSERMET	OMC138	Windmeter	TWS	Wind speed, true	kts
VAF	PEM4	Logger	Latitude	Latitude of current position	
VAF	PEM4	Logger	Longitude	Longitude of current position	
VAF	PEM4	Logger	Power1	Power measurement of Torque meter 1	kW
VAF	PEM4	Logger	Power2	Power measurement of Torque meter 2	kW
FURUNO	FE700	Depth	WaterDepthKeel	Water depth below keel	m
FURUNO	FE700	Depth	WaterDepthOffset	Offset from transducer	m
VAF	PEM4	Logger	ShaftGen1	Shaft generator power 1	kW
VAF	PEM4	Logger	Speed1	Shaft rotational speed	rpm
VAF	PEM4	Logger	SpeedlogSpeed	Speed through water from speedlog	kts
GYRO	GYRO	Gyrometer	TIROT1	Signed rate of turn	deg/min
VAF	PEM4	Logger	Torque1	Shaft torque	Nm
CONSILIUM	SALR1A	Speedlog	STWlong	Longitudinal water speed	kts
CONSILIUM	SALR1A	Speedlog	STWtrans	Transverse water speed	kts
CONSILIUM	SALR1A	Speedlog	SOGlong	Longitudinal ground speed	kts
CONSILIUM	SALR1A	Speedlog	SOGtrans	Transverse ground speed	kts
CONSILIUM	SALR1A	Speedlog	HeadTrue	Water Heading True	deg
CONSILIUM	SALR1A	Speedlog	HeadMag	Water Heading Magnetic	deg
CONSILIUM	SALR1A	Speedlog	STWknots	Water Speed	kts
CONSILIUM	SALR1A	Speedlog	STWkmh	Water Speed	kts
VAF	PEM4	Logger	Version	Wizzo software version	
FURUNO	GP150	GPS	COGT	Course over ground, true	deg
FURUNO	GP150	GPS	COGM	Course over ground, magnetic	deg
FURUNO	GP150	GPS	SOG	Speed over ground	kts
FURUNO	GP150	GPS	SOGKMH	Speed over ground	km/h

Figure A.1: Sensorlist for an S-Type Vessel

Appendix B

Dashboard Prototypes

In this Appendix the final product of the SPM System is discussed, namely the dashboards end-users will be looking at. Prototype dashboards are presented, with different features and elements explained. As mentioned before in chapter 4, the dashboards have been developed in Tableau.

In the SPM System Analysis of chapter 3 KPIs have been linked to users. This information is used as the foundation for the dashboard prototypes. Prototypes for the business development department, operators, commercial representatives, captains, chief engineers and the technical department are shown.

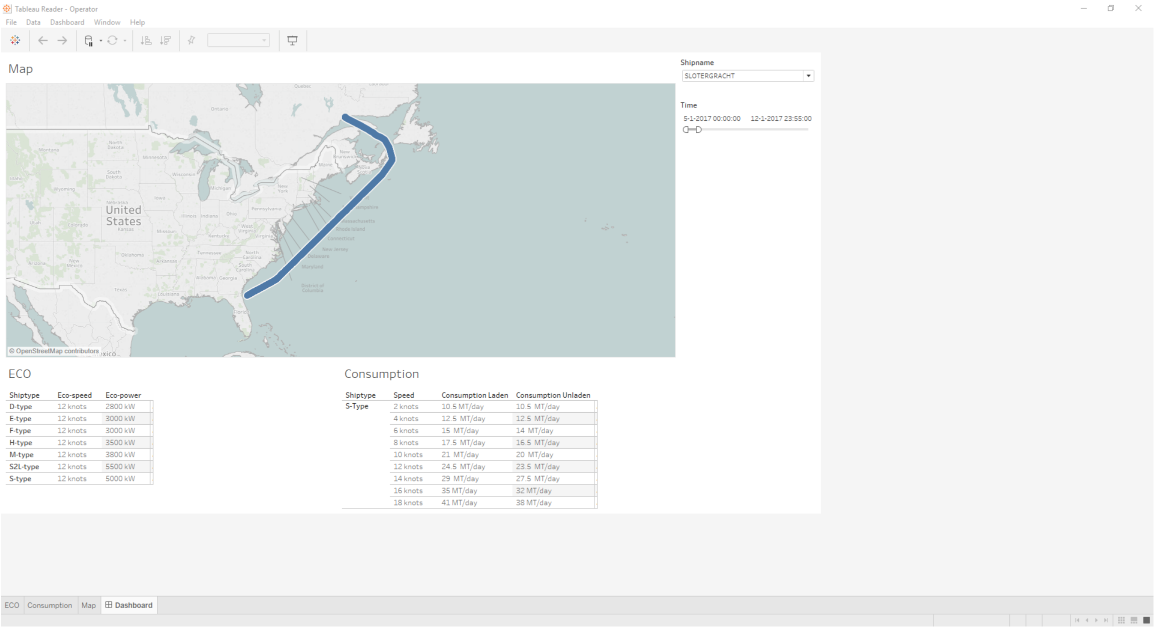
Figure B.1 shows the operator's dashboard. Included are a map view and two tables. At the right side of the screen the operator can select a ship by shipname and select a date range for the map. The bottom left table gives eco-speed per shiptype and eco-power settings per shiptype. The bottom right table contains speed-consumption data for laden and unladen condition per shiptype.

In Figure B.2 and B.3 identical dashboards are displayed for commercial reps and captains. The left table shows the eco-speed per Spliethoff shiptype and the right table giving speed-consumption data for laden and unladen condition.

The chief engineer's dashboard is shown in Figure B.4. The basic tables (eco-speed and speed-consumption) of all previously discussed dashboards are also present here. The main difference is the added main engine condition information (SFC). A drop-down menu is available where the user can select data by shipname and a date range selector is again added.

Information for the technical department is displayed over three different dashboards. Figure B.6 is a dashboard dedicated to fouling related graphs. On the right one can select data for shipname, date range, corrected- or uncorrected data and laden- or unladen condition. The second dashboard for the technical department is displayed in Figure B.7. All engine condition monitoring information is shown here. Again, a drop-down menu is available to select a specific ship and a date range selector is included.

For the business development department five dashboards are available. In Figure B.8 eco-speed related information is shown, with a drop-down list to select a ship and filters for date, corrected- or uncorrected data, laden- or unladen condition and manoeuvring data. The second dashboard contains all speed-consumption data, with the same menu's and filters as the first dashboard (Figure B.9). The fouling dashboard and engine condition dashboards of the technical department are copied directly (Figure B.10 and B.11). Finally, also a map view is available for the business development department (Figure B.12).



Shipname: SLOTERGRACHT

Time: 5-1-2017 00:00:00 12-1-2017 23:55:00

ECO

Shiptype	Eco-speed	Eco-power
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S2L-type	12 knots	5500 kW
S-type	12 knots	5000 kW

Consumption

Shiptype	Speed	Consumption Laden	Consumption Unladen
S-Type	2 knots	10.5 MT/day	10.5 MT/day
	4 knots	12.5 MT/day	12.5 MT/day
	6 knots	15 MT/day	14 MT/day
	8 knots	17.5 MT/day	16.5 MT/day
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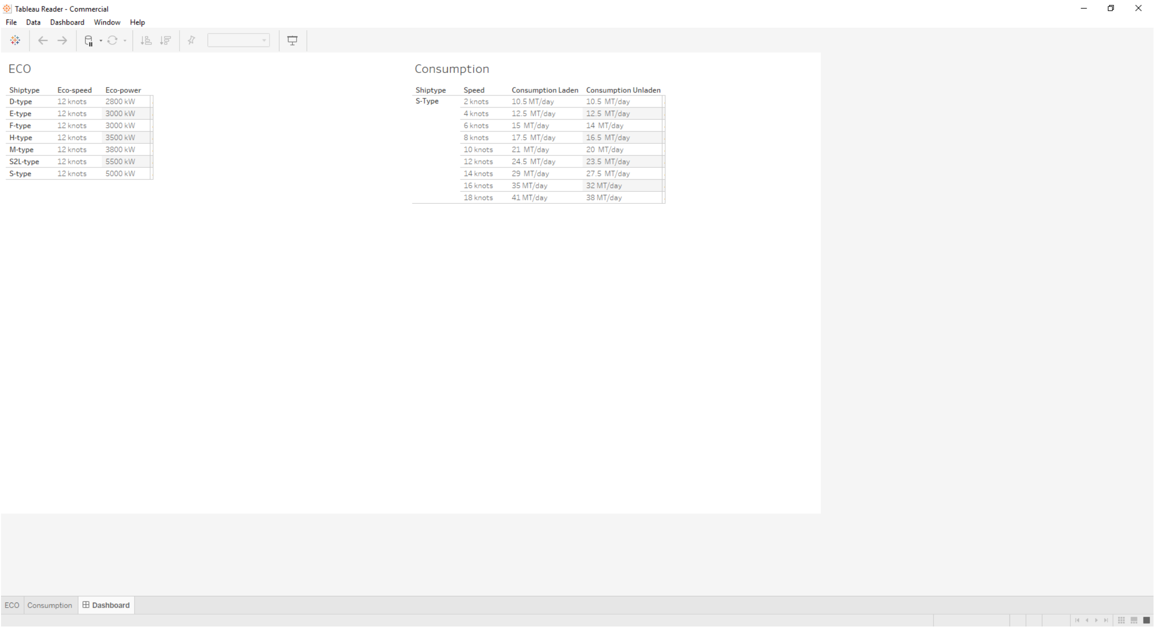
	12 knots	24.5 MT/day	23.5 MT/day
	14 knots	29 MT/day	27.5 MT/day
	16 knots	35 MT/day	32 MT/day
	18 knots	41 MT/day	38 MT/day

Figure B.1: Operator's Dashboard



ECO

Shiptype	Eco-speed	Eco-power
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S-type	12 knots	5000 kW

Consumption

Shiptype	Speed	Consumption Laden	Consumption Unladen
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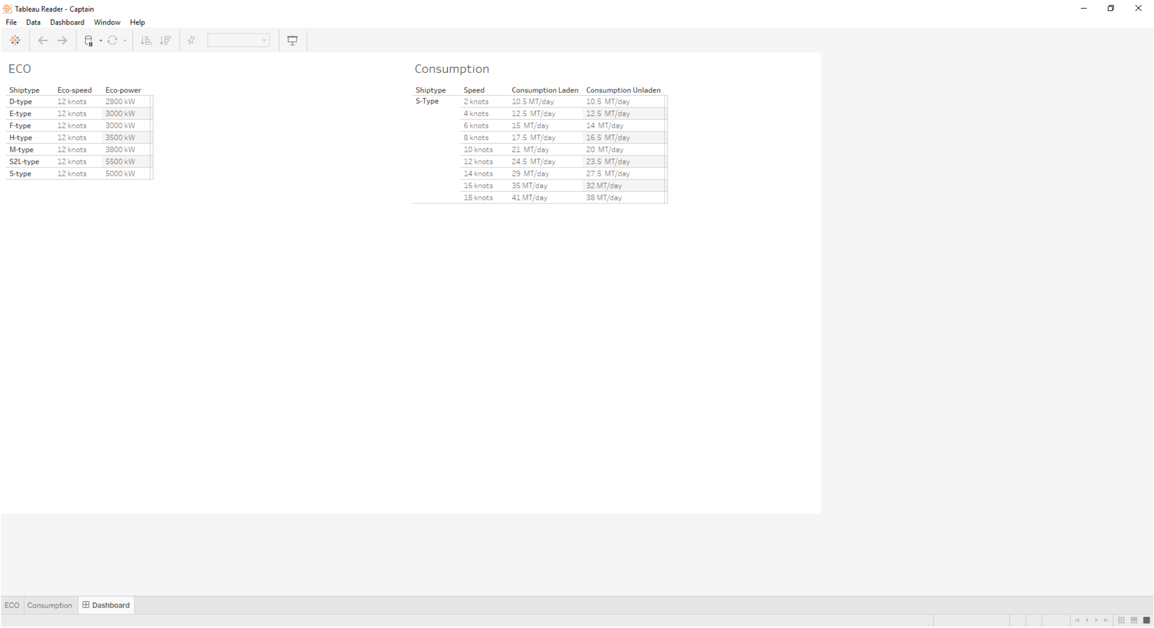
	4 knots	12.5 MT/day	12.5 MT/day
	6 knots	15 MT/day	14 MT/day
	8 knots	17.5 MT/day	16.5 MT/day
	10 knots	21 MT/day	20 MT/day
	12 knots	24.5 MT/day	23.5 MT/day
	14 knots	29 MT/day	27.5 MT/day
	16 knots	35 MT/day	32 MT/day
	18 knots	41 MT/day	38 MT/day

Figure B.2: Commercial Representative's Dashboard



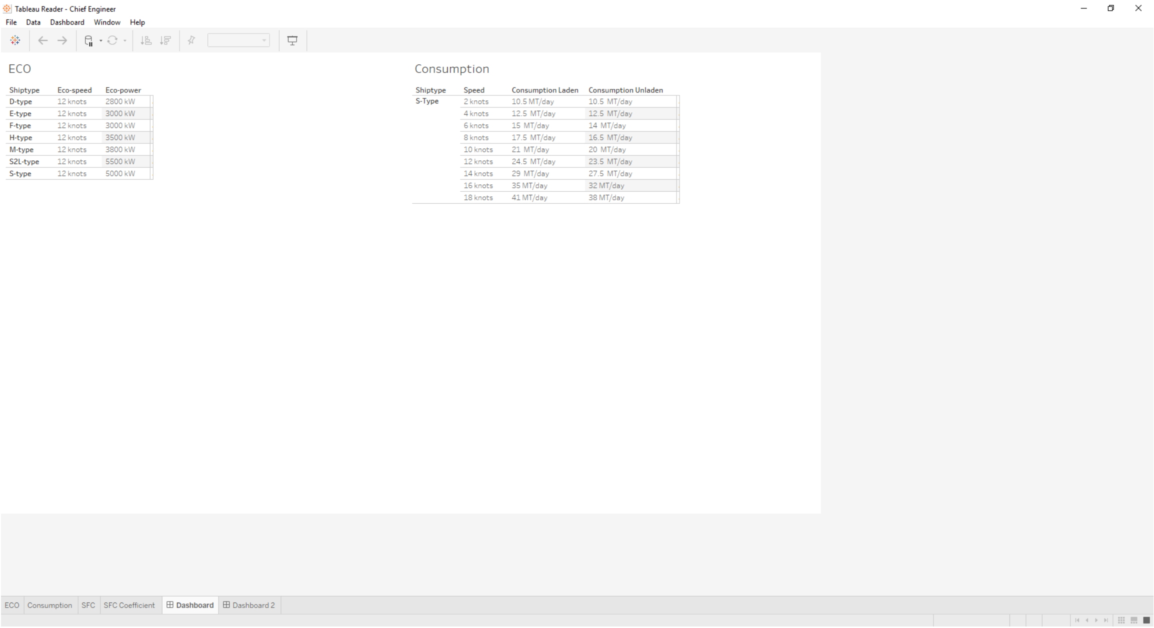
ECO

Shiptype	Eco-speed	Eco-power
D-type	12 knots	2800 kW
E-type	12 knots	3000 kW
F-type	12 knots	3000 kW
H-type	12 knots	3500 kW
M-type	12 knots	3800 kW
S2L-type	12 knots	5500 kW
S-type	12 knots	5000 kW

Consumption

Shiptype	Speed	Consumption Laden	Consumption Unladen
S-Type	2 knots	10.5 MT/day	10.5 MT/day
	4 knots	12.5 MT/day	12.5 MT/day
	6 knots	15 MT/day	14 MT/day
	8 knots	17.5 MT/day	16.5 MT/day
	10 knots	21 MT/day	20 MT/day
	12 knots	24.5 MT/day	23.5 MT/day
	14 knots	29 MT/day	27.5 MT/day
	16 knots	35 MT/day	32 MT/day
	18 knots	41 MT/day	38 MT/day

Figure B.3: Captain’s Dashboard



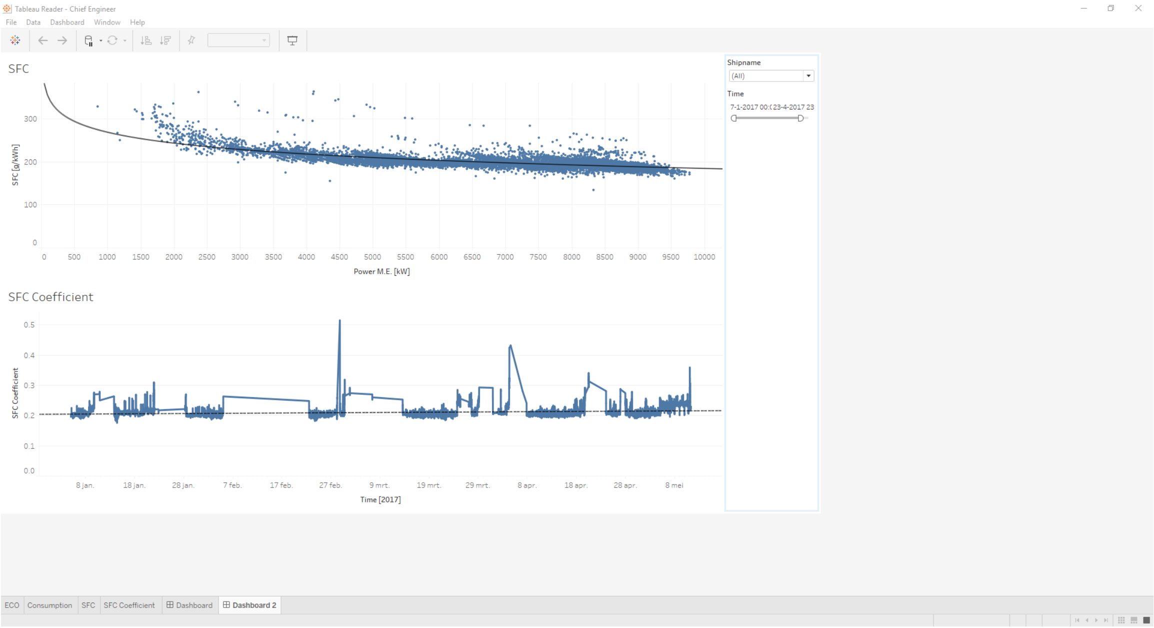
ECO

Shiptype	Eco-speed	Eco-power
D-type	12 knots	2800 kW
E-type	12 knots	3000 kW
F-type	12 knots	3000 kW
H-type	12 knots	3500 kW
M-type	12 knots	3800 kW
S2L-type	12 knots	5500 kW
S-type	12 knots	5000 kW

Consumption

Shiptype	Speed	Consumption Laden	Consumption Unladen
S-Type	2 knots	10.5 MT/day	10.5 MT/day
	4 knots	12.5 MT/day	12.5 MT/day
	6 knots	15 MT/day	14 MT/day
	8 knots	17.5 MT/day	16.5 MT/day
	10 knots	21 MT/day	20 MT/day
	12 knots	24.5 MT/day	23.5 MT/day
	14 knots	29 MT/day	27.5 MT/day
	16 knots	35 MT/day	32 MT/day
	18 knots	41 MT/day	38 MT/day

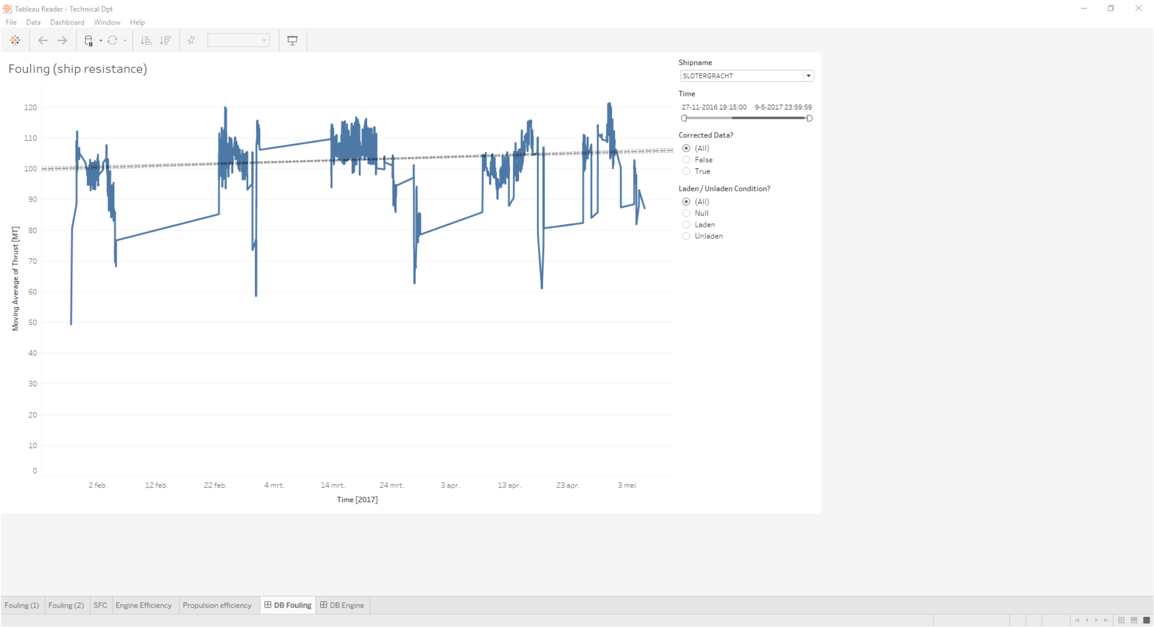
Figure B.4: Chief Engineer’s Dashboard 1



Shipname: (All)

Time: 7-1-2017 00:(23-4-2017 23

Figure B.5: Chief Engineer's Dashboard 2



Shipname: SLOTERGRACHT

Time: 27-11-2016 19:15:00 9-5-2017 23:59:59

Corrected Data?
● (All)
○ False
○ True

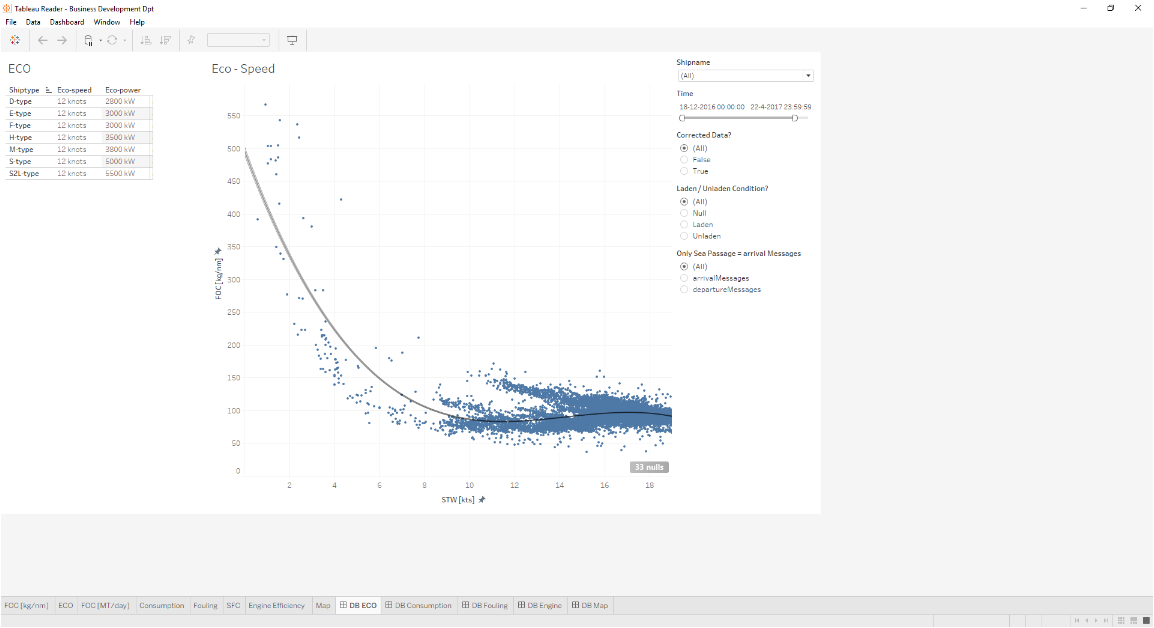
Laden / Unladen Condition?
● (All)
○ Null
○ Laden
○ Unladen

Figure B.6: Technical Department's Dashboard 1

Shipname
SCHIPPERSGRACHT
Time
27-11-2016 19:15:00 23-4-2017 23:55:00

Shipname
SINGELGRACHT
Time
5-1-2017 00:00:00 11-5-2017 06:50:00

Figure B.7: Technical Department's Dashboard 2



Shiptype	Eco-speed	Eco-power
D-type	12 knots	2800 kW
E-type	12 knots	3000 kW
F-type	12 knots	3000 kW
H-type	12 knots	3500 kW
M-type	12 knots	3800 kW
S-type	12 knots	5000 kW
S2L-type	12 knots	5500 kW

Shipname
(All)
Time
18-12-2016 00:00:00 22-4-2017 23:59:59

Corrected Data?
● (All)
○ False
○ True

Laden / Unladen Condition?
● (All)
○ Null
○ Laden
○ Unladen

Only Sea Passage = arrival Messages
● (All)
○ arrivalMessages
○ departureMessages

Figure B.8: Business Development Department's Dashboard 1

Consumption

Shiptype	Speed	Consumption Laden	Consumption Unladen
S-Type	2 knots	10.5 MT/day	10.5 MT/day
	4 knots	12.5 MT/day	12.5 MT/day
	6 knots	15 MT/day	14 MT/day
	8 knots	17.5 MT/day	16.5 MT/day
	10 knots	21 MT/day	20 MT/day
	12 knots	24.5 MT/day	23.5 MT/day
	14 knots	29 MT/day	27.5 MT/day
	16 knots	35 MT/day	32 MT/day
	18 knots	41 MT/day	38 MT/day

Shipname
SLOTERGRACHT

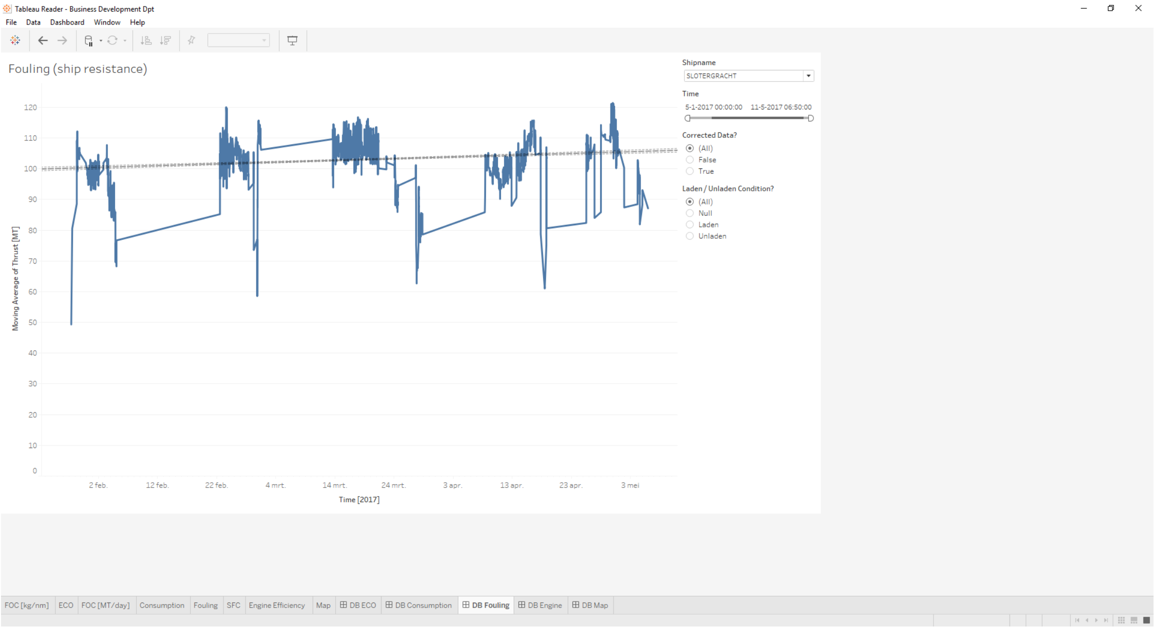
Time
27-11-2016 19:15:00 23-4-2017 23:55:00

Corrected Data?
● (All)
○ False
○ True

Laden / Unladen Condition?
● (All)
○ Laden
○ Unladen

Only Sea Passage = arrival Messages
● (All)
○ arrivalMessages
○ departureMessages

Figure B.9: Business Development Department's Dashboard 2



Shipname
SLOTERGRACHT

Time
5-1-2017 00:00:00 11-5-2017 06:50:00

Corrected Data?
● (All)
○ False
○ True

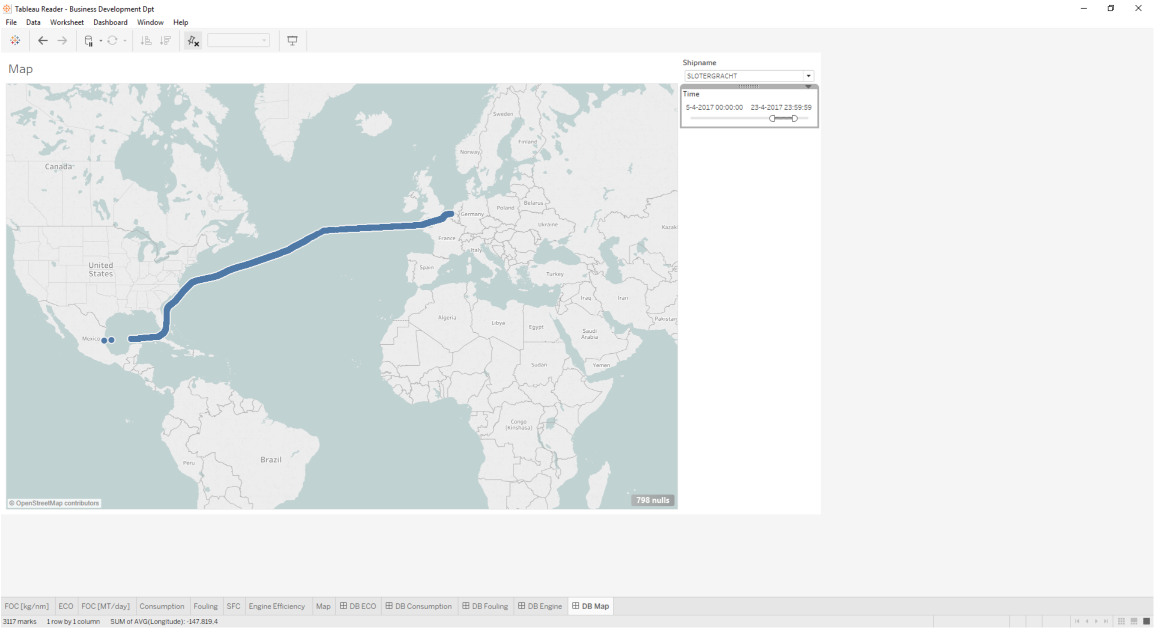
Laden / Unladen Condition?
● (All)
○ Null
○ Laden
○ Unladen

Figure B.10: Business Development Department's Dashboard 3

Shipname: SLOTERGRACHT
Time: 5-1-2017 00:00:00 19-4-2017 16:40:00

Shipname: SLOTERGRACHT
Time: 5-1-2017 00:00:00 19-4-2017 16:40:00

Figure B.11: Business Development Department's Dashboard 4



Shipname: SLOTERGRACHT
Time: 5-4-2017 00:00:00 23-4-2017 23:59:59

3117 marks 1 row by 1 column SUM of AVG(Longitude): -147.819,4

Figure B.12: Business Development Department's Dashboard 5

Appendix C

General Arrangement Spliethoff S-Type

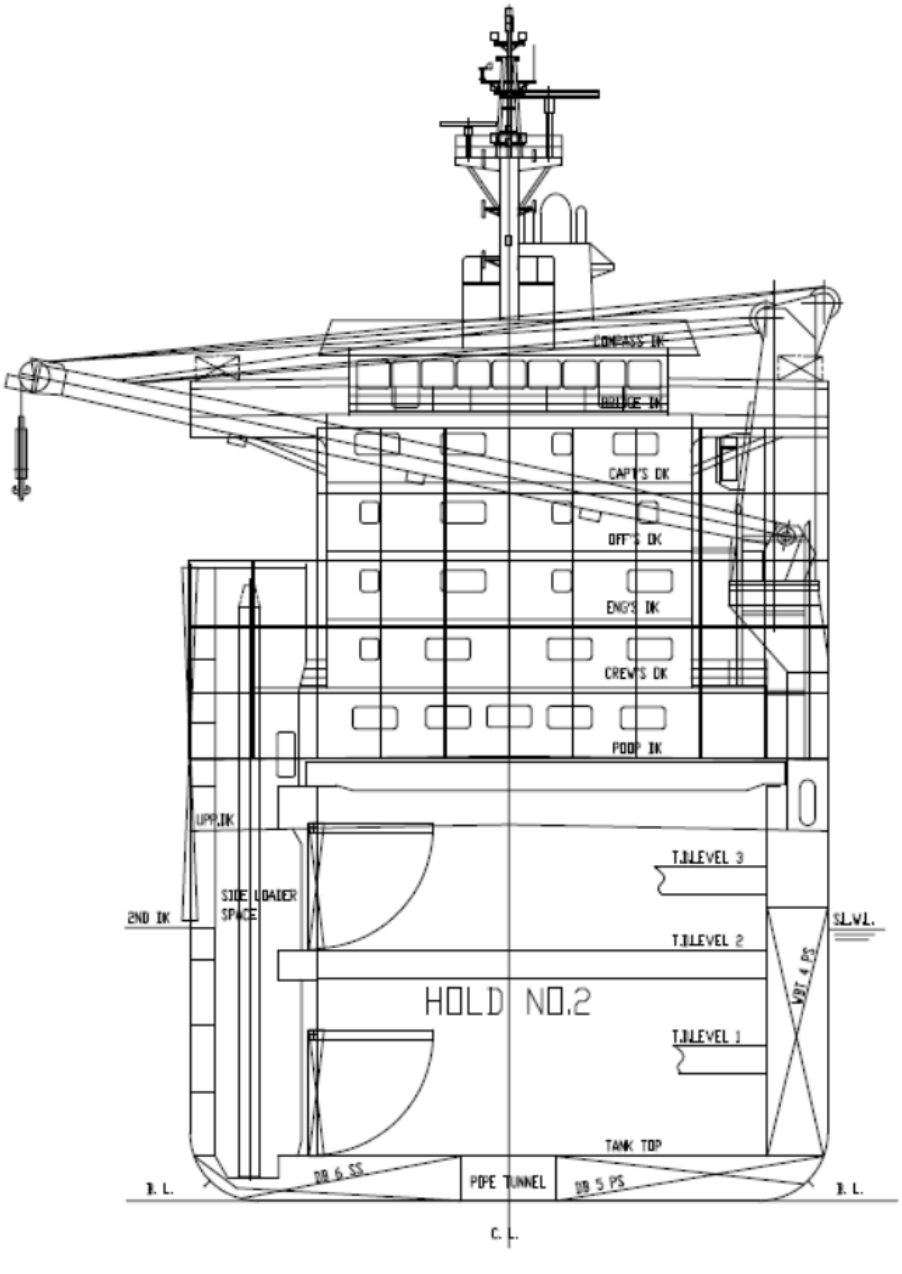


Figure C.1: Front View Spliethoff S-Type [MHI [2014]]

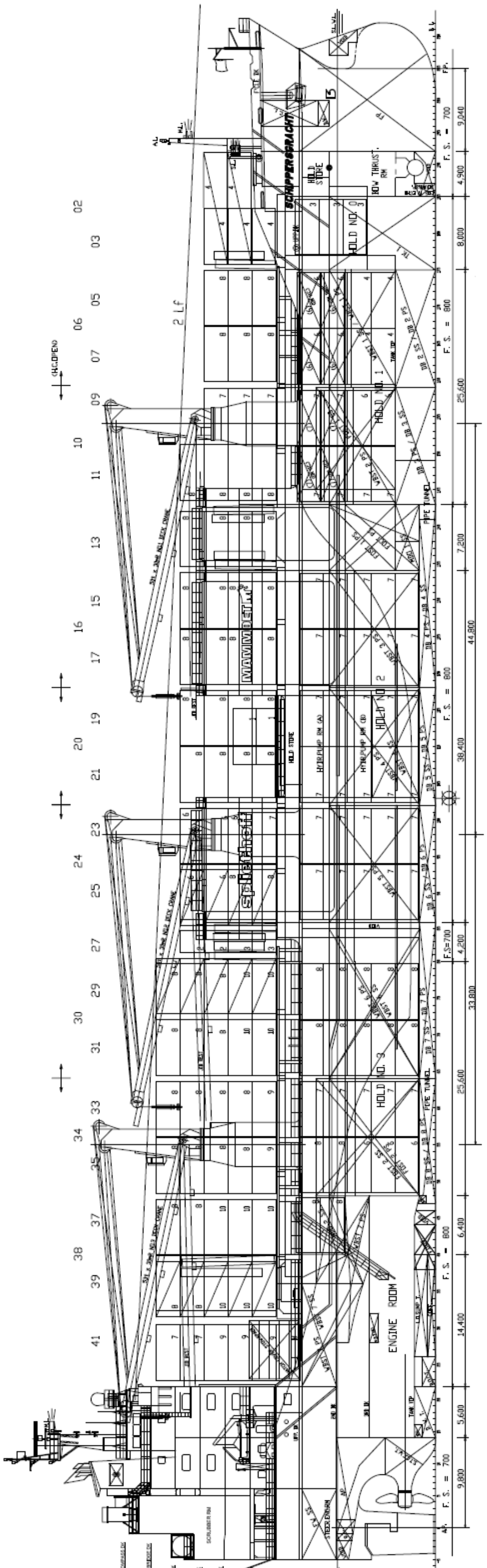


Figure C.2: Starboard View Spliethoff S-Type [MHI [2014]]

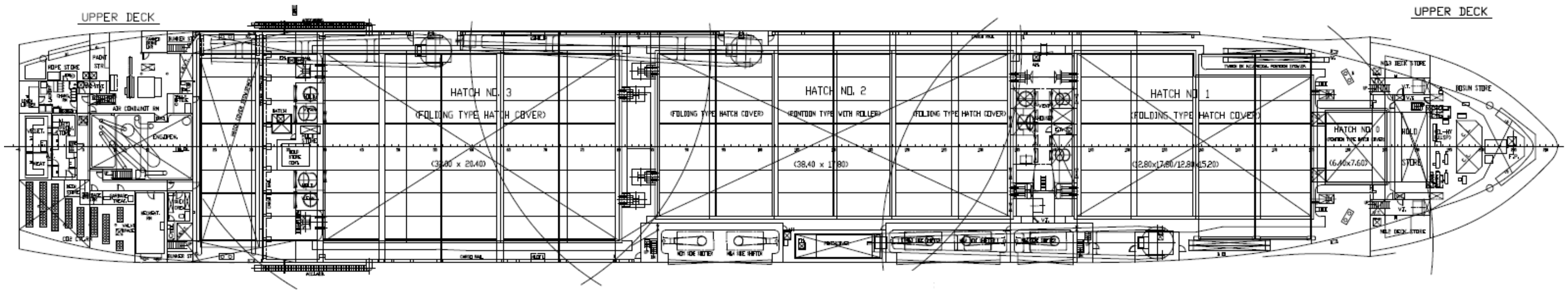


Figure C.3: Top View Spliethoff S-Type [MHI [2014]]